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Preface

This Volume contains some of the papers presented at the 5th International Conference on Water and Society, held in Valencia, organised by the Wessex Institute, UK and the Polytechnic University of Valencia. The Conference was sponsored by the International Journal of Sustainable Development & Planning and WIT Transactions on Ecology and the Environment.

The Water and Society Conference follows the success of the previous meetings, the first of which was held in Las Vegas in 2011, followed by the New Forest, UK, home to the Wessex Institute, in 2013, La Coruña, Spain, in 2015 and Seville, Spain, in 2017.

Over the centuries, civilisations have relied on the availability of clean and inexpensive water. This can no longer be taken for granted as the need for water continues to increase due to the pressure from growing global population demanding higher living standards. Agriculture and industry, major users of water, are at the same time those that contribute to its contamination. Water distribution networks in urban areas, as well as soiled water collection systems, present serious problems in response to a growing population as well as the need to maintain ageing infrastructures.

Many technologically feasible solutions, such as desalination or pumping systems are energy demanding but, as costs rise, the techniques currently developed may need to be re-assessed. The Conference addressed the interaction between water and energy systems. Many pipelines have now reached the end of their life; new (fast and trenchless) technologies for pipe rehabilitation have been developed, but are rarely used in many countries, because of the limited knowledge of the appropriate methodologies.

This meeting also encouraged trans-disciplinary communication on issues related to the nature of water, and its use and exploitation by society. The motivation for the conference was the need to bridge the gap between the broad spectrum of social political sciences and humanistic disciplines and specialists in physical sciences, biology, environmental sciences and health, among others.

The socio-political implications of a world short of clean, easily available water are enormous. It will lead to realignments in international politics and the emergence of new centres of power in the world. Also in this case, education proves once again to be the key factor of a sustainable development.

Policy makers need to be educated and advised on developing policies and regulations that will support the water systems of tomorrow. The role of society and its involvement with water is paramount. To meet the future demands for water, new standards, new training and additional support roles will best be delivered by those knowledgeable of the new technologies and direction of the industry.

The intention of the Water and Society series is to review these issues, as well as the more technical aspects of water resources management and quality, to help put forward policies and legislation that will lead to improved solutions for all.

The papers selected for presentation and included in the Conference Proceedings are permanently stored in the WIT eLibrary as Transactions of the Wessex Institute (see http://www.witpress.com/elibrary).

The Editors
2019

Contents

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FACTORS CONTRIBUTING TOWARDS HIGH WATER USAGE WITHIN POOR COMMUNITIES IN KWAZULU-NATAL, SOUTH AFRICA

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ABSTRACT
Government bodies tasked with water resource management in recent years have by default placed more emphasis on increasing the water supply rather than reducing water demand. South Africa, however, is a semi-arid country plagued by unpredictable rainfall and severe drought conditions. The water authority bodies, usually operated by the municipalities, face high water losses due to aged infrastructure. This is exacerbated by a high daily water consumption amongst indigent residents, which is about 286 L per person compared to the international norm of 173 L per person. These two factors combine and contribute towards significant economic losses. The aim of this paper is to examine factors contributing towards high water consumption in poorer communities in Kwa-Zulu Natal, South Africa. The location of the study was a low-cost housing zone comprising a population of 20,000 people. A qualitative approach in a form of semi-structured interviews with main stakeholders from government, community-based organisations and academics was used to gather data. Three themes emerged from the study: (1) the viability of the current water management system; (2) reducing water consumption; and (3) how to change consumer behaviour towards water conservation. Results showed that the current water management system for the area was feasible and affordable. In addition, reducing water usage was possible through community involvement and communication. It was further noted that consumer behaviour can change through education concerning pricing and incentives.
Keywords: water sustainability, water management, water behaviour, indigent communities, education, community engagement, South Africa.

1 INTRODUCTION

Despite the change from an apartheid to a democratic form of government in 1994, water resources still remained unevenly distributed across South Africa [1]. As a matter of fact in the wake of the political transition water was seen as a bio-political tool aimed at transforming the lives of previously disadvantaged South Africans [2]. At that time approximately 13 million South Africans lacked access to safe water [3]. As part of the government‘s effort to fundamentally restructure its water laws and regulations, new legislations were introduced which represented water as an instrument in the transformation of society towards social and environmental justice [4]. The new water policies described water as a “public right” and “economic good”. Significantly, it identified cost recovery as an integral measure towards building sustainable water services [5].

In addition, to fulfil the constitutional right to water, the government introduced a free basic water policy which meant that indigent households throughout South Africa would receive a stipulated amount of free water every month [6]. A “basic” supply means 25 L of water per person per day, easily accessible within a distance of 200m of their household, regardless of the person’s ability to pay for it. Accordingly, in July 2001, the Free Basic

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Water (FBW) policy became a national policy through a revised tariff structure that included at least 6 m^3 of free water per month (i.e. 40 L/capita/day for a family of five or 25 L/capita/day for a family of eight) [7]. Subsequently, government gradually implemented the policy within each designated metropolitan municipality's jurisdiction and increased the amount to 9 m^3 per family per month. However, South Africans have a relatively high per capita water use, around 286 L per person per day [8]. This is high in comparison to the international average of 173 L per person per day.

According to a study on household consumption in SA, many South African households used much more than 9 m^3 per month [9]. The results of the above study showed that the average South African suburban family of four uses 300 L per person per day.

This equates to Fig. 1.

300 litres x 4 people

=1200 litres per day x 30 days

=36,000 litres per month x 12 months

=432,000 litres per year

Figure 1: Annual average household consumption of a South African family of four [9].

These estimates suggest that the average South African uses at least four times more water than what is stipulated in the FBW. Despite the commendable efforts by government to improve water supply for impoverished and poorer communities, the study further highlighted that many municipalities tasked with water management lacked the administrative and technical capability to implement such water policies.

Water availability and sustainable usage is one of the key challenges of transforming the water sector and demand management in SA [10]. Over the years, the ministry in charge of water allocation, the South African Department of Water Affairs and Forestry (SADWAF) has faced challenges in calculating the amount of water people use per month in rural areas and low-cost housing areas due to poor infrastructure and lack of proper metering devices [11]. In this paper, low-cost housing areas refers to the government's program to provide houses to the poorest people living mainly in informal settlements. The criteria used to qualify for low-cost housing includes a disposable income per month of between \$0–\$100. Recipients of low-cost houses are provided with a certain amount of free electricity and 9 m^3 of free water [12]. However, the latter has turned out to be problematic for water authorities as it has become a challenge to persuade residents to pay for water above the 9 m^3 usage. Firstly, water authorities are unable to determine when water-users went beyond the stipulated 9m^3 a month [13]. Secondly, there is a culture of non-payment of services and dissatisfaction of some residents with water demand management strategies which further intensifies poor water behaviour [14]. This attitude can be attributed to the legacy of apartheid where the boycott of payment for services was an effective tool against the government [12].

It has often been argued that due to the scarcity of water resources government should not be providing it for free but put a price on its availability [13]. On the other hand, the initiative of using price as a demand management measure could give rise to more challenges facing municipalities [15]. In addition to civil protest action, communities unable to afford water will be susceptible to poverty and water-borne diseases [16]. This study takes cognisance of this and seeks to gain insight on factors contributing to high water consumption by inhabitants of low-cost housing areas in SA.

Water resources in SA which remains intricately interweaved with land resources, is vital to the continued economic development of cities and rural communities and towards the sustainable livelihoods of its people [17]. Not only are municipalities faced with high water losses due to aged infrastructure, it is also the high water consumption rates that contribute towards significant economic losses [18]. Worryingly, many of the communities based within the municipalities in SA are made up of impoverished people, which renders them particularly vulnerable to impacts of climate change and heavily dependent upon the services obtained from intact ecosystems [19].

The aim of this paper was to explore some of the factors contributing towards high water usage amongst inhabitants of poorer communities in Kwa-Zulu Natal, South Africa. This research explored how key behavioural factors influenced household water use. The location of the study is a low-cost housing area, known as Waterloo Township, situated in KwaZulu-Natal, South Africa with a population of 20,000 with the majority being of Black origin. Established in 1996, it is one of the oldest low-cost housing areas formed as part of the new government's Reconstruction of Development Plan (RDP). This plan was aimed to rebuild and develop the country which included meeting the basic needs such as jobs, housing, water and electricity and transport. Inhabitants here are recipients of FBW, which means that they are entitled to 9 m^3 of free water per month. This area falls within the jurisdiction of the eThekwini Municipality which oversees the water supply and demand.

2 METHODOLOGY

A qualitative approach in the form of semi-structured interviews with main stakeholders used to gather data. This study aimed to gain insight into high water usage amongst residents in low-cost housing areas in the Waterloo Township. A total of eight participants were selected, two each from the water authority body (municipality), community-based organisations, academia and community representatives in government (councillors).

3 DATA ANALYSIS

This study used qualitative content analysis using operating coding to create categories to theme the data [20]. Three themes emerged from the study: (1) The viability of the current water management system, (2) Reducing water consumption; (3) How to change consumer behaviour on water conservation. All data analysis was performed with the aid of Nvivo. The quotes used are representative of the views of most, if not all, participants unless otherwise stated.

4 RESULTS AND DISCUSSION

4.1 Theme 1: Sustainability of the current water management system

Given the scarce and limited availability of water in SA, it is imperative that water be managed efficiently. However the long-term sustainability of the current water management system in SA is questionable when one considers the current water crisis recently faced in the city of Cape Town, and the eThekwini Municipality may well face similar challenges in the near future. Notably, some of the interviewees expressed a concern that the current water management under the eThekwini Municipality was not sustainable. This was evident in their assertion that the cost of water supply by the municipality does not measure to the revenue generated from it. This is reflected the statement made by Councillor 1:

> "The water management system is not sustainable as there is a huge gap between supply and demand. In fact the municipality is not taking concrete steps to mitigate loss which results in non-revenue water. It's 40% presently and that's a very high percentage considering we are a water scarce country".

Echoing similar sentiments, and from a financial context, the municipality participant 1 claimed that the city suffered a net loss of R400 million from water loss per year.

> "looking at non-revenue figures of 40%, that's a huge chunk. If you look at what we purchase water for, around R1 billion a year, that's a net loss of R400 million".

The net loss was blamed on water wastage and illegal tap connections. This is consistent with studies that show SA was losing over 1.5 billion cubic metres of water a year due to failing infrastructure, such as piping infrastructure which has outlived its lifespan and illegal connections. This resulted in a net loss of more than R7 billion worth of water lost annually [21], [22].

With regard to residents in the area being recipients of FBW, Municipality Representative 1 believed that the policy was no longer functional as householders were using more than the stipulated amounts of water as well as challenges monitoring water usage in the area due to theft of monitoring devices. As such, it was noted that even though there was high consumption of water in the area, there was not revenue being generated. This is consistent with a study which reported that despite progressive water policies, there still remained an inability by the government to effectively manage and control water resources in vulnerable communities [3]. Municipality Representative 1 further believed:

> "If things don't change, we will be in crisis mode because we will either have to increase tariffs to those people who are paying and those people who are not paying will continue to abuse it".

The looming water crisis is expected to have implications on food security and health. Furthermore, if no suitable solutions are found, water scarcity will affect humanity [23]. In SA, a culture of non-payment of services and distrust in water authority bodies has contributed towards poor water behaviour [12].

However, some participants believed that even with the low storage levels currently experienced at major dams in the country, the current water management system was still sustainable. Academia Representative 1 cautioned that that dam levels were not indicative of consumption pattern, but rather storage patterns. He however, warned that the effects of climate change in the last decade has contributed significantly towards the scarcity of this resource.

> "Dam levels are indicative of what we have in storage. It's not indicative of consumption patterns. The biggest user of water is agriculture sector. Domestic users sitting at a small percentage. In the last ten years one of the destructors on the planet is climate change. Climate change has significantly impacted on the world, fundamentally so on water".

One of the most important factors fuelling the water crisis is climate change with global warming affecting water systems, precipitation, and water availability [24]. Drawing from the above, it is reasonable to assume that more stringent measures should be in place to sustain and conserve water that goes beyond the dam level. It has further shown that among the emerging constraint to water sustainability is the high water-wastage and high consumption within the poor communities that account for the high non-revenue loss to the municipalities. Consequently, it was advocated by some of the participants that water waste and consumption should be minimized particularly within these communities.

4.2 Theme 2: Reducing water consumption in low-cost housing communities

This theme aimed at gaining participants' perspective on how to get water users in poorer areas to reduce their water consumption. Majority of the participants believed that education and communication played a significant role in informing residents on issues such as climate change, water scarcity and water behaviour. Participants also noted that community involvement and the use of existing structures such as councillors are some of the ways in which residents can reduce their water.

4.2.1 Subtheme 2.1: Reducing water consumption through education and communication

Majority of the participants interviewed suggested that water consumption in the poorer communities can be reduced through education and communication. Consequently, community councillors called for more communication and education programs to educate individuals on ways to preserve water and calculate their consumption of water. For example, Councillor 2 challenged the municipality to take the initiative to educate people on water use and meter readings:

> "The municipality must take the initiative to come here and educate people on water use, meter readings etc".

Furthermore, Councillor 2 lamented on an initial municipality project, "War on Leaks Project", aimed at educating members of the community in locating and fixing leaks on their property, which fell apart due to lack of feedback from the municipality. The afore-mentioned participant pointed to the fact that the project would have created employment within the community, as well as reduce water loss due from unreported leaks.

> "As a Councillor in the area, I have been here 3 and half years, we only had communication from the municipality once. It was for the War on Leaks project where a feasibility study was conducted to seek out young people who can be employed to report leaks. However, that seems to have fallen away. There has been no feedback from the municipality since then. It would have been an excellent initiative as it would have created employment within the Waterloo community on one hand, and decrease water loss as a result of unreported leaks on the other hand".

The project was aimed at training 10,000 youth countrywide to locate and fix leaking pipes, however, it was halted due to budget constraints [25]. It was a short-lived vision that would not have only created employment within poor communities but also save water by locating and fixing leaks.

Another concern expressed by Councillor Two was that the communities only become aware of water consumption beyond the FBW limits when they received bills to settle the outstanding amounts of money for the extra water used.

> "Unfortunately, people only become aware of their billing account when it has already become a major issue. There seems to be no concerted effort to manage water within the FBW limit. Communal pipes are a big problem here. There is no regular maintenance and leaks are not reported timeously".

In fact, studies show that municipalities were struggling to manage FBW due to administrative and technical capabilities. Significantly, there was widespread theft and vandalism of monitoring devices on residential properties [10], [23].

Reiterating the call to educate communities on water conservation, Academic Water Representative 1 advocated for the education of school children to learn to appreciate the value of water. This could ultimately lead towards change in their behaviour.

> "In terms of conserving water any other time, there is lack of communication. Education plays a role in all aspects of our lives. I believe if people are educated then there will be a change in behaviour. I also think it should start at school level. Educate the children. So that they will learn to appreciate the value of water".

It has been shown that people who are aware of their water situation was more likely to develop the appropriate water conservation behaviour [26]. The two municipality representatives were adamant that the communication department within the municipality was adept enough to assist consumers with their water consumption and billing queries. This was in the form of roadshows, public advertisements, educational tours, school campaigns aimed to educate the people on water conservation and water demand management.

However, despite the perceived drive to educate the people, one of the representatives from the municipality acknowledged that they faced a challenge related to the language barrier to effectively deliver their message to the people.

> "One of the challenges we experience is the language barrier. Many people in rural areas, English is not the first language. I believe there needs to be a change in approach. Try to be more in line with the receiving audience. At the moment, the municipality has invested in pamphlets with lots of pictures so that grass root people can understand. People can learn to conserve water by changing their behaviour. They can find and fix leaks. One small drip per minute is almost 53 gallons of water wasted per year. Buy water-efficient appliances. Turn the water off before a vacation. Reuse old water and Insulate hot water pipes. Education plays a major role. And it should begin at school level".

In order to change people's behaviour towards water conservation it is important to equip them with the correct knowledge on how to save water. This effort is dependent on communication and language. Language barriers can hamper effective communication. However, speaking in a language that communities can relate to can encourage them to appreciate the environment as well as seek their commitment in changing their water use behaviour [26].

From the above statement, it is assumed that educating people is the key to changing their behaviour towards water conservation. Academic Water Representative 2 reiterated the sentiments of the above-mentioned authors:

> "Educating members of the public and especially those from areas where there is high water consumption, is critical to making them understand issues such as water scarcity and climate change. This will create acceptance and make them more inclined towards water conservation efforts. Therefore, if people have a basic understanding of how water resources management and planning functions, they will begin to understand the associated economic and environmental benefits. As such, if consumers understood how water was priced and how much their used, this can contribute to healthier water behaviour".

4.2.2 Subtheme 2.2: Reducing water consumption through community involvement

From the previous subtheme, communication and education were noted as important factors towards community involvement in water conservation. This notwithstanding, community representative 1 was emphatic that community involvement in any of water conservation strategy was a key factor. It was noted from this statement that communities needed to feel that they were part of the solution to the water problem. As a consequence, communities must be engaged at all levels in order to effectively conserve water.

> "Community involvement is a key factor. Communities need to feel there are part of the solution. Therefore, they must be engaged at all levels. The only time we hear about water cuts or restrictions is when there is a drought. Then we are told to cut down on consumption. However, this is something that has to be communicated to the people all the time".

Community engagement and awareness programmes with municipalities may help to develop trust and more effective monitoring of service delivery such as water provision within the communities [27].

Academic water Representative 2 reaffirmed the need for a community participation model as a way to reducing water consumption but lamented that the community is often excluded from the solution process.

> "the community is largely excluded from contributing to planning and decision making processes".

Whereas most of the interviewees agreed with the above statement, it must be noted that there are many water conservation initiatives in SA to create awareness around this dwindling resource [28]. However, the apathy is attributed to many citizens, particularly those in poor communities, who do not consider water conservation a priority [27]. In summary, the municipality can make greater effort to engage with communities their serve by involving them in decision making processes. In this way, communities feel they are contributing to a solution to a problem that affects them directly. Although majority of them believed education and communication were more plausible strategies, most believed that community participation was the key to changing consumer behaviour towards water use. Hence, the use of councillors to engage more often with the community was proposed by some of the interviewees.

4.3 Theme 3: How to change consumer behaviour towards water consumption

Water conservation is of utmost importance in a semi-arid country like SA given that it's in the middle of its worst drought in decades. As such, it is imperative that communities are aware on the need to conserve water. However, it was found that the attitude of the people living in the low-cost housing areas was a point for concern. Troublingly, payment for basic services like water and electricity in SA remains a challenge because there has been culture of non-payment [12]. Therefore, this undoubtedly calls for more innovative approaches to encourage a water saving culture and behavioural change. It is claimed that a change in behaviour will have a far more beneficial effect than draconian punitive economic actions. As such, all interviewees agreed that the best way to change people's behaviour was to make them feel part of the solution. Community Representative 2 stated:

> "People who are receiving water bills are people who are using above the limit of free water provided by the municipality. That's where the municipality needs to

intervene. Instead of sending bill with these amounts that people in the poor areas cannot afford, they should come and see what the problem is. That is why people are using so much water. Most of the time it is due to leaks and burst pipes".

Council representative 2 echoed the above sentiments that inhabitants of low-cost housing communities are left out of the problem-solving mechanisms when it comes to water conservation.

"Inhabitants don't feel like they are included in problem solving mechanisms when it comes to water conservation. Therefore, there is lack of interest on their part. This is reflected in their attitude towards water scarcity and the need to save water. They feel they are not important enough to be part of solutions. The lack of communication from the water authorities has contributed towards this behaviour".

Several studies indicate that the most obvious method of influencing consumption is pricing. However, it may not be influential in the context of a given amount of free water, and a culture of non-payment. This presents a challenge in many countries. Therefore, the effort to educate communities about water resource and water demand management issues is a mammoth task and over time will manifest itself more profoundly [27].

5 CONCLUSION

SA has one of the most progressive constitutions in the world enshrining water as a basic human right. However, while it recognises the right to safe clean water, putting it into practice is somewhat more challenging. The findings of this study highlighted the challenges surrounding interaction between individuals, communities and the municipality at the local level. By understanding the reasons which influence the demand for water in poor communities, their consciousness about their water situation and their willingness to use it more consciously, one can begin to develop the appropriate strategies for implementing rational use of water for this part of the population. This study has shown that the ability of the state to effectively manage water resources in low-income areas remains a huge challenge due to poor water conservation behaviour on the part of inhabitants. The study found that this was the result of poor engagement between the municipality and the community. Stronger efforts to involve the community by making them feel part of the solution through participatory and educational programs may be a way forward in helping them use water within the amounts stipulated in FBW.

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DRINKING WATER: AN OVERVIEW OF THE HUMAN RIGHT TO SAFE DRINKING WATER IN MEXICO

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ABSTRACT

Good management of the water resource to guarantee water security in terms of quantity, quality and protection against droughts and floods, is transversal to all aspects of economic development. Solutions must be adapted to the local conditions in each country, basin, city, project or management area, in order to ensure the fulfillment of the human right to safe drinking water, sanitation and healthy environment for water. Mexico has irregular human settlements in urban, rural, ejidal and communal areas, which demand an increase in potable water and sanitation services, which, adding the regularized population, generate a demand for water that the water operation system must meet. To safeguard society from this problem, it is necessary to have good planning, have control establishing priorities in drinking water services, such as: failures in water distribution networks for human consumption, redesign of infrastructure to react adequately in events such as earthquakes, droughts, floods, climate change, population growth (sample aqueducts, dams and treatment plants); quality control of drinking water, institutional capabilities, development of technology, etc. That is, water problems are not just hydraulics, hydrology, water quality, irrigation and drainage, economy problems, etc., but they are also social and human resource training issues. This paper addresses an approach that starts with water security to achieve the fulfillment of the human right to water. Mexico has several institutions working on this issue, through some indicators, it is expected that in the short term, there will be many advances in this issue.

Keywords: water, water security, human right to water and sanitation, water school.

1 INTRODUCTION

In Mexico there are irregular human settlements in urban, rural, ejido and communal areas, which demand an increase in potable water and sanitation services, which, adding them to the regularized population, generate a water demand that Drinking Water and Sanitation Operating Agencies (OOAyS by its acronym in Spanish) – main providers of these services at the municipal level – must attend. To safeguard society from this problem, it is necessary to have ~~a~~ good planning, have control establishing priorities in drinking water services, such as: Failures in water distribution networks for human consumption; redesign of infrastructure to react adequately in events such as earthquakes, droughts, floods, climate change, population growth: aqueducts, dams and treatment plants; registration of the population to attend; quality control of drinking water; action protocols; institutional capabilities; conduct research; develop technology; form necessary human resources for this change, etc., similar to what is observed in Fig. 1.

That is, water problems are not just theoretical and engineering issues on topics such as hydraulics, hydrology, water quality, irrigation and drainage, economy, etc., they are also social and human resource training issues. To the extent that from all these areas the human right to water is addressed, greater compliance will be achieved. The Mexican Institute of Water Technology (IMTA, by its acronym in Spanish), for the moment, apart from the hydrological–hydraulic aspect, addresses social, economic and professional capacity development issues. The purpose of this work is to visualize Mexico's efforts to implement

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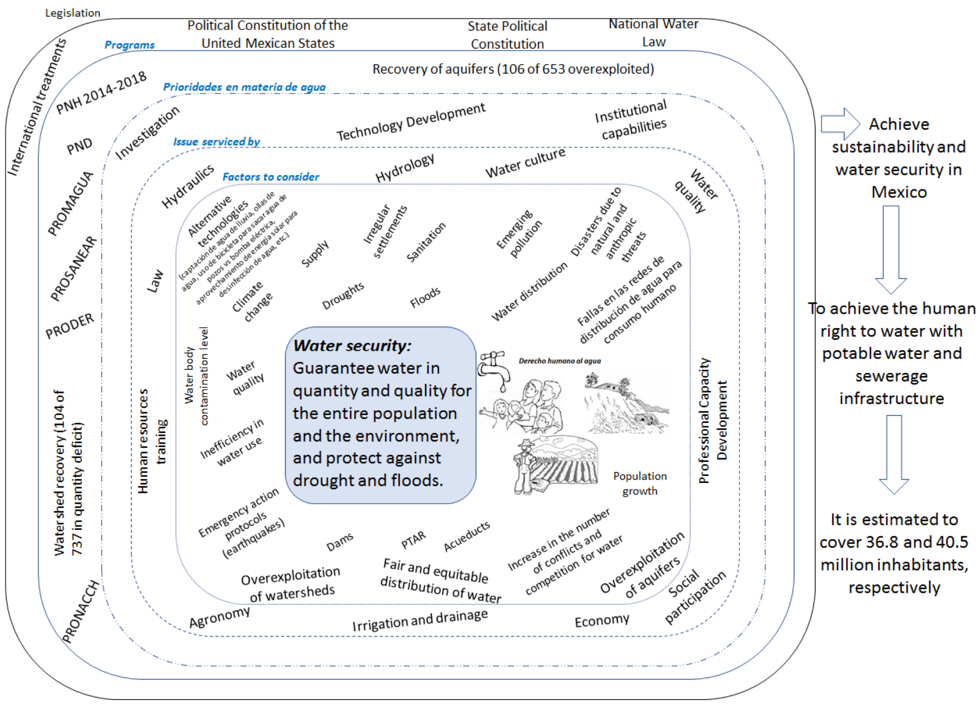

Figure 1: Conceptualization of the problem to set priorities and planning activities.

the Human Right to Water and Sanitation (HRW&S) through the premise that by ensuring water security and a good water culture, it would be easier to implement HRW&S.

2 METHODOLOGY

In order to reach our proposal, we established three aspects: 1) study a comprehensive vision of water security to guarantee the human right to water and sanitation; 2) analyze the recommendations by the special rapporteur on human rights to drinking water and sanitation of the United Nations; and 3) establish the challenges of OOAyS to comply with the human right to water and sanitation.

2.1 A comprehensive vision of water security to guarantee the human right to water and sanitation

Water security here is considered as guaranteeing water in quantity and quality for the entire population and the environment, and protecting them against drought and floods [1]. Fig. 1 shows a scheme of how, based on water security, the fulfillment of the human right to water is hoped to be achieved, considering five levels of priority grouping, where order one (or the most external level) is the legislation that includes international treaties, the political constitution of the United Mexican States, state political constitutions, and the National Waters Law.

Secondly, there are the programs designed by the Mexican government for the attention of the water issue that includes the National Development Plan (PND), the National Water Program (PNH), the Wastewater sanitation program (PROSANEAR), the Program of Return of Rights (PRODER), the National Program against Hydraulic Contingencies (PRONACCH), studies for the recovery of watersheds (of which 104 of 737 are in deficit), and technical studies for the recovery of aquifers (of which 106 of 653 are overexploited), among others.

Thirdly, there are *water priorities* that include, among others, technology development, research, and a revaluation of institutional capacities. In the fourth level of nesting *the problem addressed from the point of view of the sciences* that study it such as hydrology, hydraulics, water quality, agronomy, irrigation and drainage, economics, law, water culture, social participation, development of professional skills, training of human resources, etc.; and finally, the *factors to consider* such as inefficiency in water use, overexploitation of watersheds, fair and equitable distribution of water, population growth, overexploitation of aquifers, increase in the number of conflicts and competition for water, emerging pollution, level of contamination of water bodies, climate change, droughts, floods, disasters due to natural and anthropic threats, irregular settlements, failures in water distribution networks for human consumption, supply, sanitation, water quality, wastewater treatment plants (PTAR), water treatment plants, dams, aqueducts, emergency action protocols (earthquakes), alternative technologies (rainwater harvesting, water pots, bicycle use to draw water from wells vs. electric pump, use of solar energy for water disinfection, etc.).

2.2 Analyze the recommendations by the special rapporteur on human right to drinking water to drinking water and sanitation of the United Nations

To this vision is added the series of recommendations on the fulfillment of the human right to water and sanitation issued by the special rapporteur on human rights to drinking water and sanitation of the United Nations [2], in his assessment of the situation in Mexico in May 2017 (Fig. 2), some of which are mentioned below.

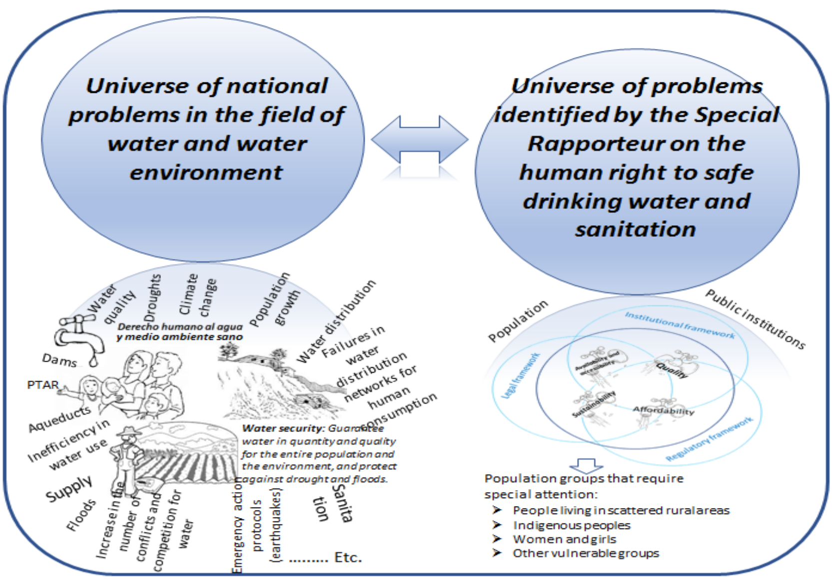

Figure 2: Problem identified regarding the management of the water resource, based on observations of the Special Rapporteur on human rights to drinking water and sanitation.

Availability and accessibility: (a) Avoid claiming official coverage figures that are misleading and may delay the application of essential measures to improve services and access to drinking water and sanitation; (b) An alleged good performance should not be used to justify the large reduction in the water and sanitation budget in 2017; (c) The human right to water and sanitation requires that the domestic needs of all people, families and communities be the first consideration and receive the highest priority among the various uses of water, as also explicitly required in the National Water Law (LAN); (d) The inequalities in the water supply in the city are related to the level of wealth. Human rights to water and sanitation (DHAyS by its acronym in Spanish) must be met, respected and protected for all members of society, regardless of their social and economic status and the situation of their home. Irregular settlements must be formalized and water and sanitation services delivered to these locations; (e) The human right to sanitation does not necessarily require collective solutions, but it establishes the obligation of governments to support individual solutions to meet the requirements in terms of hygiene, health and the environment; (f) There is a collapse of sewerage networks or insufficient funds: costly wastewater treatment plants that are not in operation due to lack of maintenance and resources for its operation.

Quality: (a) Update the current standard, in a rigorous, open and participatory manner, to allow more adequate monitoring and supervision of drinking water and aimed at health protection; (b) Relying on bottled water impairs accessibility and affordability of the water supply; (c) Ensure that the program of using the income obtained from the soft drink tax continues to be implemented, to support the installation of drinking water sources in public schools. Initiative with support of the General Law of Educational Physical Infrastructure; (d) Strengthen the quality control of the water supplied by the suppliers. More thorough quality monitoring. Water authorities and providers must guarantee the right to information and provide systematic information to users about the quality of the water they consume, regardless of the individual requests or complaints received. A national guideline on that issue would be very positive.

Affordability: (a) The financial sustainability of the water and sanitation system is essential and depends on an appropriate system of water rates, but it is essential to ensure the comprehensive maintenance of services for people with lower incomes or those living in poverty; (b) Often the poorest pay more for water and spend more time and energy to get it (they use alternative – expensive – ways to get water: bottled water, tank trucks and informal suppliers); (c) There is no definitive legal safeguard that prevents disconnection due to lack of economic capacity to pay; (d) The revised national legislation on water and sanitation services must include a provision that clearly prohibits the disconnection of users who do not have the financial capacity to pay the bills corresponding to those services; (e) In some places there is fraud, since houses are sold without having the necessary permits to access services and supplies, an unacceptable fact in the fulfillment of the human right to water and sanitation.

Sustainability: (a) There are cases of costly infrastructure projects for water supply, sewerage and wastewater treatment executed by federal and state authorities. They stop working quickly due to lack of maintenance and trained personnel, as well as the high costs required for energy and maintenance; (b) Several PTAR that are not in operation, causing a major problem of contamination of water sources. No appropriate solution is contemplated for residents, and local authorities expressed frustration and highlight their lack of ability to address the issue due to lack of financial and technical resources and not having sufficient support from state and federal governments.

Population groups that require special attention: (a) People living in scattered rural areas should be considered; indigenous peoples; women and girls; other vulnerable groups (homeless); (b) The amendment to article 4 of the Constitution added the sixth paragraph to recognize the human right to water [3], [4], recognizing that everyone has the right to access, dispose and sanitize drinking water for personal and domestic consumption, in a sufficient, healthy way, acceptable and affordable, as a human right to water, in said decree it was established that Mexico would have 360 days to issue a General Water Law, which is still pending today.

Fig. 3 shows the series of legislative review, which is necessary to be able to carry out a proposal for a General Law on Access, Disposal and Sanitation of Drinking Water, so that this proposal makes it easier to comply of the aforementioned human rights in the field of water.

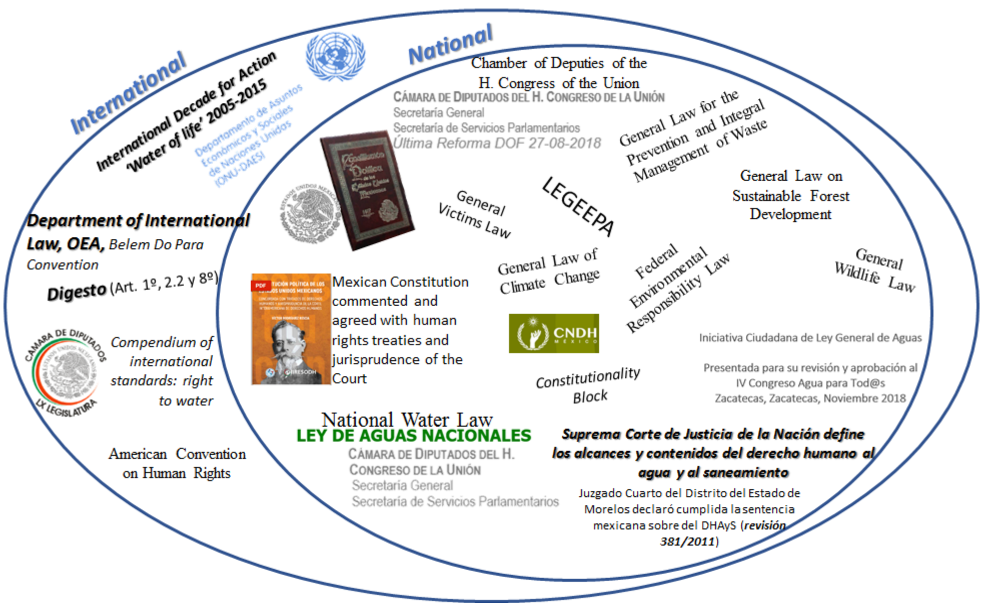

Figure 3: Legislation by scope in the subject of human right to water and sanitation in Mexico.

The General Water Law that mandates the transitory article 3 of the decree that amended the Constitution refers only to the human right to water for domestic and personal consumption. The human right to water needs to establish public policies that organize its progressive realization. Its elements must correspond to dignity, life and human health, whose main factors are the following: (a) Availability, (b) Quality, (c) Accessibility (physical accessibility, economic accessibility, non-discrimination, access to information).

While Mexico determines the amount of water associated with the human right to water, it is suggested that the first 35 l/hab/day be charged so that they are available to any citizen – including those of the first decile of income – and, from that volume, the price of water includes not only the direct cost of providing a citizen service, but also the environmental cost and the opportunity cost of the water itself, as well as the direct or cross-subsidies necessary to support the families of less economic resources, the maintenance cost of the

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hydraulic infrastructure and the financial cost to expand the coverage and improve the quality of the domestic public service of drinking water and sanitation [5].

2.3 Establishment of challenges of OOAyS to comply HRW&S

In Mexico, the Drinking Water and Sanitation Operating Agencies (OOAyS) are responsible for the distribution of the vital liquid to the inhabitants of a city, municipality or locality. This activity implies big challenges of OOAyS. This function requires trained personnel to operate the infrastructure to provide the corresponding services, as well as adequate infrastructure, tools and equipment. In Mexico, the National Water Commission (CONAGUA by its acronym in Spanish), with the support of IMTA, developed and implemented the concept of the Water School from 2016, an intensive program that seeks to professionalize the personnel of the subsector institutions, in order to improve the capacities of both OOAyS personnel, authorities in different fields (federal, state, municipal) and citizens, in aspects that we must improve in order to reach a balance that allows the flow of activities under full awareness of the consequences that will exist in case any of the entities involved does not comply with their share.

From the awareness that every citizen should have about the care for their water, that is, having the knowledge of water management from the source of origin to the tap in a house, through the operating part of the OOAyS, to the making of public policy decisions that authorities from their field must make for the benefit of all citizens, will therefore result in compliance of the human right to water and sanitation.

Initially the program was developed under six themes identified as priorities: (1) Analysis of costs and fees for services; (2) Energy efficiency; (3) Management and operation of wastewater treatment plants (PTAR); (4) Macro and micro measurement; (5) Commercial system; and (6) Operating system, drinking water supply subsystem.

As of 2017, the program was reinforced with more topics contributed by IMTA, allowing different actors to have a greater spectrum of possibilities to meet their professionalization needs.

Fig. 4 shows in a schematic way, the integration of the benefits of the dissemination of knowledge that the Water School offers, with the challenges that OOAyS face in fulfilling the human right to water and sanitation, through quality services. Listed below are the issues that at the Water School has addressed and offered to OOAyS personnel and the objective they pursue [6].

Water and Education: Oriented to raise awareness and teach various aspects of water and its importance for the maintenance of life, health, food production and for all economic activities, emphasizing the need to take care of it and use it responsibly. It covers teaching strategies, physical and chemical properties of water, importance of water for life and terrestrial systems.

Analysis of costs and fees for services: Oriented to identify, calculate, project and design, cost structures and tariff structures (with accounting, financial and consumption information), to establish strategies and actions that increase physical and commercial efficiencies, with a tendency to achieve a survival financial coverage (rates/costs).

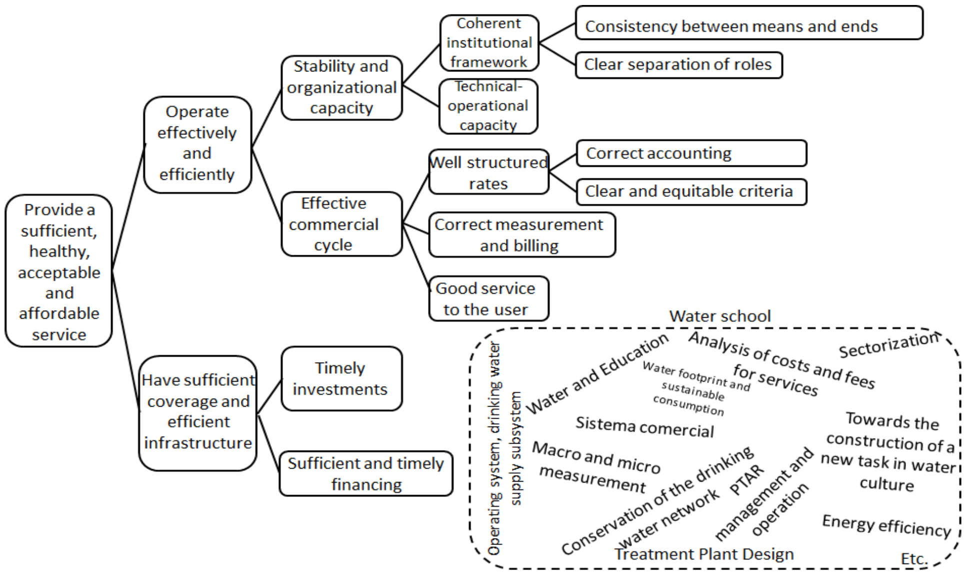

Figure 4: Challenges of the drinking water and sanitation operating agencies to meet DHAS and courses aimed at addressing them. *(Source: Generated from [7].)*

Attention to users in the request for services: in water management entities: know and apply the techniques and procedures for the detection of the needs and attention of a user of drinking water services, as well as for the collection and administration of information Documentary generated during the attention of the services offered, which allows to offer a quality service, with the aim of obtaining the certification in the Competition Standard EC0153.

Conservation of the drinking water network: Know the main components of a drinking water network, have the elements to prepare the workplace for the maintenance of the drinking water network and apply the necessary techniques to repair and install pipes and fittings of the drinking water network. The lack or failure of organizations in the maintenance of the water supply and distribution infrastructure, increases the OOAyS activities and has a strong impact on the quality of services and prices offered to the public, in addition to shortening the useful life of the infrastructure, with the aim of obtaining certification in the Competition Standard EC0141.

Quantification of drinking water consumption with measurement: reinforce knowledge to prepare documentation and equipment for the determination of drinking water consumption with measurement and to record the reading for the determination of drinking water consumption with measurement, in order to obtain the Certification in the Competition Standard EC0140.

Design of treatment plants: Know the elements to consider in the design of wastewater treatment plants, taken at the start of the design expense. Currently, due to population growth, as well as changes in lifestyle, the wastewater produced is of a very diverse type and demands more complex processes for its treatment.

Energy efficiency: Know, analyze and evaluate the most common problems related to energy saving and efficient use of resources that a pumping station has to reduce bill payments with excessive costs for consumed electricity. The technical specifications, measurement methods, test requirements, pumps and motors selection, efficiency prediction, factors that affect efficiency and those that increase it are described.

Management and operation of wastewater treatment plants (PTAR): Know the legal framework (NOM 01 SEMARNAT 1996, NOM 02 SEMARNAT 1996, NOM 03 SEMARNAT 1996, NOM 04 SEMARNAT 1997, NOM 14 SEMARNAT 2003 and NOM 15 SEMARNAT 2007), the quality parameters, the importance of wastewater sanitation, the reuse alternatives of these and the generated sludge; as well as the most adequate and efficient operating conditions of a treatment plant.

Towards the construction of a new task in water culture: Reflect on the work of the institution regarding the promotion of water culture, exploring conceptual and methodological tools to strengthen its work in the field. Environmental education concepts. Institutional and citizen practices on water culture, sustainable practices of water management, guiding principles on environmental education and water culture, such as: The earth charter; pillars of education; education for world citizenship and new water culture; the human right to water; techniques for evaluating the impact of water culture programs.

Water footprint and sustainable consumption: Understand the concepts and importance of “virtual water” and the “water footprint” (green, blue and gray) of a product, of the consumer, of a company, etc., as well as the global dimension of water management, derived from the trade of products with high water requirements; and the need and importance of sustainable consumption and reflect on the actions to be taken to achieve it.

Installation of the household drinking water: Strengthen the knowledge to perform the installation of household drinking water supply, which includes preparing the documentation, materials, tools of the household outlet, placing the household outlet, testing and delivering the household outlet, with the objective of obtaining certification in the Competence Standard EC0237.

Macro and micro measurement: Know the different measurement systems, the instruments used and their applicability according to the physical conditions of the water, the users and the conditions of the environment, as well as know the national process of certification of meters (national meter standard NOM-012-SCFI-1994 and complementary standards NMX) and its comparison with international standards (international meter standard ISO-4064-1 fourth edition 2014-06-01).

Promotion of water culture: Have knowledge and theoretical–practical elements that will apply in water culture actions, with the aim of obtaining certification in the EC0180 Competence Standard.

Sectorization: Apply the tools to develop a sectorization program for drinking water distribution networks. Criteria for tracing hydraulic sectors; Field actions to sectorize; Water outlets to another sector; Flow, pressure and residual chlorine measurement; Know the volume injected into the sector; Calculate the efficiency of the sector and compare with the theoretical; Determine the actions to be taken to improve efficiency.

Commercial system: Provide knowledge for the promotion, sale and collection of services and the expansion of the user market. Obtain the optimum economic performance of the services, by selling and charging as many users as possible. The above includes the subsystems of marketing, user registration, determination of consumption, and billing and collection.

Operating system, drinking water supply subsystem: Know the main elements of an efficient supply system, detect anomalies and propose your infrastructure operation improvement plan, highlighting the immediate, medium and long-term actions, with their corresponding investments.

All this training or improvement of the competences to the personnel, is focused to standardize the capacities of the technical and operative personnel of the institutions that provide the drinking water and sanitation services of the country.

3 DISCUSSION

All those findings, the complex point of view of water security, the precisions of the ONU's rapporteur, and the water culture that OOAyS has implemented inside their offices, allow us to notice and recognize the benefits of public websites on evaluation of the Human right to water and sanitation and healthy environment in Mexico, which has been increasing the number of indicators to evaluate this human right.

In the proposal of the National Water Program (PNH 2019-2024), the first objective was to progressively guarantee the human right to water and sanitation, especially to the most vulnerable populations. Measuring the degree of compliance with the human right to water, sanitation and healthy environment in Mexico, is an issue of which at least three institutions have carried out actions in regard to and published their information on public websites, and correspond to: (1) The citizen initiative and social development (INCIDE social AC); (2) The Ministry of Governance; and (3) The National Human Rights Commission (CNDH).

The social INCIDE A.C. publishes the Observatory of social policy and human rights, and in the field of water includes the indicators called the human right to water and the human right to a healthy environment, on its website http://observatoriopoliticasocial.org/derecho-a-la-agua/, both are grouped into indicators of accessibility, availability, quality and affordability, although not all groups of indicators are developed, as seen in [8]. In addition, in the right to a healthy environment, such as quality indicators include air pollution issues. INCIDE A.C. publishes the next indicators:

Accessibility (right to water): (a) Population coverage with drinking water (%); (b) Origin of drinking water supply in housing 2016 (%); (c) Origin of drinking water supply in housing by federative entity 2016 (%); and (d) Provision of rooftop tank 2016 (%).

Availability (right to water): (a) Periodicity with which homes receive drinking water 2016 (%); (b) Frequency with which homes receive drinking water by state 2016 (%); (c) Concession volume of water for consumptive use (%).

Accessibility (right to a healthy environment): (a) Population coverage with drinking water (%) and (b) Forest and forest area (hectares).

Availability (right to a healthy environment): (a) Average natural water availability per capita; (b) Frequency with which homes receive drinking.

Quality (right to a healthy environment): (a) Daily per capita generation of urban solid waste; and (b) Mexico's position within Organization for Economic Cooperation and Development (OCDE) countries on the environment issue of the OCDE Index for a Better Life.

The Ministry of Governance publishes the National System for the Evaluation of the level of compliance with Human Rights (SNEDH), on its website https://snedh.segob.gob.mx/, where one of the five rights groups is Law to the Environment, as seen in [9], addressed in five categories: Receipt of the right, financial and budgetary context, state capabilities, equality and non-discrimination, access to public information and participation, and, access to justice. In each category it classifies in structural, process and result indicators. Grossly, its matrix of indicators includes areas such as: (a) Population with piped water; (b) Population with improved sanitation service; (c) Ecological risk; (d) Sustainability of protected areas; (e) Environmental budget; (f) Energy production and renewable sources; (g) energy service, etc.

For its part, the National Human Rights Commission publishes the National Human Rights Violation Alert System, on the website http://appweb2.cndh.org.mx/SNA/ [10], however, it is in the process of generation and publication of indicators for the evaluation of compliance with the Human Right to Water, Sanitation and Healthy Environment in the field of water.

4 CONCLUSIONS

In this study, an approach that begins with the water security is approached to achieve the fulfillment of the human right to water, passing through elements of improving the capacities of the personnel of the institutions that provide drinking water and sanitation services, through the "Water School", that has come to strengthen the knowledge of water administration from the source of origin to the faucet in a dwelling, through the operative part of the operating agency until making large public policy decisions that the authorities from their field must take for the benefit of all citizens and as a result of, comply with the human right to water and sanitation.

Mexico has several institutions working on this issue, through some indicators that focus directly on the issue of the human right to water and sanitation, these being structural, process or results, as seen at Public websites on evaluation of Human right to water and sanitation and healthy environment in Mexico; Given the objective one of the PNH 2019–2024, it is expected that, in the short term, there will be many advances in this issue.

It is important to focus on the information hidden, implicitly, inside an indicator published by those institutions, that data could help us build new indicators.

There is a lot of work to be done, the efforts identified are still insufficient if we look at the universe of actors and institutions involved, the operating time that some programs carry, their scope often limited in terms of the amount of resources or the capacity of some institutions to join the programs.

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EVALUATION OF THE MANAGEMENT OF THE LAURENTIAN GREAT LAKES: THE ROLE OF US CONGRESSIONAL POLICYMAKING

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ABSTRACT
This research examines the importance of tone and issue framing by the United States Congress, using the case of the Laurentian Great Lakes (Great Lakes) from 2000 to 2019. Researching the tone of United States congressional committees, subcommittees and their witnesses, it is determined that congressional committees conduct hearings reflecting their public policy tone instead of more open discussions of the policy issues confronting the Great Lakes today. There is a statistically significant weak to moderate relationship of the tone of the committee, reflecting the same tone as the hearing. Similar to the tone of the committees mimicking the tone of the hearings, it appears that the tone of the witness reflects the tone of the hearing being conducted by the congressional committee. There is a statistically moderate to strong relationship between the tone of the witness and the tone of the hearing they attend. This is especially true for hearings conducted with an environmental protection tone and, to a lesser extent, with the tone of hearings and witnesses focused on commerce, industry and transportation. The research results lead to concerns regarding the fragmentation of Great Lakes public policymaking and the inability to address concerns for the Great Lakes, such as climate change, pollution and invasive species.
Keywords: Great Lakes, congressional policymaking, public policy, issue definitions.

1 INTRODUCTION

The five Laurentian Great Lakes in North America (referred to as the Great Lakes) were formed during the Wisconsin glaciation period as recently as approximately 14,000 years ago. The lakes include Lake Superior, Lake Michigan, Lake Huron, Lake Erie, and Lake Ontario. These lakes, with the exception of Lake Michigan, form an aquatic border between eastern United States and Canada. Eight states have borders adjacent to the lakes: Illinois, Indiana, Michigan, Minnesota, New York, Ohio, Pennsylvania and Wisconsin, as well as the Canadian provinces of Ontario and Quebec. The Great Lakes basin constitutes a population of more than 30 million people which includes approximately 10% of the population in the United States and more than 30% of the Canadian population. These lakes represent close to a fifth of the planet's and 84% of North America's supply of fresh surface water [1]. The lakes directly generate more than 1.5 million jobs and $60 billion in wages annually and include habitats for more than 3,500 plant and animal species, some of which are found nowhere else on Earth [2]. The region collectively forms a $4.7 trillion economy, which is ranked as the fourth largest in the world [3]. The lakes have gone through significant degradation and restoration over the years related to commercial, industrial, agricultural, recreational, and transportation uses. Canada and the United States began international management of the lakes with the 1909 Boundary Waters Treaty. Management of the Great Lakes has evolved over time into a sophisticated and complex regime of institutions with numerous government agencies, commissions, and policies outlined in treaties and government regulations to both protect and utilize the ecosystem.

There are three branches of the United States federal government: the executive branch comprised of the President and federal bureaucracy; the legislative branch reflected in the United States Congress; and the judicial branch that includes the Supreme Court and a series

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of other federal courts. The United States constitution imposes a variety of checks and balances to limit each branch of government's influence, creating a co-equal tripartite balance while maintaining some distinction of duties and roles. The Congress is charged with crafting legislation, which is critical in the issue definition process for the Great lakes. Both chambers of Congress, the House of Representatives and the Senate, must agree on any piece of legislation, including all federal program funding, in order for the legislative bill to be passed onto the President; who signs the bill into law. This research examines the Congressional role in managing the Great Lakes, specifically examining the role of congressional hearings, which operate through congressional committees, and the witnesses who testify on the Great Lakes. It especially pays attention to the linkages of tone between the committees and witnesses in congressional hearings over time regarding the lakes. Because the lakes are such a significant natural resource, it is critical to understand the role of the United States congressional participants in framing the policy solutions surrounding this ecosystem.

2 LITERATURE REVIEW

Congress has a significant role in shaping the health of the Great Lakes in terms of policymaking. In the United States, congressional committees establish jurisdictional boundaries for policy issues, while committee hearings define and frame issues. Policy boundaries established by committees in congress need jurisdictional reinforcement to maintain continuity and distinction from other committees who may be looking to expand their policy jurisdiction [4]. As a result research on congressional public policy making is useful in understanding how issues concerning the Great Lakes are created and change over time. Research shows that a committee seeking to expand its scope of influence can use hearings to encroach on the jurisdictional boundaries of another committee [5]. Over time, committees can have a monopoly over certain issues which then can be challenged by other committees. In some policy domains like smoking, wetlands, and nuclear energy an erosion of issue dominance by the committee's monopoly of the policy jurisdiction can occur [6]. In these cases, research studies have shown that new committees and witnesses serve to redefine the policy and the committees staked out jurisdiction; this has been referred to as "turf wars" that take place in congressional policymaking among committees [5].

The role of congressional committees and their hearings, along with the role of issue definitions forming the basis of policymaking for the Great Lakes over time has been studied. Policy regarding the use and management of the lakes has been characterized as occurring in three distinct eras of time [7]. These eras each reflect dominance of a certain tone in congressional committees, hearings, and testifying witnesses. Tone is used in policy research to understand the propensity or tendency of how an issue is framed. The influence of these committees and witnesses help to define the issues and policies that are addressed in the Great Lakes ecosystem. The policy issues have been defined and re-defined over time, reflecting the priorities for the lakes during that particular time frame. The use of symbols, rhetoric, and congressional hearings reflect how these lakes are defined and managed over time. When policy change occurs in Congress, the tone is reflected in the committees and witnesses who participate in congressional hearings.

Era I of congressional policymaking on the lakes occurs from 1789–1965 with a dominant tone focusing on navigation, commerce, agriculture, and transportation. In 1966, issue definitions shift; focusing on environmental protection and human health [7]. By 1984, Era III ushers in what has been coined as an "agenda-sharing" time period reflective of a bounded issue model rather than one of dominance of a particular tone of public policymaking as was witnessed in Eras I and II. The three eras of congressional policymaking on the Great Lakes are:

- Era I Navigation, Industry, and Commerce Dominance (1789–1965)
- Era II Shift to Environment and Health Dominance (1966–1983)
- Era III Agenda Sharing (1984–1999)

There are several non-congressional actors involved in the Great Lakes policy arena. The Clean Water Act charges the U.S. Environmental Protection Agency (EPA) with leading the effort to meet the requirements of the Great Lakes Water Quality Agreement. The act also statutorily established the Great Lakes National Program Office within EPA, charging it with, among other things, cooperating with federal, state, tribal, and international agencies to develop and implement specific action plans to carry out responsibilities under the agreement. In addition to the various governmental agencies involved in Great Lakes, several nongovernmental organizations have established environmental protection goals [8].

2.1 Congressional policymaking on the Great Lakes

Early in the history of the United States, the lakes were defined as being a navigation venue for commerce and population migration or transit to the Midwestern region of the country. The lakes were used by explorers, and later industrial entrepreneurs for their natural resources such as beaver fur, timber, and metals. The tone of the hearings, committees and witnesses focused on these types of issue definitions for the lakes. By the mid-1960s, the modern environmental movement in the United States shifted the issue definitions of the lakes to concerns about environmental protection and human health. This shift is reflected in the tone of the committees and hearings transitioning to concerns about pollution and contamination of the lakes versus their development for navigation for commerce and industry. A third transition occurs by 1984, when a bounded issue model evolves from the two previous eras. In Era III the previous tones of Eras I and II share the agenda in Congress. Rather than the dominance of a single-issue monopoly, multiple sets of many issues are reflected in policy making. This can be explained by the need to provide a sustainable use and development approach where one use does not create a negative impact on the environment or other users' needs for the lakes. This type of issue definition allows multiple definitions of how the lakes are managed and valued for the purpose of mutual coexistence. This is important because a negative impact by one user of the lakes can have devastating impacts on another. For instance, industrial uses of the lakes can negatively impact recreational, agricultural or public health sectors. Under this bounded issue model, congressional committees and their subcommittees handle differing aspects of the lakes simultaneously through different hearings without a dominating tone of influence. As a result, more than one issue definition of the lakes is portrayed in the hearings and witnesses.

2.2 Era IV improving the management of the Great Lakes (2000–2019)

This research examines the time period from 2000 to mid-2019 (Era IV) to determine if Great Lakes policymaking in the United States has evolved into a new or altered issue definition from the agenda-sharing reflective of the bounded issue model. Research questions explored include the definition of Great Lakes policymaking in congressional hearings, committees, and witnesses over the past 20 years.

A few of the major issues discussed in congressional hearings during this era include:

- 2002 Great Lakes Legacy Act
- 2004 Great Lakes Regional Collaboration
- 2008 Great Lakes Compact

- 2010 Great Lakes Restoration Initiative
- 2012 Great Lakes Water Quality Agreement

The beginning of Era III creates a more sophisticated and complex foundation for managing the lakes, building on the policy work in Era II. It creates a variety of initiatives to address the human health and environmental protection of the lakes from a diversity of pollutants of the past. This work has continued to be refined in Era IV with an increased push from Congress on the EPA and other implementing agencies to focus on better methods and management to integrate across the fragmented policymaking system for the lakes. For instance, since 2000, the Government Accountability Office (GAO), an investigation arm of Congress, strongly recommends improvement for the continued management of the lakes [9], [10]. Some of the pollutants, known as bio-accumulative chemicals of concern (BCC), pose risks to humans and wildlife that consume them by remaining in the ecosystem. During Era I, the GAO recommended that the methods and standards for many of these BCC's (like mercury) be improved and better monitored during this period [9], [10]. Under the Great Lakes Legacy Act of 2002, 19 sites have been remediated.

The Great Lakes Restoration Initiative (GLRI) established in 2010 had as its foundation the 2004 Great Lakes Regional Collaboration. The goal of the 2010 initiative was to accelerate progress by targeting and prioritizing the largest threats to the lakes. This did not create new policies for the lakes but focused on accelerating work to complete already established areas of concern such as remediation of contaminated sites around the lakes, additional protection from invasive species, and nonpoint source pollution impacts to nearshore human health [11]. The GLRI is the largest investment in the Great Lakes in two decades and funds a variety of activities including grants and the direct implementation of Great Lakes Legacy Act projects [12]. The third Action Plan under the Great Lakes Restoration Initiative is expected in draft form in by the end of 2019. The plan will outline priorities and goals for the GLRI for the years 2020–2024. However, the theme of the last 20 years of Great Lakes policymaking appears to be one of not necessarily new and bold initiatives for the lakes but improving the management of the programs in place.

In 1972, Canada and the United states signed the Great Lakes Water Quality Agreement. It was amended in 1983 and again in 1987. During Era IV, the agreement was updated in 2012 to enhance water quality programs that ensure the chemical, physical, and biological integrity of the Great Lakes [13]. Another major cooperative arrangement within the United States occurred in 2008, when the Great Lakes Compact was approved by the legislatures of the eight Great Lakes states and by Congress. Under the Compact, eight Great Lakes states agree to adopt water-conservation plans and to abide by Compact rules for allowing and managing diversions of Great Lakes water. The Compact recognizes the lakes as a shared resource where no single state owns the lakes, but all states are stewards of this shared resource. As such, a defining feature of the Compact is its emphasis on using regional cooperation to manage the lakes as a single ecosystem [14].

At the close of the first decade of the 21st century, the International Joint Commission which is a binational organization that coordinates Great Lakes issues across Canada and the United States provided overview reports on the lakes. It concluded that significant challenges continue in the management of the lakes. This includes the increase in harmful algal blooms in Lake Erie, the slow pace in addressing chemicals of mutual concern, and the spread of previously introduced invasive species. The Commission emphasizes that governments also need to pay additional attention to infrastructure investments that are essential to reduce risks to human health. It specifically states that that the water quality of western and central Lake Erie remains unacceptable [15].

Era IV does not reflect new challenges for the management of the lakes, but rather continued challenges that have not yet been resolved through governmental programs. The GAO reported that restoration efforts for the Great Lakes lacked leadership and organization and required a comprehensive strategy similar to ecosystem restoration projects in South Florida and the Chesapeake Bay of the United States which tended to be more effective [16]. This research examines if there has been a change in tone in Congress that may have resulted in a change in policy focus on the lakes to address these concerns and challenges and also establish a direction for future policy making by Congress.

3 RESEARCH DESIGN AND METHODS

3.1 Sample description of Era IV improvement of managing the Great Lakes

This research examines the current era of Great Lakes policymaking which begins immediately after the conclusion of Era III, January 2000. The research concludes with the most recent available data as of August 2019. Using the ProQuest Congressional Publication database, a keyword search was performed to identify congressional hearings concerning the Great Lakes conducted between 2000 and August 2019 [17]. An examination of all hearings for relevancy yielded a final dataset of 147 congressional committee and subcommittee hearings dealing directly with Laurentian Great Lakes policies. The dataset was hand coded to systematically analyze and evaluate the tone of the hearings, committees, subcommittees and witnesses testifying at these hearings. After nonparametric statistical testing, policy making eras were compared to examine changes in policy making.

The dataset includes a total of 20 committees, 31 subcommittees, and 442 witnesses. The number of hearings (Fig. 1) and witnesses per year (Fig. 2) illustrate the sample used in this analysis over time.

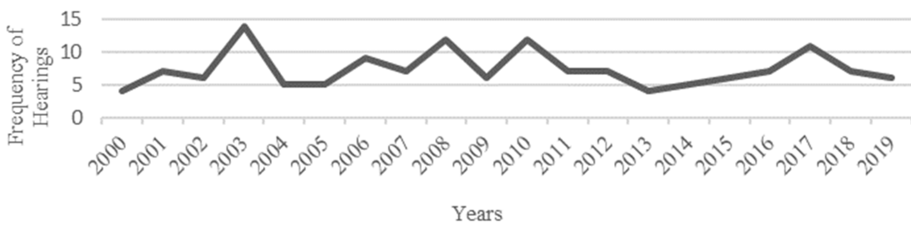

Figure 1: Congressional Hearings on the US Great Lakes 2000–2019 (n=147).

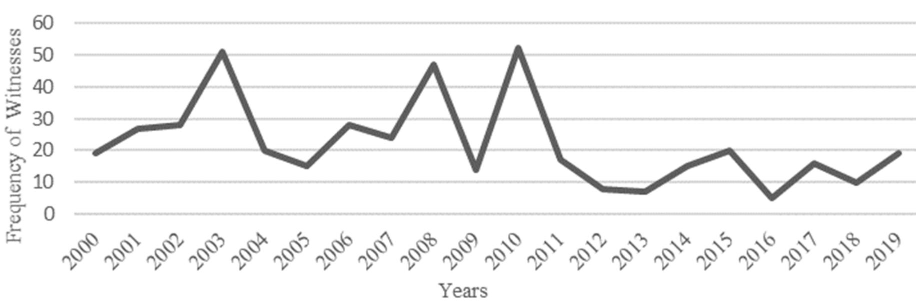

Figure 2: Congressional US Great Lakes Witnesses from 2000–2019 (n=442).

Based on these figures, it appears that there has been an ebb and flow of hearings ranging from a high of 14 hearings conducted in 2003, to a low of four hearings in both years 2000 and 2014. This indicates that Congress consistently conducts hearings on the Great Lakes with some variance in its attention per year. Likewise, the number of witnesses has a range from a high of 52 participants in 2010 to a low of only 5 witnesses in 2016. This range indicates that Congress appears to vary its attention and gathering of input from witnesses perhaps due to its priorities of other policies in a given year.

3.2 The tone of hearings, committees and witnesses

The measurement and analysis of several variables was conducted in order to provide a detailed examination of who has influence over congressional Great Lakes policymaking. The congressional chamber, committee and subcommittee conducting the hearings was noted. The hearing subject was included in the coding for the overall topic of the hearing. Topics focused on broad categories such as environmental protection, commerce and industry, transportation, natural disasters, and terrorism and border security. Hearings were also coded for being legislative if the purpose included a statute consideration. This is important because previous research has shown that congressional committees frequently use non-legislative hearings to expand their jurisdiction over time [6], [5]. Non-legislative hearings, which do not consider a piece of legislation for action, take the form of oversight, investigations or briefings on issues.

Often policy experts and affected parties serve as witnesses at these hearings. Individual witness tracking was employed in order to discern how often and under which committees and subcommittees the individual testified. For further analysis, witness organizational representation was then grouped into broad categories: federal agencies, state and local governments, trade associations, federal elected officials, academic researchers and institutions, think tanks and advocacy groups.

When examining congressional policymaking, one of the most important variables in the literature is the “tone” of the hearing, witness and committee. Past research has shown that while gathering information from witnesses, committees tend to only hear from participants reflecting a tone similar to the tone of the hearing or committee.

To investigate if this congruence of tone is occurring in Great Lakes policy during this time period, hearing, committee and subcommittee, and witness tone was identified and tracked over time. Tone is defined as being broadly environmentally protective of the Great Lakes ecosystem or supportive of its development for commerce, industry and transportation. If the tone was not discernible from the congressional documents, it was coded as neutral.

Changes in tone are particularly important indicators of policy changes and re-definition of the understanding of the Great Lakes. Tonal changes over time help to indicate the different eras of issue specific policymaking. Nonparametric statistical tests are used to test if there are significant changes in the tone and the relationship among the hearings, committee, and witnesses.

4 RESULTS

While many policy participants have a role in the management of the Great Lakes, the role of the committees of Congress, and their subcommittees, is essential. The work of congressional committees and their subcommittees of Congress take place in hearings with witness testimony. Hearing testimony includes gathering information from witnesses as well as the opinions and concerns of groups potentially affected by Great Lakes policies.

4.1 Congressional committee and hearings from 2000–2019

A change from the past eras in terms of the committees and subcommittees conducting hearings on the Great Lakes occurred during Era IV. The US House of Representatives dominates with over 74% of the hearings being conducted in the chamber. Having more committees, it is not surprising that this chamber conducts more hearings than the US Senate. From 2000 to 2019, three of the total 20 committees involved with Great Lakes policymaking conducted 64% of the hearings: Appropriations 37.4%, Transportation and Infrastructure 16% and Environment and Public Works 10%. The other 17 committees each held less than 10% of Great Lakes hearings, creating a fragmented approach to policymaking regarding a complex ecosystem. While the number of committees and subcommittees conducting hearings has not significantly changed from the past, the focus on appropriations is a departure. In both Era II and Era III congressional committees and their subcommittees were focused on issues of environmental concern for approximately a third of the hearings. Today, committees are focused on funding programs through the Subcommittees on Energy and Water Development (14%), and Water Resources and the Environment (9.5%), with the remaining 29 subcommittees conducting less than 7% of the hearings during this period. This indicates that Era IV is focused on funding programs that have been created in past congressional policymaking rather than generating completely new approaches or initiatives.

Research has shown that across eras, congressional committees tend to conduct hearings that are aligned with their policy agenda. Thus, the tone of the committee can be correlated with the tone of the hearing conducted (see Table 1).

Table 1: Tone of the committees and their hearings from 2000–2019 (n=147).

Tone of the hearing	Tone of committee			
	Environmental protection	Commerce, industry, transportation	Neutral	Totals
Environmental protection	86.4% (19)	9.1% (2)	4.5% (1)	100% (22)
Commerce, industry, transportation	59.1% (26)	40.9% (18)	0	100% (44)
Neutral	54.3% (44)	40.7% (33)	4.9% (4)	100% (81)
Totals	60.5% (89)	36.1% (53)	3.4% (5)	100% (147)
Kendall's Tau-b=.177 (p=.018), Gamma=.329 (p=.018), Chi-Square= 10.32 (p=.035)				

The results showed that there is a statistically significant and weak relationship of the tone of the committee reflecting the same tone as the hearing in Era IV (Kendall's Tau-b=.177, p=.018; Gamma=.329, p=.018; Chi-Square= 10.32; p=.035). The environmental protection tone of the committee frequently reflected the same tone of the hearing (86.4%) more often than committees with a commerce, industry, and transportation tone (40.9%). Era IV results demonstrate that congressional committees continue to use hearings to reinforce their policy positions and agenda for the Great Lakes. This poses a significant dilemma for the Great Lakes since congressional policymaking has not evolved into a sustainable development or collaborative approach towards management of the ecosystem. In fact, it may indicate that different programs in Congress have become entrenched in their jurisdictions rather than moving into a collaborative approach to lake management. It could also indicate a decline of the two major tones regarding the lakes and the potential for the evolution of a new tone or definition of the lakes. The strength of these nonparametric correlations is much weaker than in previous research which reported a strong relationship between the tone of the committee and the hearings they conduct. If this Era IV decline in correlation of tone between hearing and the committee continues into the future, it may be indicative of an erosion of committee jurisdictions.

4.2 Witnesses who testify before Congress on the Great Lakes from 2000–2019

Of the 443 witnesses who testified in hearing during Era IV, most were male (84%) participating before non-legislative hearings (55%). Previous research demonstrated of witness testimonies included 557 witnesses during Era II, and 858 witnesses in Era I. This indicates that while there is a continued reliance on male witnesses, there are significantly fewer witnesses participating than in past eras of hearings. Witnesses appear about 30% of the time before the House Transportation and Infrastructure Committee, with the House Appropriations Committee (18%), and Senate Environmental and Public Works Committee (13%) hearing from the next largest amounts of witnesses. Remaining committees attribute for less than 10% of witness testimony. This means witnesses are more likely to testify before committees that are interested in transportation and infrastructure issues than other issues associated with the Great Lakes.

Representatives of the executive branch of the federal government and its agencies represent the most frequent witnesses (26.7%) with the U.S. Environmental Protection Agency being the largest repeat witness with 21 appearances. This is a large increase from the agency's previous years of participation indicating it has become a major participant in the hearings. The Great Lakes Indian Fish and Wildlife Commission, the Army Corp of Engineers, Fish and Wildlife, and the National Oceanic and Atmospheric Agency each range from 12–15 total repeat appearances before Congress. These are all federal agencies except for the Great Lakes Indian Fish and Wildlife which represents 11 Ojibwe tribes in Minnesota, Wisconsin, and Michigan who reserved hunting, fishing and gathering rights via treaties with the United States. Other witness categories that frequent the hearings include state and local governments (17%), trade associations (13%) and federal elected officials (11%) from the surrounding Great Lakes states. In Era III, trade associations only comprised 8% of the witnesses. It appears that the federal government as well as the state and local governments remain major participants in congressional hearings, with similar levels of representation as Era III [18]. As in other policy areas, think tanks, academic researchers and institutions witnesses are not frequent participants. Instead, it appears that the specific users of the lakes tend to be represented [19]. There were no repeat appearances within or across committees that would classify a witness to being a hyper-expert in Great Lakes policymaking in Congress [18].

When analysis is performed using tone of the witnesses compared to tone of the hearing, it appears that hearings do not reflect a diversity of information, rather the tone of the witness reflects the tone of the hearing being conducted by the congressional committee (Table 2). This can indicate that committees are not receiving a wide range of information which may bring a different perspective to the topic of the hearing. There is a statistically moderate to strong relationship between the tone of the witness and the tone of the hearing they attend (Kendall's Tau-b=.438, Gamma=.778, Chi-Square= 96.86, $p<0.0001$). This is especially true for hearings being conducted with an environmental protection tone of the hearing (90.3%) and similar, but to a lesser extent, with the tone of hearings and witnesses focused on commerce, industry and transportation (53.4%). However, like the results of tone of the congressional committee and the hearings they conduct being weaker than in past eras of Great Lakes policymaking, these results reflect a weaker relationship compared to the previous eras.

Table 2: Tone of witness and hearing from 2000–2019 (*n*=442).

Tone of the hearing	Tone of witness			
	Environmental protection	Commerce, industry, transportation	Neutral	Totals
Environmental protection	90.3% (298)	9.4% (31)	.3% (1)	100% (330)
Commerce, industry, transportation	45.6% (47)	53.4% (55)	1.0% (1)	100% (103)
Neutral	77.8% (7)	22.2% (2)	0	100% (9)
Totals	79.5% (352)	19.9% (88)	.5% (2)	100% (442)
Kendall's Tau-b=.438, Gamma=.778, Chi-Square= 96.86 ($p<0.0001$)				

5 CONCLUSIONS

It appears Great Lakes policymaking continues to reflect a bounded issue model where policy issues coexist but are not worked on across congressional committee jurisdictions. Like the previous eras, navigation, commerce, and industry share the agenda with environmental protection and human health. This appears to be a continuation of the agenda sharing set of issues that emerged in Era III.

After three eras of congressional policymaking, old problems persist, and some new ones are cropping up. Policymakers have determined that the Great Lakes are suffering from a set of disorganized programs [16], [20]. Since the opening of the St. Lawrence Seaway in 1959, ballast water has increasingly become the dominant pathway for non-native species to enter the Great Lakes. A variety of invasive species are a threat to the ecosystem of the lakes via ballast waters, and from the release of non-native species during flooding events [21], [22]. Non-native species continue to be a challenge for Great Lakes policymakers, particularly concerns about the Asian Carp [23]. This has been an ongoing threat to the lakes. The non-native species permanently alter the ecosystem of the lakes usually through creating an imbalance in the food web.

The lakes continue to be plagued with legacy pollutants and emerging contaminants that pose environmental and public health concerns [24]. Legacy pollutants include heavy metals, polychlorinated bi-phenyls, dichlorodiphenyltrichloroethane, naphthalene, and dioxin [25]. While these chemicals were mostly banned or phased out decades ago, they have entered the Great Lakes ecosystem as the result of industrial accidents or spills, or through the disposal of hazardous materials, and persist in soil and aquatic sediments. They also bioaccumulate and bio-magnify, meaning that the concentration in animal tissues increases from bottom-dwelling microorganisms up the food web to increasingly larger fish and wildlife. Great Lakes fish monitoring studies indicate a considerable decline in legacy pollutant concentrations throughout the 1970s and 1980s. However, the decline began to slow around 1990, and mercury concentrations started to increase in recent years. In addition to well-known legacy pollutants, chemicals of emerging concern released to the Great Lakes ecosystem are being detected in water, sediments, fish, and wildlife [26]. Chemicals of emerging concern identified as threats to the Great Lakes watershed include per- and polyfluoroalkyl (PFAS), polybrominated diphenyl ethers (PBDEs) and current use pesticides [27]. PFASs have been produced and used in various industries and consumer products for over fifty years because of their water and oil repellence, thermal stability, and surfactant properties that make them extremely useful in industry. Since the first report on the worldwide contamination by PFASs, they have been detected in the human body, air, sediment, sludge, fish, and wildlife all over the globe, including high concentrations in Lake Ontario [28]. Per-fluoroalkane sulfonic acids (PFSAs) and perfluoroalkyl carboxylic acids (PFCAs) are two classes of PFASs that have been the focus of environmental research, monitoring, and regulatory efforts due to their occurrence, persistence and potential toxicity with significant concern about contaminated drinking water globally [29]. Several studies have shown that some PFASs can be classified as multisystem toxicants as well as developmental toxicants. PFOA and PFOS may be carcinogenic at relatively high doses, and repeated oral exposures may exert toxic effects [28]. In addition to legacy contaminants, nitrification and invasive species, these contaminants of emerging concerns are infiltrating the lakes and have poorly understood ecological and human health consequences [30].

Era IV reflects a focus on managing the lakes based on programs that were built as foundations from the previous eras with some exceptions like the emerging contaminants. The concern is what future policies are required for dealing with resiliency planning in preparation for climate change can take place in Congress [31]. For instance, water levels have always been a policy issue considered by Congress because they impact transportation and industry, as well as recreation and human health [32]. According to some modelling of climate change impacts on the lakes water resource managers need to prepare for the large interannual variability in lake levels, some of which have already been experienced in a nascent manner in the lakes [33]. Likewise, seasonal hypoxia and algal blooms in the lakes is not a new problem but can accelerate in occurrence based on climate change considerations creating widespread risks for the Great Lakes ecosystem [34]. Programs are well established to monitor and measure the Great Lakes with the awareness of climate change impacts [35]. The challenge to this acknowledged threat of climate change is that to plan for resiliency and coping with the changes that will occur to the lakes over time. This will require more cooperation and integration of congressional action than is currently taking place. It is anticipated that climate change impacts cannot be planned for or addressed with the bounded issue model where issues co-exist and rarely interact cooperatively. The International Joint Commission report stated that there is no Great Lakes basin-wide perspective, approach or strategy for addressing climate change [15]. The Commission recommends that there needs to be global leadership by jointly developing a binational approach to climate change adaptation and resilience in the Great Lakes. In 2018, the International Joint Commission issued guidance on how climate change could be addressed as a framework which should be also reflected in congressional policymaking [36].

Based on the past eras of policymaking in Congress in conjunction with this research that examines the last 20 years, planning for resiliency may be an important focus and re-definition for meeting the challenges into the future. Managing the Great Lakes in coordinating basin-wide goals and a monitoring system face several challenges from the lack of clearly defined organizational leadership and congressional policymaking [10]. One recommendation to strengthening the collaborative approach required for management of the lakes in the challenge of climate change is to improve committees' analytical capacities and using committees as independent sources of information on policy problems and solutions [37]. Great Lakes focused hearings conducted with joint committees that reflect a diversity of witnesses and interests is one solution. This approach could move congressional policymaking from the bounded issue model of past eras to a model with a more balanced tone reflecting the diversity of issues that can be negotiated and addressed with compromise. This approach may prove effective for the challenges of future resiliency planning.

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EFFECT OF POPULATION DYNAMICS AND LAND USE ON THE CONTRIBUTION OF SEDIMENTS TO RESERVOIRS FOR HYDROPOWER GENERATION

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ABSTRACT

Sediment load in reservoirs causes loss of reservoir storage and reduces its usable life. There are management strategies focused in sediment removal or reducing trapping in reservoirs, and there are basin management strategies oriented to reduce sediment production and load reaching reservoirs. In a social and political moment, like the present time in Colombia, rural return migration is expected. Ex ante evaluation of strategies to reducing sediment production is required, in order to implement them previously and avoid the acceleration of the reduction of the usable life of reservoirs. This paper presents the assessment of the impact on sediment production in a basin according to different land use planning strategies, in the context of the rural population dynamics expected in the coming years in Colombia. The San Carlos River basin contributes to a reservoir for hydropower generation, which currently generates the major percentage of hydropower energy in the power generation matrix of Colombia. We implemented on the basin the TETIS model, a distributed conceptual hydrological and sediment model. This model allows to estimate sediment production, through simulation of solid discharge series at anywhere in the basin. The TETIS sedimentological sub-model was calibrated and validated using reservoir sedimentation volumes as an estimator of the total sediment transport. Different strategies and alternatives for land use were established, including lack of planning and agricultural policies. Results show an increase in the sediment production in the long term, if a policy on the adequate use of the soil is not implemented. The results allow to define the strategic zones of the basin where the efforts for the implementation of good agricultural practices, reforestation and soil conservation must be focused.

Keywords: sediment production, population dynamics, management of catchments.

1 INTRODUCTION

The San Carlos River basin contributes to a reservoir for hydropower generation, which currently generates 10.5% of hydropower energy in the power generation matrix of Colombia [1]. This basin presents high rates of erosion, which assure a significant production of sediment moving downstream, they consequently causing loss of reservoir storage and reducing its usable life.

For the town of San Carlos, the last decade of the past century, as well as the first of the present century, became the worst lapse of time in its history, when the violence devastated a big part of its population. People abandoned their properties, constituting a forced displacement to the big cities of the region. In a social and political moment, like the present time in Colombia, experiencing a post-conflict scenario, rural return migration is expected for the next years, in a territorial dynamic that urge to be characterized and controlled.

In the context of repopulation of the San Carlos basin, for the suitable operation of the reservoir, a question must be asked: how much the sediment rate is affected by the population return and their new land use, even in controlled or in uncontrolled conditions? It seems to be clear that the State of Colombia should assume a role of leader, in order to build a vision of future for the region and an analysis of situation for it, as well as a construction of a strategy, and a provision of a holistic and integrated plan directed to achieve this control,

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inside a framework of participation of all the social actors presented in the zone. The contribution of the hydropower company owner in this process becomes particularly relevant, especially in the decision-making structure related to the basin management. For this last, Ex ante evaluation of strategies directed towards sediment reduced-production is required, in order to implement them proactively, then avoiding the acceleration of the reduction of the usable life of reservoirs.

This paper presents an assessment of the impact of different land use planning strategies on the sediment production in the mentioned basin, in the context of the rural population dynamics expected in the coming years in Colombia. The analysis was founded over a hydrologic modelling using the sediment model TETIS (a distributed conceptual hydrological and sediment model). This model allows to estimate sediment production, through simulation of solid discharge series anywhere in the basin. The TETIS sediment sub-model was calibrated and validated using reservoir sedimentation volumes as an estimator of the total sediment transport. The use of TETIS was integrated to an original approach to stablish critical zones for repopulation based on the values of the slope and the soil erodibility factor K of the Universal Soil Loss (USLE) Equation [9]. These two variables are widely relevant in the Andean Mountain Ranges. The methodology allowed to obtain the sediment rate associated to four different scenarios that reflect similar levels of repopulation control. For these scenarios, diverse strategies and alternatives for land use were established, considering lack of planning and agricultural policies. Results show an increase in the sediment production in the long term, if a policy on the adequate use of the soil is not implemented. The results also allow to define the strategic zones of the basin where the efforts for the implementation of good agricultural practices, reforestation and soil conservation must be focused.

Finally, it is important to highlight that, more than to exhibit a detail model, this research endeavor to provide a robust and general approach that will serve to both stakeholders and Colombian State to identify potential changes in sediment production associated to variations in the use of land, and consequently, to support their decisions related to sediment production and control in the broad scope of the Integrated Water Resource Management (IWRM) [3], for basins with similar attributes and problems.

2 METHODOLOGY

The sediment rate under different scenarios of return to the territory was obtained by implementing the TETIS hydrological model [4] in the basin. For the hydrological model calibration, discharge flow data were used in a gauging station and for the sediment sub-model calibration, the reservoir's bathymetry data were used, from which the sediment rate that the basin brings to the reservoir is estimated. With the TETIS model calibrated, a sediment rate contribution baseline is run with the current state of coverage and soils. On the other hand, a map of the most critical areas in terms of erosion is obtained, combining the map of the K parameter of the USLE equation with the slope map of the basin. Four territory occupation scenarios were established in accordance with the most critical zones with respect to erosion, from Scenario 1 without control, to Scenario 4 with control. Below, each methodology step is described in detail.

2.1 TETIS hydrological model implementation

In the basin, the distributed hydrological model TETIS was implemented, which is a distributed conceptual model for hydrological simulation that has a sub model that allows the simulation of solid discharge. The model has been used with satisfactory results in different climate scenarios, in basins with a wide range of areas and for different purposes [5], [6]. The sediment sub model calibration was carried out using the sediment contributions to the reservoir calculated in different reference studies, from the bathymetries carried out in the last ten years and considering the reservoir entrapment percentage, obtained from studies provided by the company that operates the hydropower plant.

The model requires for its implementation the construction of raster type maps, which are derived from the basin DEM, such as slopes, flow velocities that are related to the slope, flow directions and flow accumulated. In addition, the soil and coverage characteristics are necessary, such as hydraulic conductivity in the upper soil layer (in saturated conditions) Ks, hydraulic conductivity in the lower soil layer (subsoil) in saturated conditions known as percolation capacity Kp and the useful water content of the soil (Hu), obtained by

$$Hu = \frac{\rho_b P(H_{cc} - H_{pmp})}{100\rho_w}, \tag{1}$$

where Hu is the useful water content for the horizon (mm), ρb is the apparent density of the dry soil (gr/cm^3), P is horizon thickness (m) or the root depth in the horizon, Hcc is field capacity in percentage, Hpmp is the wilting point in percentage and ρw is water density. These parameters are derived from the basin soil map, the geological units map, and the land cover map. From the soil modal profiles, using the SPAW software [7], the Ks, Hcc, Hpmp and ρb values are obtained. Hu map is obtained by combining the field capacity with the depth of the roots of each basin cover. The Kp is derived from the geologic map. In Francés et al. [8], it is possible to find more detail of these parameters and how the model works. The model has eight correction factors that allow modifying the initial parameters maps, in order to calibrate the model in a more efficient way, through the use of the Nash index, and the error in volume.

The sediment sub model allows estimating the solid discharge rate, considering the land use effects, crop practices, and soil characteristics, based on the following relationship that includes USLE parameters and discharge flow:

$$q_t = 23210 S_0^{1.66} \left(\frac{Q}{W}\right)^{2.035} \frac{K}{0.15} C\, P, \tag{2}$$

where q_t: Unitary sediment discharge, s_0: Slope, Q: Discharge per unit width W, K soil erodibility factor, C is the cover management factor (dimensionless, ranging between 0 and 1) and P is practices factor (dimensionless, ranging between 0 and 1).

The K value is obtained from the equation proposed by Wischmeier and Smith [2]:

$$\mathrm{K} = \frac{2.71x10^{-4} M^{1.14}\,(12 - M.O) + 4.2(b-2) + 3.23(c-3)}{100}, \tag{3}$$

where K is the soil erodibility factor, M is the particles percentage (% of silt) x (100% clay), M.O is the organic matter content (%), b is the soil structure (between 1–4) and c is soil permeability (between 1–6), both given by Wischmeier and Smith [2].

Factor C in eqn (2) is the cover-management factor, which is the ratio of soil loss from an area with specified cover and managements to soil loss from an identical area in tilled continuous flow [11]. It is one of the most influences factors in the erosive model, as the vegetal cover reduces the rain energy at the moment of the interception and prevents it from falling directly to the ground, as well as controlling the speed of the runoff water. The values of C are small when the soil is protected from the rainwater impact and the surface runoff action, and vice versa; ergo, the higher the value of C, the lower the soil coverage, that is, there is less protection. The determination of C is made from tabulated values depending on whether they are agricultural crops or forest vegetation [2]. In this article, tabulated C values were used for the different coverages, according to preliminary studies in the basin and in similar regions (see Table 1).

Table 1: Factors C and P for land covers adopted from preliminary studies of the basin.

Land Cover	C	P
Mosaic of crops, pastures and natural zones	0.394	0.1
Open forest	0.002	0.7
Pastures	0.11	0.7
Secondary vegetation or in transition	0.002	0.7
Riparan Forest	0.002	0.7
Scrubland	0.002	0.7
Mosaic of de pastures with natural zones	0.11	0.7
Grasslands, pastures and herbaceous vegetation	0.11	0.7
Fragmented forest	0.002	0.7
Dense forest	0.002	0.1
Mosaic of pastures and crops	0.11	0.7
Continuous urban texture	0	0.4
Artificial water bodies	0.5	0.7
Mosaic of crops with natural zones	0.394	0.1
Urban settlement	0	0.4
Hydraulic constructions	0	0.4

Factor P in eqn (2), is the soil-loss ratio with a specific support practice to the corresponding soil loss with up and down slope tillage [10]. The values P-factor ranges from 0 to 1, in which the highest value is assigned to areas with no conservation practices (deciduous forest); the minimum values correspond to built-up-land and plantation area with strip and contour cropping. The lower the P value, the more effective the conservation practices [11]. In this paper, tabulated P values were used for the different coverages, according to preliminary studies in the basin and in similar regions.

In the sediment production sub-model, the calculated transport capacity is first used to propagate the sediments downstream, by size fraction according to the percentage present in suspension and as bed material. Then, if there is still transport capacity, the soil is eroded proportionally to the percentage of the corresponding size fraction of parent material [8]. This material is taken into account in the TETIS model through the sand percentage maps, silt percentage and clay percentage, obtained from the basin soil map.

The simulation performed is continuous on a daily scale, and therefore potential evapotranspiration data are required. The latter is obtained from temperature data of a station located on the basin, using the Thornthwaite equation. The model uses a crop factor to estimate the real evapotranspiration from the potential and the coverage type.

2.2 Critical zones for erodibility according to slope and K ranges

From the map of the parameter K, reclassified from 1 to 4 and from the slope also reclassified from 1 to 5 according to the matrix shown in Table 2, a map for critical zones for erodibility is obtained, which indicates with a numerical value the most critical erosion areas and slope in the basin, 9 being the most critical places for repopulation, with the highest slopes and the highest erodibility.

Table 2: Values for critical zones according to slope and K ranges.

	K range	<0.11	0.11–0.15	0.15–0.2	0.2–0.25
Slope range [%]		1	2	3	4
0–12	1	2	3	4	5
12–25	2	3	4	5	6
25–50	3	4	5	6	7
50–75	4	5	6	7	8
>75	5	6	7	8	9

2.3 Scenarios for land cover change after repopulation

Four scenarios of land cover change after repopulation were built. Scenario 1 is the population return to uncontrolled areas: The forest zones in areas 6, 7, 8, 9 of the critical zones for erodibility map are converted to crop areas, this implies a decrease in the Hu parameter of the model, because of the depth of the roots of the forest (1.5 m) is greater than that of the crops (0.8 m). Parameter C increases from 0.002 to 0.394 and without practices for cropping, that is, Factor P remains at a value of 0.5. Scenario 2 is the population return to the areas with control over the forest areas in category 9: Forest areas in category 6, 7, 8 are converted to crop areas. Hu and C parameters changes in the same way as in Scenario 1 and the factor P remains at 0.5. Scenario 3 is the same population return established in Scenario 2, but implementing control over cropping practices, changing the P factor to 0.1. Finally, Scenario 4 is the population return, preventing the occupation of forest areas in categories 8 and 9. Only areas of forest in categories 6 and 7 are converted into crop areas. The values of Hu and C in these categories change in the same way as in the previous scenarios and best practices for cropping are established, with a value of factor P of 0.1

3 STUDY BASIN AND DATA DESCRIPTION

The Basin of San Carlos is located in the Department of Antioquia (Colombia), in the Andean mountain range. It covers an area of 284.32 km^2 and drain its waters to a reservoir for hydropower purposes. The reservoir is conformed mainly for contributions of the rivers San Carlos and Guatape. The annual mean precipitation is 3700 mm/year. The maps of geomorphological parameters for the model TETIS are derived from a DEM (ASTER Global Digital Elevation Model Version 2) resized to a resolution of 100 m x 100 m and the parameters related to soil characteristics, explained in a prior section, are derived from the map of soil and of geological units of the basin, and from the map of land covers following the Corine and Land Cover Methodology adapted to Colombia and updated by state entities in the 2013–2014 period [11]. Data of precipitation and discharge are for the 2014–2015 period. With this information, a base line of sediment production in the basin is defined, over which different repopulation scenarios for the territory are modelled. Land covers in the basin are shown in Table 1: 40% of the basin area is forest distributed in dense, open, fragmented and riparian; 20% are zones covered by pastures in the categories of pastures, grasslands, pastures and herbaceous vegetation; 8% corresponds to crops and mixing of crops with pastures and natural zones; 21% of the basin surface is covered by secondary vegetation or in transition and Scrubland and just 1% corresponds to urban continuous and discontinuous settlement. The other 10% of the basin is distributed in the remaining categories. There exists a large zone of forest around the reservoir, corresponding to the owner company protected area, and the rest of forest, secondary forest vegetation and scrubs are dispersed over the basin, with some predominance to be located near the border line, in the zone with larger slopes. The crops are located in the middle and upper part of the basin. The average slope is 33%, with values of 75 to 190% located near the border line of the basin, in the middle and upper part of it.

According to the San Carlos 2016–2019 Development Plan [12], the municipality has been presenting a growing repopulation dynamics, for which obtaining a consistent and reliable census, needed to support decisions about new urban and rural housing, is hard task. Even so, it is known that at least 2000 homes were abandoned between 1998 and 2007 due to the armed conflict, and also, that the families that have returned to the town, have found their houses and lands in a deplorable state, demanding this to rebuilding them again.

Overcrowding in some areas becomes evident the necessity of a detailed study that allow to stablish the availability of lots and the definition of expansion zones regulated by the Municipality's Territorial Ordering Scheme. According to the Colombian Beneficiary of Social Programs System SISBEN, in 2015 in San Carlos [12] there existed 4970 homes, from which 2595 were urban and 2375 rural (634 in population cores and 1741 dispersed in rural zones). As the qualitative housing deficit for 2015 was acknowledged in 30.8% [12], a repopulation process located in rural zones is highly probable to occur in the coming years.

The Colombian State recognize the need to integrally repair the victims of the conflict. This repair implies not only a monetary compensation and goods restitution, but also an accompaniment in reference to a variety of aspects, inside of which the good practices to use the lands are included. The individual and collective repair processes also require identifying the lands legally subject to be occupied by the population that will return in condition of victims, and this task, for its own nature, can be not only difficult, but expensive in terms of time and resources. It is expected that not less than 8.000 persons were victims of the armed conflict in San Carlos. According to the Citizen Rights Protection Brief [12], only in 2005, 1621 farmers, 1681 housewives and 2129 children and young persons arrived in Medellin, one of the three largest cities in the country. None of them found suitable spaces to integrate their lives socially, culturally and economically in the city. Following the statistical data provided by ILSA [13] in the act of declaring the state of emergency, the Municipality of San Carlos presented the projection of repopulation in two stages, with a whole amount of native persons to be returned to their lands of 5000 people. These two stages can be summarized in Fig. 1.

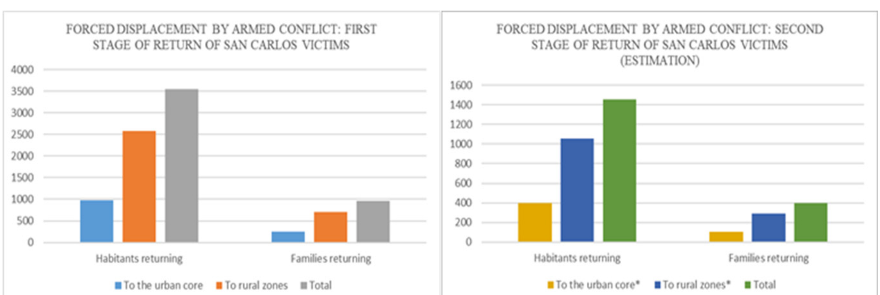


Figure 1: Population in condition of victims of the armed conflict expected to return to san.

For the first stage, the data to build the figure was entirely declared by the San Carlos Town Hall. These data can be found in ILSA [13]. For the second stage, the data in the figure is an estimation based on the difference from the total of habitants expected to be returned to the town and using the percentages of the urban and rural portion of the first stage.

Both the amount of people returning to the Municipality and the potential use of the land that these persons will do, broadly justify all the technical efforts – of which this research is a part – to understand the effects of the possible scenarios, and consequently, the measures of management over the basin that should be adopted.

4 RESULTS AND DISCUSSION

Flow Discharge calibration is performed for the year 2015, using the series of daily discharge in a gauge station located in the middle part of the basin, with a Nash Index of 0.521 and a volume error of 0.212%. Validation of the model is performed for the year 2014, for which the Nash Index is equal to 0.42 and the error in volume is -21.937%. Simulation lapse covers the periods of calibration and validation and encompass until 2017 in an effort to obtain more robust results according to the provided sediment rate. Solid discharge was calibrated according to the annual rate of sediment contribution reported in studies of the hydropower company owner, based on comparing of different bathymetry measurements among years 2008 and 2015. The percentage of trapping was also reported by the company. The resultant rate of production of the model for the current condition results in a value of 0.75 Mm^3/year. This value has been validated by comparing with other studies over the same basin, in which the sediment contribution rate has also been estimated. According to Hermelin [14] this rate has an associated value of 0.88 Mm^3/year, while other studies from the company declares a value of 0.72 Mm^3/year.

The factors P and C have been obtained from assigning the values shown in Table 1 to each of the covers in the basin. In the current conditions, low values of C are predominant, due to the high percentage of forest, scrubs and secondary vegetation of the basin. The last also implies high values of P. The map of K (see Fig. 2) locates the parts with more susceptibility to erodibility in the middle and upper zones of the basin, alternated with some areas with low values of K.

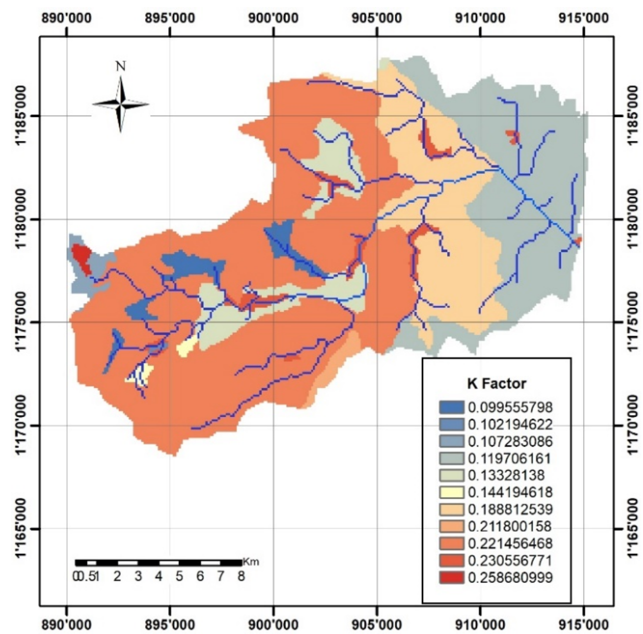


Figure 2: K factor.

The map of critical zones for erodibility (see Fig. 3) intensifies those of high values of K, located in the parts with higher values of slopes, near the border in the north and the west of the basin. The effect of combining de factor K with the variable slope is that high values of K can be disaggregated in function of the slope, this implying a more real scenario for the critical condition.

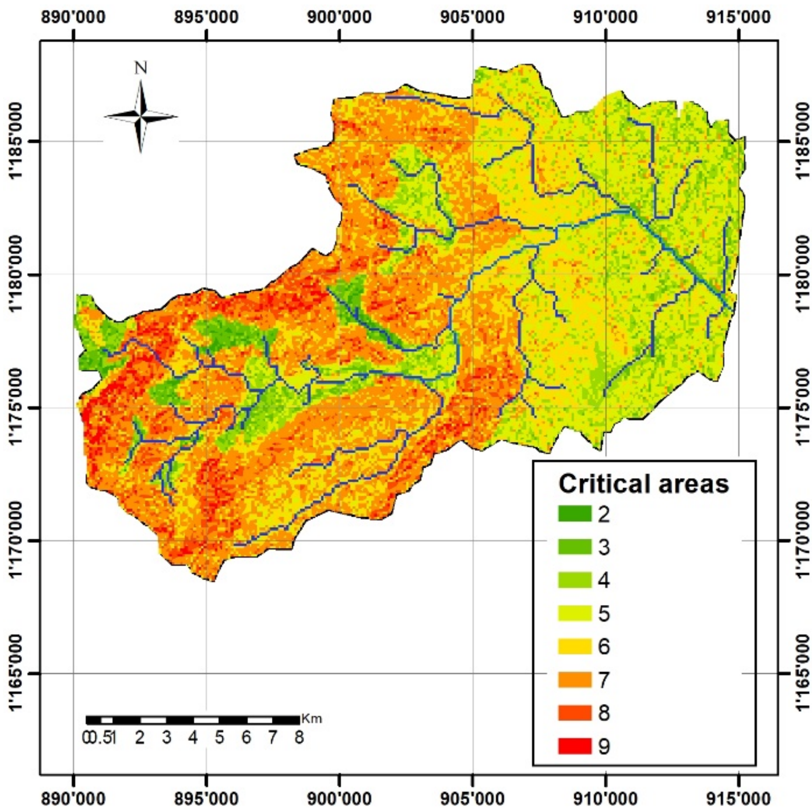
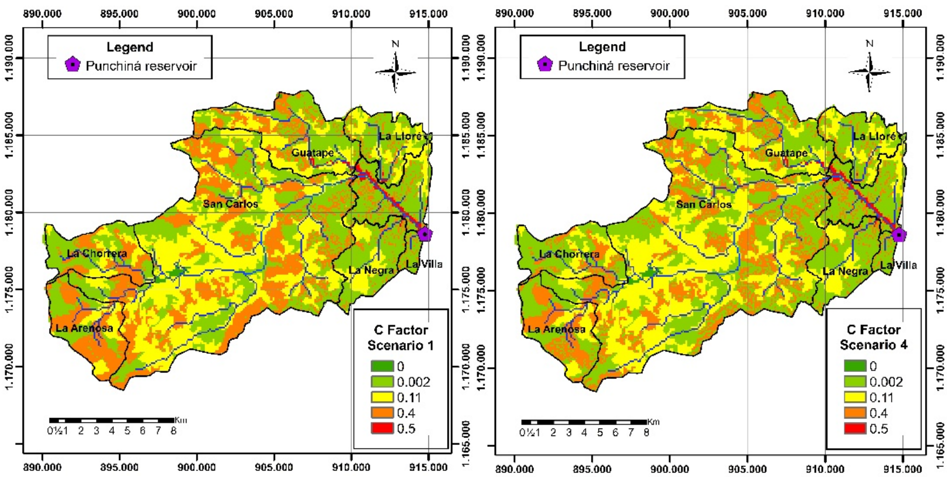


Figure 3: Critical areas according to slope and K ranges.

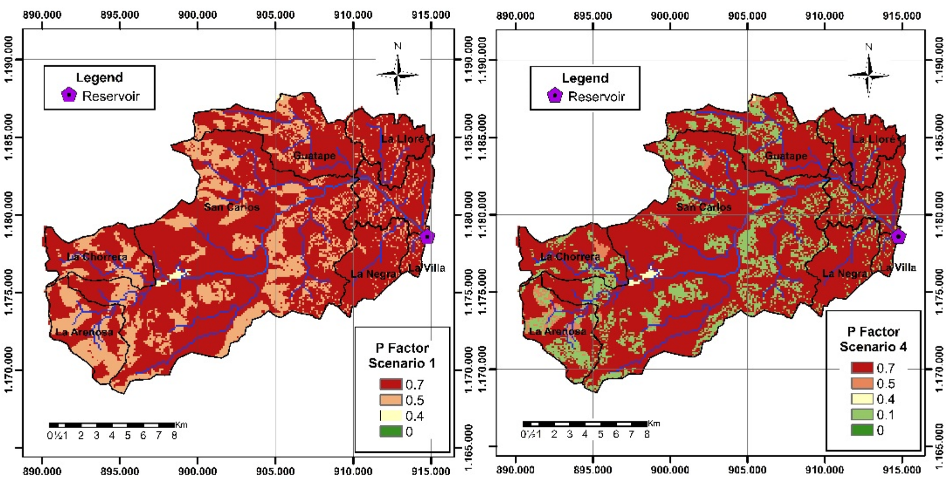
In the first scenario, 61.99 km^2 (21.9% of the basin area) of forest cover is transformed in crops. Scenarios 2 and 3, since they did not consider the critical zones associated to a value of 9, transform 59.6 km^2 of forest to crops, which corresponds to a 21.1% of the total area.

Finally, for Scenario 4, the critical areas 8 and 9 are considered to be objects to more control, and consequently only the 18.1% of the area is transformed from forest to crops. As it was described in the Methodology section, changing the land cover from forest to crop implies a change in the parameter Hu, and also in the factors C and P.

The change in the scenarios that represents the biggest effect over the results of the rate of sediment contribution is the factor P. As it can be observed in Fig. 4, in the transition from forest to crop among the worst (1) scenario and the more positive (4) scenario, this value diminishes, also reducing in a direct way the flow of solids that is produced in each cell simulated by the model.



(a)



(b)

Figure 4: Factor C and P for extreme scenarios: unfavorable, favorable. (a) Factor C, Scenario 1 (left) and Scenario 2 (right); (b) Factor P, Scenario 1 (left) and Scenario 4 (right).

The result for all the four repopulation scenarios is an increment on the sediment production rate with respect to the current rate (see Table 3). The rises of 177.7% and 150.7% over the current rate are explained for the fact of changing forest for crops without implementing good practices for cropping. This result warns about the strong control that the Colombian State must apply, and similarly, about the initiatives that the basin stakeholders must carry out, in order to achieve an integrated management and to emit regulation standards directed to protect the areas located in the critical zones 8 and 9. However, the most abrupt change is evidenced among Scenarios 2 and 3, where the only difference between both scenarios consists in implementing best practices for cropping. More detailed results for

Scenario 3 can be produced if a more precise way – considering practices subject to be implemented in the basin – to calculate the value of P is adopted. Nonetheless, this big reduction in the rate of sediment contribution should capture the attention of the State and the stakeholders, on the need of taking ex ante restraints, in order to prevent significant contributions to the reservoir. The difference between Scenarios 3 and 4 is small, because the forest area in level 7 corresponds only to a 3% of the total area.

Table 3: Sediment production for different scenarios of repopulation.

Scenario	Sediment production rate (millions of m^3/year)	% of variation
Original	0.756	-
1	2.100	177.7
2	1.896	150.7
3	0.774	2.4
4	0.771	2.0

According to the Colombian National Water Study [15], in the process of characterization of the sediment production due to water, water erosion in hillsides is predominantly influenced by the power of the flow and the resistance to the erosion. The first factor depends on topography and climate, while the second factor depends on the land cover and the properties of the soils [15]. As the land cover has been considered in the present research as a variable of every possible scenario, the influence of the topography has been denoted by the variations in the slope, which is highly representative of the changes in topography over de Andean Mountain range. The influence of climate is explicit considered by the conceptual hydrological and sediment model TETIS, used in this research. The resistance to the erosion was considered in the present study by means of the soil erodibility factor K, and by other variables that describe the composition and texture of the soil. This approach can be complemented in the future by adding new variables to the analysis in order to stablish the critical zones for repopulation, or even more, by considering a more detailed spatial variability of climate than those made by TETIS. For this approach, a land cover based on crops was adopted as a hypothesis for the modelling of sediment production. This is technically well supported by the tendency for rural scenarios of post-conflict, where repopulation is composed of farmers. Of course, the consequence of considering other types of land covers, as pastures or wood plantations, should be reflected in substantial changes in the values of C and P. As well as the type of land cover to be predominant as the repopulation takes part, the exact amount of persons to come back to their lands is unknown to the present. This quantity, joined to the extension of every type of land cover derived from the repopulation, must be integrated to a more detailed modelling in the future, so the final results can be used in a decision support system of small scale.

5 CONCLUSIONS

In this paper, an exercise of hydrological modelling for an Andean basin is proposed, under four possible scenarios of territorial occupation, according to the population dynamics expected for the next years of the post-conflict process in Colombia. In a successful way, the influence of repopulation in zones where the land cover is currently forest, over the sediment production rate, was assessed in a basin that contributes to one of the reservoirs for hydropower purposes more important in the hydroelectric matrix of Colombia. In detail, it was found that the sediment production rate in the basin is much more sensible to implementing best practices of cropping, than to the change of land cover. Under all the scenarios of repopulation, the sediment production rate grows with respect to the original rate for the years 2014–2015. The change from forest to crops in highly critical zones, triples the current sediment rate, if there are not any best practices of cropping introduced. When best practices are considered in the model sediment production rate increases only 2% with respect to the original value.

This research provides a robust and general approach that will serve to both stakeholders in the basin and Colombian State to identify potential changes in sediment production associated to variations in the use of land, and consequently, to support their decisions related to sediment production and control in the broad scope of the IWRM for basins with similar attributes and problems.

The achieved results evidence the relevance of the role of the Colombian State, its responsibility and potential capacity of control over the repopulation process and specifically, over the use of the land (type of use and best practices). Further than that, it is clear that a high level of technical basin management is crucial to assure, not only the future operation and use of the hydropower reservoir of the study case, but to preserve the basic parameters of the ecosystems that integrate the basin. In the same context, the role of other stakeholders, primarily the hydropower owner, and the territorial environmental authority, become decisive to reach and preserve a proactive basin management level. Finally, the work shown in this paper is suggested to be part of a set of tools that can be integrated in a multi-criteria decision support framework for the use local and regional authorities.

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WATER SECURITY: IS SOUTH AFRICA OPTIMALLY PURSUING ITS OPTIONS?

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ABSTRACT
Water is a crucial input to domestic, agricultural and several production activities; it is the source of life and prosperity to many. There is a symbiotic relationship between water and society and, in particular, water influences agriculture, industry, transport, energy, and health. South Africa is a water-scarce country with a considerable projected risk of imbalance between resource requirements and availability. As such, the country needs to manage its limited water resources carefully and prudently to ensure sustainable water security going forward. While the country is working hard to address the challenge, evidence on the round indicates the approach is far from optima – particularly shown by the prevalence of ageing infrastructure due to poor maintenance, high non-revenue water (41%), widespread river pollution from anthropogenic activities, and limited pursuit of alternative water sources. To improve the country's future water security, a more open embrace of non-conventional water sources and improved efficiencies on the traditional approaches is recommended.
Keywords: conventional water sources, water management, water scarcity, water security, South Africa.

1 INTRODUCTION

Water is a critical input to domestic, agricultural and several production activities; it is a source of life and catalysis for prosperity to many. Notably, there is a symbiotic relationship between water and society, with water influencing agriculture, industry, transport, energy, and health [1], [2]. Given its pivotal and influential role, it is essential that countries carefully and sustainably manage their water resources. This is particularly essential in areas where water is scarce, as is the case in South Africa. Notably, it is well documented that the country is water scarce and experiences frequent drought spells. Paradoxically, some posit that South Africa does not have a water crisis [3]. Notwithstanding these varying views, South Africa needs to manage its limited water resources carefully and prudently to ensure sustainable water security going forward. One critical question the country faces is whether it is keeping pace with developments and measures to safeguard the country's water security. It is important to note that the security of a country's water resources is found in its infrastructure, institutions and regulatory frameworks that guide the management of water delivery.

This paper looks at critical factors influencing water security in South Africa and interrogates the sustainability of the country's water management approaches. This paper also reviews South Africa's openness to non-conventional water supply sources in light of the level of water scarcity risk. Finally, the paper concludes with recommendations to improve country's long-term water sustainability and resilience.

2 METHODOLOGY

This paper is in an exploratory article that reviews current water management approaches in South Africa. The study uses secondary research, particularly making use of extant literature, observations of current management practices, as well as attendant implications and challenges to draw conclusions of whether South Africa is optimally utilising its water resources to ensure water security. The study is designed to help water professionals,

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practitioners, and water resource planners, in South Africa and beyond, to take a broad and considered view of all the potential options available as well as taking key decisions in time.

3 GLOBAL VIEW ON WATER SECURITY

Water security is defined as “the reliable availability of an acceptable quantity and quality of water for health, livelihoods, and production coupled with an acceptable level of water-related risk” [1]. Water insecurity is a global phenomenon. Globally, there are over 760 million people with no access to safe drinking water [4]. Over the years this figure is likely to have gone up, given the economic challenges experienced in many places. However, in many cases, the primary problem is not physical scarcity, whereupon demand exceeds supply, but rather socio-economic water scarcity, that is, water scarcity caused by a lack of investment in appropriate water infrastructure or insufficient human capacity to satisfy the demand of water in areas where the population cannot afford to use an adequate water source. A number of factors influence socio-economic water scarcity, including insufficient political will, inadequate investment in water infrastructure projects, lack of skills to manage projects and exclusion of certain groups because of their inability to pay, political affiliation, disability, race or social status. For a country to have a sound water security system, it needs to be able to overcome these impediments.

From the foregoing, it can be said that water availability and access are becoming a critical global risk. It is also clear that a change of approach is needed to better manage water insecurity in a number of nations and local communities. While in some cases, socio-economic water scarcity may overlay physical scarcity, solving socio-economic water scarcity has potential to address the majority of household water stress challenges. However, comprehensive solutions should tackle both physical and socio-economic water scarcity. To fully grasp South Africa’s water security position, the following sections look at its water situation as well as highlighting management approaches and challenges experienced.

4 SOUTH AFRICA’S WATER RESOURCES SITUATION

South Africa is one of the water-stressed countries in the world; ranked as the 30th driest country globally [5]. The country is predominantly reliant on surface water which accounts for 77% of water supplies, with the remaining portion supplied from groundwater (9%) and return flows (15%) [6]. Notably, a significant portion of the country’s surface water resources is imported from neighbouring Lesotho, supporting the country’s economic nerve-centre of Gauteng, and most surface water sources have been allocated.

Agriculture is the dominant water user, utilising about 67% of the country’s water, followed by urban use (18%), mining (5%), rural (3%) and the remainder distributed among afforestation, power generation and international obligations. The country’s reliable surface water yield to be about 14.2×10^9 m^3/yr [7]. Further, there is an estimated additional 3.5×10^9 m^3/yr of utilisable groundwater available [8]. By 2015, South Africa’s water demand was estimated to have reached 15×10^9 m^3/yr [9]; with the demand projected to rise to 17×10^9 m^3/yr by 2025.

Considering the above statistics, it can be considered that South Africa currently has enough water to meet its demand, or almost, in balance. It is, however, estimated that demand will outstrip supply by 2025 [7]. Some recent research suggests that water demand would have exceeded available yield by as early as 2017 [9]. Whichever statistics is considered, the message is clear to water professionals; South Africa has limited water resources to cater for its growing demand and, as such, needs to manage its water resources very wisely and optimally. Achieving this requires overcoming several challenges as outlined in the subsequent sections.

4.1 Water management in South Africa

A number of challenges threaten South Africa's long-term water supplies and security. Notable challenges include: that the country is naturally water stressed (physical water scarcity), with most of the river basins and water management areas being in deficit; water requirements continue growing, driven by a growing population, improving livelihoods as well as industrial and agricultural development; aging infrastructure with concomitant high water losses; and continued deterioration of the quality of water in rivers due to anthropogenic-related pollution. Due to the growing demand, the water availability per capita is steadily decreasing.

Further, the country is susceptible and vulnerable to the ravaging effects of climate change, particularly the effects of long-term droughts. For example, over the past 3 years, several parts of the country experienced severe drought episodes, including the devastating drought incidents of 2017 that affected the Eastern Cape, Northern Cape and the Western Cape. These drought episodes were so severe that the City of Cape Town was projected to be running out of water by June of 2018 – an event famously dubbed Day Zero.

While acknowledging some of the advanced water systems that South Africa has [10], amongst which include complex inter-basin transfer schemes and the world-renowned transboundary water transfer from Lesotho, the country's water management needs to improve to ensure it meets present and future strategic needs. More importantly, the systems require improving to ensure resilience. For example, the vulnerability or lack of resilience of the system was exposed through the Western Cape drought, whereupon City of Cape Town struggled to effectively manage the ramifications of the drought. Several areas require improvement including water allocation and water use efficiency across the board; water quality management; preservation of the health of several endangered river systems; infrastructure development and management; and incorporation of climate change principles in both the planning and management of water resources. These issues are further discussed in the next sections.

4.1.1 Improving water use efficiency

In terms of water use, three indicators point to non-optimal water management in South Africa. First, records show that South Africa's non-revenue water has increased to 41% [11], up from 37% a few years back. While comparable to several other developing countries, which average between 40% and 50% [12], this level of unaccounted for water is quite high for any country, let alone for a water-stressed country such as South Africa.

Second, studies have shown that South Africa is over-exploiting its freshwater resources. Several authors indicate that as early as 2015, the country was over-abstracting its water resources, with annual demand estimated to be 15.6 billion m3 against a supply 14.6 bn m3 [13]–[15]. Recent research shows that more than 60% of South Africa's rivers are being over-exploited [15]. Such practices are unsustainable and, therefore, not recommended and deserve reviewing for improvement.

Third, South Africa's average per capita water consumption of 235 *l/d* is considerably too high for a water scarce country, particularly when compared with other water scarce countries around the world.

In particular, this is way above the global average of 185 l/c/d. Such levels of water consumption, coupled with the high-water losses experienced in the country's water supply networks, further exacerbate South Africa's risk. For a water stressed country, reduced per capita consumption supported by conservation practices will go a long way curtail water supply risk.

4.1.2 Water quality and river health management

The prognosis for South Africa's river health is also not encouraging. Notably, the country's water sources are increasingly being polluted, rendering several water sources unfit for use or making treatment more difficult and costly. Prominent sources of pollution include large volumes of sub-treated wastewater discharged from dysfunctional sewage treatment works, industrial effluents discharged into rivers, mining waste as well as agricultural chemicals runoff into receiving streams. For example, in Gauteng, South Africa's economic hub, 74% of wastewater treatment works fail to comply with a least two key effluent discharge parameters [2]. Similarly, wastewater works in Limpopo Province seldom treat effluent to acceptable standards [16].

This poor performance of wastewater works observed across the country point to increased threat to South Africa's water quality and, concomitantly, the country's water security. Pollution of water sources reduces resource availability. The Department of Water Affairs' own reports, the Green Drop Reports, reveal that several wastewater treatment plants across the country discharge into rivers effluent that fail to meet regulatory requirements [17]. The reports show that in each year of assessment, between 2009 and 2013, only 50% of the wastewater treatment plants were compliant – quite a dismal performance. These challenges are influenced by inadequate investment in wastewater treatment infrastructure, shortage of skilled manpower in the sector, poor planning as well as entrenched corruption [18].

Pollution is considered more insidious and much more difficult and costly to remediate [3]. In South Africa, water pollution is projected to reach catastrophic levels in the near future [2]. This is corroborated by a number of scholars who show, through long-term data analysis, show that the quality of most South African rivers and dams has significantly deteriorated over the past 20 years [9], [19]. As remediation of polluted sources is difficult and costly, water contamination therefore poses a huge threat to the country's water security. In addition, water contamination increases water treatment costs. Expanding populations, growing economies and climate change notably continue exerting pressure on quality of water in South Africa. Decrease in water quality results in reduced available water. It also leads to increased treatment costs for both domestic and industrial water. These developments have negative knock-on effects, including reduced crop yields, compromised food security [18], and general societal health.

4.1.3 Climate change effects

Climate change impacts the hydrological cycle, altering the quantity and timing of the rains and, subsequently, river flows, coping capacities of water infrastructure and management systems [20]. Climate change is a real threat to national water security. An IPCC report projects that climate change will impact rainfall patterns as well as river flows and levels globally [21]. In South Africa, it is projected that the impacts of climate change on water could exacerbate existing challenges as well as creating new ones. Research indicates that climate change effects in South Africa are likely to: increase flooding or drought in some parts of the country, increase temperature with concomitant increased evaporation, and bring changes to rainfall run-off across the country. Areas particularly projected to experience reduced rainfall and run-off include: the south-west parts of South Africa, the central-western areas and the extreme north. On the contrary, the KwaZulu Natal area, parts of the southern Mpumalanga and the Eastern Cape are projected to experience higher rainfall and extreme run-off. It is, however, important to underscore that both low and high rainfall events compromise the country's water security. As such, appropriate management measures are required to mitigate the effects and impacts of climate change on the country's water security.

While South Africa has progressed significantly in climate change research and the development of mitigation measures, it recognises gaps remain that still need addressing. Particular knowledge gaps include research on climate change impacts on municipal infrastructure. This is a critical gap considering the growing urbanization and that more than 40% of the South African population now resides in urban centres [22]. Misra [23] reinforces the existence of gaps in climate change management, citing impacts on groundwater – a resource which needs prioritisation in South Africa as it is currently underutilised.

4.1.4 Infrastructure development and management

The state of a country's infrastructure influences and is closely intertwined with a nation's socio-economic growth. In particular, the state of a region's water infrastructure has a bearing on its effectiveness on resource management and stewardship. While South Africa has satisfactory national water resource infrastructure and water services infrastructure in its major metropolitan cities, it faces significant infrastructure quality challenges in many municipalities, particularly in small centres and in rural nodes. A recent SAICE Infrastructure report [24], attests this understanding. The report rates the country's national water resources infrastructure, bulk regional infrastructure, and major urban infrastructure at D, C^+, and D^-, respectively. The rating scale used to classify the infrastructure is shown in Table 1. These ratings are low, underscoring the poor state of the country's water infrastructure.

Table 1: Rating scale for South Africa infrastructure report card. *(Source: SAICE [24].)*

A	B	C	D	E
World class	Fit for the purpose	Satisfactory for now	At risk of failure	Unfit for purpose
Infrastructure is comparable to the best internationally in every respect. It is in excellent condition and well maintained, with capacity to endure pressure from unusual events.	Infrastructure is in good condition and properly maintained. It satisfies current demands and is sufficiently robust to deal with minor incidents.	Infrastructure condition is acceptable, although stressed at peak periods. It will need investment in the current medium-term expenditure framework period to avoid serious deficiencies.	Infrastructure is not coping with demand and is poorly maintained. It is likely that the public will be subjected to severe inconvenience and even danger without prompt action.	Infrastructure has failed or is on the verge of failure, exposing the public to health and safety hazards. Immediate action is required.

The poor state of water infrastructure has several implications on South Africa's water security. Specifically, poor and ageing infrastructure are jointly propagating inefficiencies through increases in water losses. Old and poorly maintained water systems are resulting in high incidence of leakages and bursting of pipes leading to the recorded high non-revenue water for the country. This is also compounded by cases of illegal connections, particularly in informal settlements. As a result, South Africa's non-revenue water levels rose from 37% to a high 41%. Overall, these statistics signify continued deterioration of water infrastructure network with concomitant threats to both water supply assurance and national water security.

4.1.5 Under-investment in water infrastructure

In addition to the challenges of poor infrastructure maintenance, South Africa struggles to invest in new infrastructure. There is significant under-investment in both water and sanitation infrastructure sectors. For example, the water resources infrastructure sub-sector requires about R70 billion (US$1 ~ R15) per annum in investment; of this requirement, only R43 billion is available, leaving a shortfall of R27 billion annually. The funding shortfall is also exacerbated by historical backlogs associated with previous apartheid regime. A significant number of people still need to be given access to clean and safe water. Taken over years, such infrastructure investment shortfalls inflict huge impacts on the state of the country's water infrastructure as well as the state of water security. The challenge of under-investment and associated implications are, however, not limited to South Africa [25]. The under-investment is also growing as global economies, including South Africa, struggle. As such, South Africa, as other global nations, need to raise the bar in infrastructure investment to address the challenge, inviting all pertinent parties including the private sector.

5 DISCUSSION

From the foregoing, it is clear that South Africa needs to seriously look at ways to improve its national water security going forward. While proposed solutions have been researched locally and internationally, optimal combinations need to be considered for the country's best outcomes. Such solutions should be designed at multiple levels, covering the various sectors for greater effectiveness. Solutions can be grouped into technical or behavioural approaches, and comprehensive solutions normally require a combination of both approaches appropriately packaged for greater impact. Technical approaches include traditional engineering solutions involving resource-augmentation projects such as construction of storage reservoirs, transfer schemes and tapping into alternative water sources such as desalinated water and reclaimed water. On the other hand, behavioural approaches include pecuniary and non-pecuniary approaches designed to reduce demand through improved human behaviour. The following sections look at the options that South Africa can explore, with the options divided into traditional (conventional) approaches and nonconventional approaches. Traditionally, supply-side and technical solutions have been more favoured. This, however, has to change going forward if optimal water management is to be achieved.

5.1 Conventional water management approaches

Key among conventional options is the exploration of new groundwater and surface water resources, supported by use of advanced engineering. This approach has worked for long, with greater focus on surface water development. However, in South Arica, 98% of the affordable and viable surface water resources have been allocated. The WARMS database shows that the country's estimated water use ranges between 15 and 16 billion m3/annum, nearly exceeding reliable yield [6]. With most of the surface water resources almost allocated, there is very little room for cheap and easy to access water resources to tap into. In addition, the country is not endowed with many high-yielding aquifers. Under these circumstances, two options to improve the country's water security obtain and are proposed. These options comprise: (i) optimizing use of the limited surface water resources, and (ii) reviewing current allocations in view of growing demand and future requirements.

For a country with 41% non-revenue water, considerable room exist to improve, gaining efficiencies in water use per capita through demand management and conservation strategies. Also, the country can optimally develop the remaining few surface water resource sites. However, optimised development of the few remaining surface water sites could attract a higher unit price, while water reallocation may be resisted by current water right holders. Such decisions, although not popular among existing water rights holders, are necessary to ensure equitable use as well as sustainable water supply for the future. Demand management and water conservation strategies are, unfortunately, not the favourite options for political decision-makers. Nonetheless, for improved national water security, tough decisions are required, calling for all to contribute to the success.

5.2 Non-conventional water management approaches

Severe resource scarcity at all times call for a shift from traditional approaches to new approaches, including historically non-conventional options. It is, however, essential to introduce such approaches carefully, professionally and without exposing people to undue risk. In this regard, under growing water resource limitations, it is time South Africa embraces and, timeously, start incorporating non-conventional options such as sea water desalination and water reclamation options into the water mix. It is recognised that these options have been recommended for South Africa by the water professionals and officials, and that they appear in the country's strategies and future water mix options, particularly in reconciliation strategies for most water management areas. South Africa even has national strategies, as part of the National Water Resources Strategy [26], for desalination and water reuse; evidence of strategic commitment by the country on the two options.

However, what is clearly lacking is the will power to implement projects from this domain, and to make such decisions promptly to enable timely and effective implementation. Current practice shows that only and only when there is a severe water crisis, usually triggered by drought, are non-conventional water options accorded priority. A classical case in point is the prioritisation of both seawater desalination and water reuse in Cape Town when the region is experiencing severe drought episode. Prior to the drought, seawater desalination and water reuse ranked lower in the City's water reconciliation strategies – only to be accorded priority during the drought period when the City experienced severe water shortages. These options should not be considered crisis options, but rather be considered as normal options at all times. At such instances, these projects are hastily considered and implemented usually at a high premium. Such an approach is not cost efficient, resulting in end-users paying exorbitant price for the water. Sadly, because of the hurried nature of the decisions and the associated premiums such hurried decisions attract at heightened risk, these options will always be viewed as second class options when reviewed during normal times. The evident reactionary approaches result in non-optimal and unsustainable solutions to the country's water supply systems.

6 CONCLUSIONS

South Africa's long-term water security cannot not be said to be fully guaranteed – the faces a number of challenges and has a lot of work to do to ensure assured water security going into the future. Physical water scarcity provides a backdrop that complicates the efforts towards improved water security as this calls for considerable capital investment to diversify the mix for limited resource. While the country is working hard to address the challenge, its approach is not yet optimal as evidenced by the prevalence of ageing infrastructure, significantly high non-revenue water, growing river pollution from anthropogenic activities as well as the limited pursuit of alternative water sources. In order to improve the country's future water security, a more open embrace of non-conventional water sources as well as improved efficiencies on the traditional approaches are recommended, and senior decision-makers need to take the lead.

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DECISION SUPPORT SYSTEMS FOR WATER RESOURCE MANAGEMENT APPLIED TO ANDEAN SUPPLY MICRO-BASINS

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ABSTRACT
Different aspects affect the availability of water, among them the dispersion of human settlements, the mismanagement of water sources, and the lack of implementation of plans, programs, and projects in watersheds. The Tabacay river micro basin is of great importance because it is the only water source that supplies the city of Azogues and rural populations. However, no tools have been developed for the planning and management of the resource. A Decision Support System is proposed through the hydrological simulation of the contributions of the basin and the application of urban supply criteria to identify the problem of the study area. Among the results obtained, it is observed that currently in the Tabacay river basin the guarantee of irrigation demand complies with the UTAH-Division of Wildlife Resources (DWR) criterion for the next 30 years, while guaranteeing demand for human consumption in a short-term scenario. it is not fulfilled, with the population increase problems appear for the urban supply. Finally, some non-structural and structural measures are proposed which, through the simulation of scenarios, can reduce the water deficit in the micro-basin.
Keywords: Decision Support System (DSS), Andean micro-basin, demands, failure, guarantee.

1 INTRODUCTION

Water is a resource that is related to numerous human activities and the environment in which they develop [1]. The advance of economic activities and the change of land use due to inadequate territorial planning have favored the soils of watersheds to be affected and degraded, causing a direct effect on the quality of water resources due to diffuse pollution from lands, primarily agricultural and livestock. In addition to that, there may be direct pollution by urban wastewater discharges without treatment and industrial activities.

The water resources management includes two components that must be integrated, the first is the management of the sources of the resource, and the second is that the demands that exist must be met [2]. To preserve the resource, both qualitatively and quantitatively, it is necessary to include a hydrological and water resources planning in a watershed that allows adequate management and conservation of water [3]. To improve the planning of the resource have developed several methods that have a scientific basis of great importance and the cohesion of all these methodologies allow the development of a Decision Support System (DSS).

There are watersheds in which water planning has not been emphasized and which have neglected the two fundamental components of analysis, that is to say; these systems do not know their recourse potential, and therefore they find themselves in a situation in which satisfying the demand is left to the fortune. For this purpose, the decision support system AQUATOOL and its SIMGES module have been used, which can be approached to the management of the basin in a precise manner. The contribution of the DSS to the management of an area with great interest in its charge for the provision of a city was analyzed, and management alternatives were proposed to mitigate this water problem, in this study aims to evaluate the optimal management options so that there are no failures in the endowment towards the city and that the simulations performed are a contribution to decision-making in

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the management of the resource. After executing a hydrological model of contributions of the river basin that has an optimal adjustment with the series of observed data, the simulations of scenarios can be carried out depending on the problems that are analyzed in the study area. Raising situations with simulations allows optimizing economic, technical, and human resources, giving managers the possibility to make the right decisions.

2 STUDY AREA

The study area is located in the south of Ecuador, in the city of Azogues (Fig. 1). It is a micro basin that has typical characteristics of high-altitude areas, in which the rivers have high turbulence, low flows, high slopes and water temperatures around 12°C in its source in the upper zone of Páramo.

The micro basin of the Tabacay River, with an approximate area of 65 km^2, presents an Andean area climatology in which the average annual temperature is approximately 15°C, rainfall around 1100 mm / year and according to Ochoa-Sánchez et al. [4] the evapotranspiration realities in basins close mark values of 620 mm per year. The analyzed area is of great importance for the city since by the geographical location it is the only source of direct supply for population endowment and irrigation.

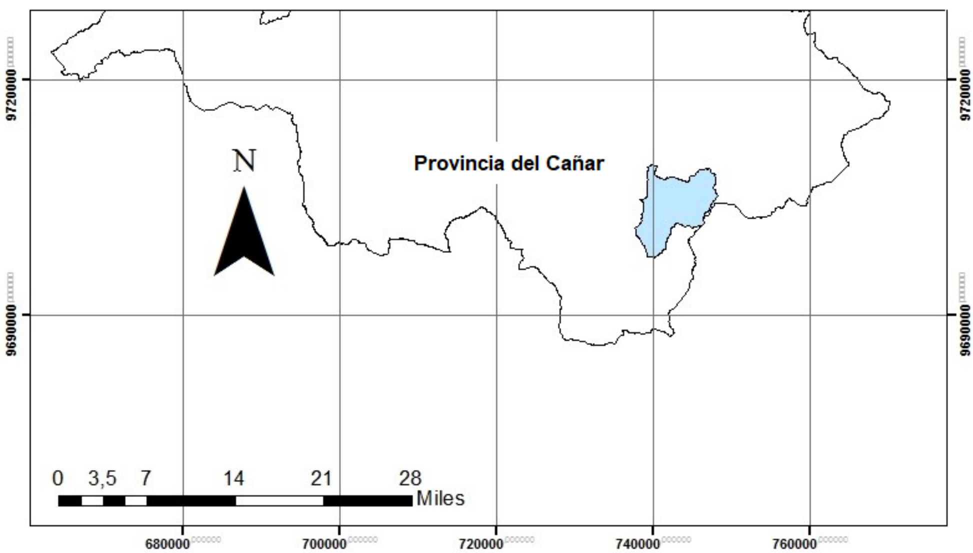
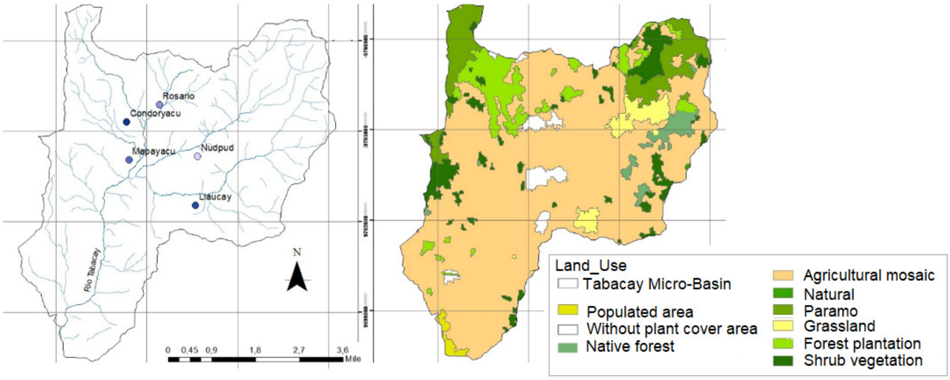


Figure 1: Location of the studied area.

The Tabacay River micro basin is formed by five main rivers Mapayacu, Condoryacu, Rosario, Nudpud and Llaucay in which water is collected for the population, in addition to the confluence between Condoryacu and Rosario, a direct intake is made for irrigation. The water catchment of the main rivers supplies the city of Azogues with an urban beneficiary population of 37150 inhabitants and the direct intake of irrigation is taken to an area of around 45 km^2. The amount of land dedicated to agriculture is high, and it is not planned satisfactorily, so the problems of water resources increase. The change in land use has produced an increase in the pollutants that reach the bodies of water, and therefore, the potential it has for provision decreases (Fig. 2).



(a) (b)

Figure 2: (a) Captures of the basin for water supply; (b) Uses of soil.

2.1 Water resources problems of the Tabacay River micro basin

The Tabacay River basin presents some specific characteristics that affect the management and exploitation of the water resources:

1. The activities of human origin such as, agriculture, livestock and urban planning affect the quality of water [5], There are specific discharges and diffuse pollution in many stretches of the analyzed river, this directly affects availability for human resources.
2. The Paramo reflects its importance in the ability to store water in its soil and then feed rivers and streams [6]. The intervention in this area puts at risk the conservation of protected areas, water regulation and sources of drinking water supply for the city of Azogues.
3. Another of the significant problems in this basin is the lack of information on the behavior of the flows that it contributes, we work with data collected and measured monthly in each one of the captures, but it leaves a high uncertainty of the real behavior. By not having regulation, the available resource cannot be used in its entirety.
4. There is no regulation system, so the problems of resource allocation become more complicated, difficult to analyze and solve.

3 METHODS

The management model is constructed in which the different elements of the analyzed system are introduced: the demands and their returns, the water inlets through the run-off and the river sections [7], to be analyzed in different scenarios of exploitation of the resource. Water resources systems analysis comprises all the necessary elements to describe a river basin [8]. In this way, a water resources model can be proposed that allows decision makers to choose possible alternatives; proper planning is the best way to meet goals set in water management.

3.1 Data collection

For the analysis of the water resource management in the Tabacay river basin, the data from meteorological stations located in the study territory are analyzed, it is analyzed for a period between 2010 and 2016 since it is the information available. To precipitations and temperature with which the evapotranspiration of the system is determined. For the flow data, the water intake measurements were determined to the catchments that are then taken to the supply. We work with two demands in the model, the first is the demand for drinking water supply for the Azogues city, and the second is the demand that has the channels for irrigation of the cultivated area. With the endowment, there is no problem since there are measured data, but the allocation given to flooding is difficult to quantify since there are several water withdrawals along the rivers that are not registered. In situ work, all existing irrigation water intakes have been measured, and their value has been quantified, the average values of the measured values have been worked on and are presented in Fig. 3.

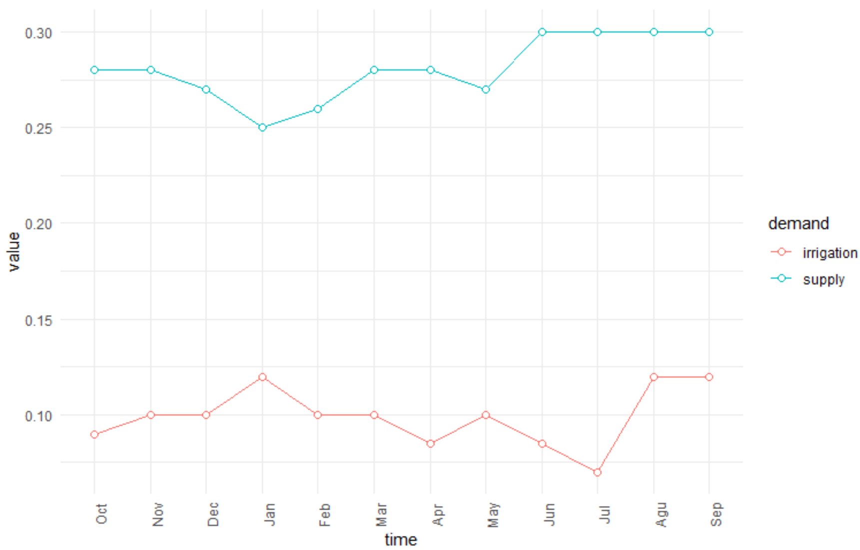


Figure 3: Comparison of the demands in the area of analysis.

3.2 Model development

The simulation is carried out using a mass balance, expressed in eqn (1)

$$V_f = V_i + A_e + A_i - P_f - E - S_c - S_v. \tag{1}$$

This equation is commonly used to determine the volume of water at the end of a period, considering the amounts of water at the beginning of the analysis and the contributions and losses that exist in the system.

To correctly manage the resources, first, we must know the current situation of the micro-basin with its tributaries, to simulate this we work with AQUATOOL and particularly with the SIMGES modules, which is a generic DSS developed at the University of Valencia, Spain. It was originally designed for the planning stage of decision-making associated with complex river basins. Its base focuses on classic system analysis methodology, but the software has been incorporating the new requirements that mark current needs through the modules [9]. Since this study proposes the adequate management of water, the use of the SIMGES module allows an analysis sufficient to know the state of the system, to make scenarios and to propose suitable alternatives. Fig. 4, shows the general scheme of the Tabacay river basin, made from the components proposed by AQUATOOL; this is the base point of the simulations and analysis to offer other scenarios.

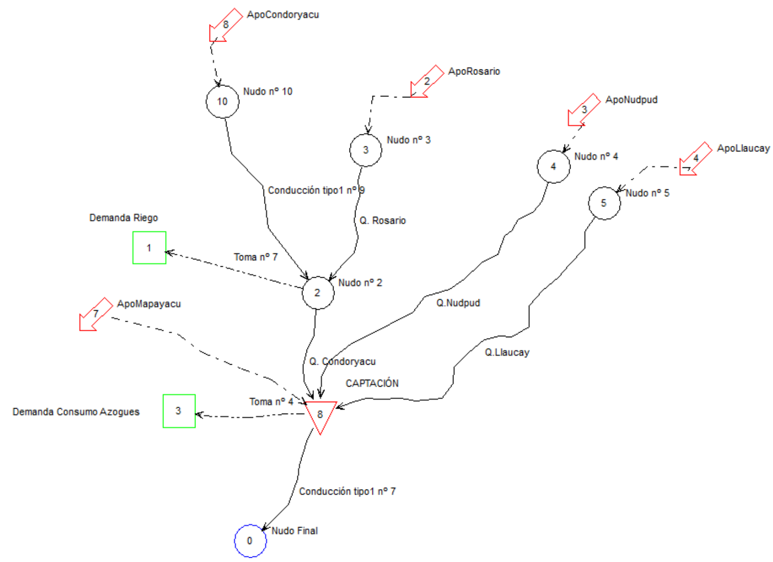


Figure 4: Outline of the Tabacay river micro-basin.

In the scheme the demands analyzed for the system are observed, the irrigation demand is the grouping of the measurement of the data in all the water abstraction for this purpose. Two simulations of scenarios are carried out: current and future. Calibration for the simulation of the current situation is the basis for setting the future scene in which the demands grow, and the system is regulated with a virtual reservoir. In case of a breach in the satisfaction of the demands as proposed [10], the implementation of a reservoir with an ideal capacity for total satisfaction of the demands is planned; However, this perfect capacity means that there will be no physical, economic, social and environmental restrictions in the construction of the infrastructure. The reservoir that is observed in the figure is only for the capture of water in the current scenario and will serve to simulate the future situation with the virtual regulation.

4 RESULTS

The results of the two proposed simulations are presented and analyzed, although the second is divided into two alternatives, the first is analyzed with the introduction of future demand and the information of the series of historical monthly contributions, assuming that the natural regime The flow of the sub-basin will not change with time and later, the entrance of a reservoir with ideal characteristics is planned so that there are no faults in the water supplies.

4.1 Simulation of water resources systems using SIMGES

The adjustment of the model in the current scenario is developed as proposed by Paredes et al. [11] where the oldest data is used for the validation and the most recent for the calibration of the model. With this consideration, we have worked with the data series of (2010–2014) for validation and (2014–2016) for calibration (Fig. 5).

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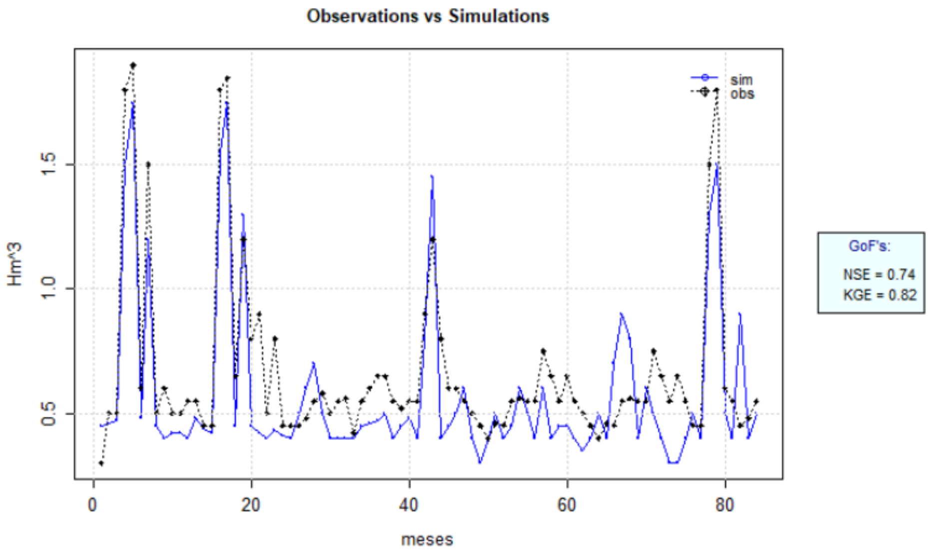

Figure 5: Comparison of contrasted values and simulated for the calibration and validation of the model.

The indicators for statistical and graphical goodness-of-fit measures between observed and simulated values show relatively high relations between the data, it has been used The Nash-Sutcliffe efficiency (NSE), with a value of 0.74 and the Kling-Gupta Efficiency (KGE) that provide a diagnostically interesting decomposition of the Nash-Sutcliffe efficiency which facilitates the analysis of the relative importance of its different components (correlation, bias and variability) in the context of hydrological modelling [12], the value of the KGE is 0.82; this indicates an adequate behavior of the observed and modeled data since it has taken into account phenomena such as extreme events within the analysis basin.

According to the statistical indicators [13], they could be classified within a category of "Very Good," which gives us the certainty to raise future scenarios with confidence in the results obtained.

4.2 Analysis of scenarios

The possible management alternatives to the system were studied to determine the optimal strategy that could be implemented with the lowest social, economic and environmental impact. In this study, four scenarios were analyzed (Table 1), in the first one there is a population growth according to the National Institute of Statistics and Census of Ecuador, in this scenario it is explained how the system behaves without any intervention, assuming that there is no variation in the water quality and quantity of the system, this analysis gives the baseline to raise scenarios of improvement to the system. In the second scenario, the creation of an operation reservoir for the supply to the population that allows diminishing the supply failures. In the third scenario, the data of agricultural demand vary, considering the months of highest rainfall as months in which the demand for the resource falls, since this is not considered within the allocation for irrigation and results in an unnecessary loss of the resource and the fourth scenario a combining the above strategies so they are compatible with each other. Finally, the advantages and disadvantages of each action strategy were analyzed.

Table 1: Summary of the scenario's simulations.

Scenarios	Analysis		
	Definition	Advantages	Disadvantages
S1: Growth population	Growth of the population of the Azogues city and therefore more significant need for water resources	Allows the analysis of a near future within the main demand in the basin	Does not consider other demands as irrigation
S2: Virtual reservoir	Implementation of a reservoir to be able to perform operating rules for the optimization of the resource in the basin analyzed	Reduce the failures in the endowments for the demands in the basin, allow that they can raise management rules for the water resource according to the demands and the importance of each of them	The reservoir is considered without economic and social restrictions, returning a virtual analysis
S3: Decrease in irrigation flows	Optimization of the water used for irrigation through the analysis of the times of the year when there is more significant rainfall	It reduces water consumption due to the demand for irrigation, which makes it possible to have available resources for the endowment and to minimize the failures in the two demands	Analysis that lacks complete reliability because there is no concrete data on the need for water from crops
S4: Combination of previous strategies	Combination of possible scenarios. S1 + s2 + s3. All scenarios are compatible	All scenarios are compatible between them and allow a comprehensive analysis of the area. The previous scenes have a high possibility of being fulfilled since it depends on the growth of the population of adequate management of the basin	Social and economic cost of users who have their own wells and manage them in a particular way

When projecting the population it is feasible that there are failures, because the hydrographic basin contributions do not increase and demand is made, this provides an imbalance in the management of the basin, as the population increases, either due to natural causes or migrations, demand for consumption is higher, leading to problems of scarcity [14] and this risk increases with inadequate management of the basin.

The reservoirs represent with certainty a first category water reserve [15] for the planning of the water resource if in basin problems for the fulfillment of the demands are identified, planning a reservoir is possibly the best alternative. But, before deciding on the construction, it is vital to analyze the magnitude of its advantages through the application of simulations that indicate how the presence of this structure in water management will improve. The simulation of the reservoir is the best alternative to quantify the advantages according to the economic and social cost that this represents [16]. In this investigation, none of the limitations are considered, and the scenarios are analyzed having an ideal volume for the supply to the system. Another of the topics of high interest analyzed is an optimization of the water that is used for irrigation. In water systems, more than 60% of the resource is allocated to this demand [17], and most of the time there is inadequate consumption of distribution, efficiency problems are usually the most recurrent. In the basin, there are declared monthly values for irrigation demand without considering hydroclimatic variations or the need for water in the crops.

5 DISCUSSION

For the first simulation scenario, the projection of population growth can be made, there are faults in the endowment, the contributions of the hydrographic basin do not increase and the demand, the response proportionally with the growth of the population, the results are presented in Table 2.

Table 2: Results of the simulation for the consumption demand of the Azogues city in 2030.

Demand	Monthly failures	Monthly guarantee **G**	Maximum Monthly deficit (Hm3)	Maximum deficit two months (Hm3)	UTAH-DWR criterion		
					D	E	F
Azogues supply	12	91.67	0.25	0.25	6.05%	7.73%	16.3%

According to the UTAH criterion, it is considered that there are failures when one of the following circumstances occurs: the cumulative deficit in one year exceeds the D% of the demand, the deficit in two consecutive years exceeds the E% of the demand and the deficit in 10%. consecutive years exceeds F% of demand [18]. There are six monthly failures for the demand for human demand, through the monthly guarantee formula we obtain a value of 91.67%, in breach of the 95% guarantee. The maximum monthly deficit and the maximum consecutive deficit in two months was 0.25 Hm3. According to the criterion UTAH-DWR the assurance of the demand meets for the first two years, while for ten years does not meet the test giving values higher than those raised for domestic use (D = 5, E = 10 and F = 16).
With the entrance of the reservoir with the ideal economic and social conditions we can see (Fig. 6) that there is no month with failures in the endowment, the volume of the reservoir is 0.8 Hm3 and in the simulation it is analyzed how its capacity varies according to the water supply and in Fig. 7 are the results with the optimization of the use of water for irrigation.

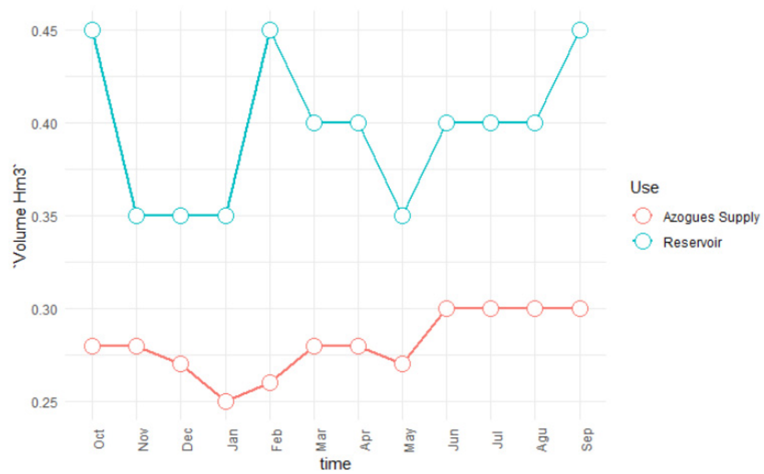

Figure 6: Endowment with the presence of a reservoir. No system failures.

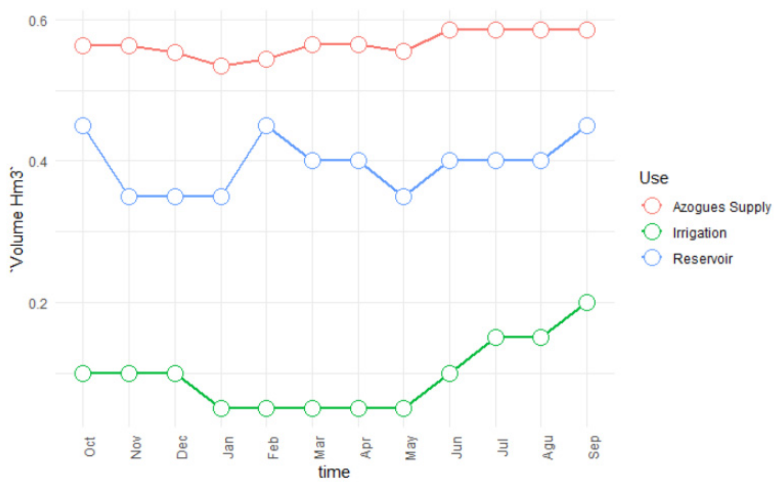

Figure 7: Presence of a reservoir and irrigation supply optimization. No system failures.

The allocation of water for irrigation decreases and a rule of operation is used in conjunction with the reservoir to manage the basin with priority of endowment for the city. Only optimizing the watering can be seen as the volume of the idea reservoir decreases to 0.5 Hm3, which is the volume of water needed to operate the basin without problems. In Fig. 8, the simulation is analyzed until the year 2030 with the increase of the population, the optimization of the irrigation and the presence of the virtual reservoir, decreasing the failures to 5 monthly and increasing the guaranteed rate to 97% fulfilling the criterion of warranty analyzed.

The increase in the need for water by the population is evident, but with the proposed strategy that includes the reservoir and the optimization of the irrigation system, the year 2013 is reached with few faults, within the UTAH criterion.

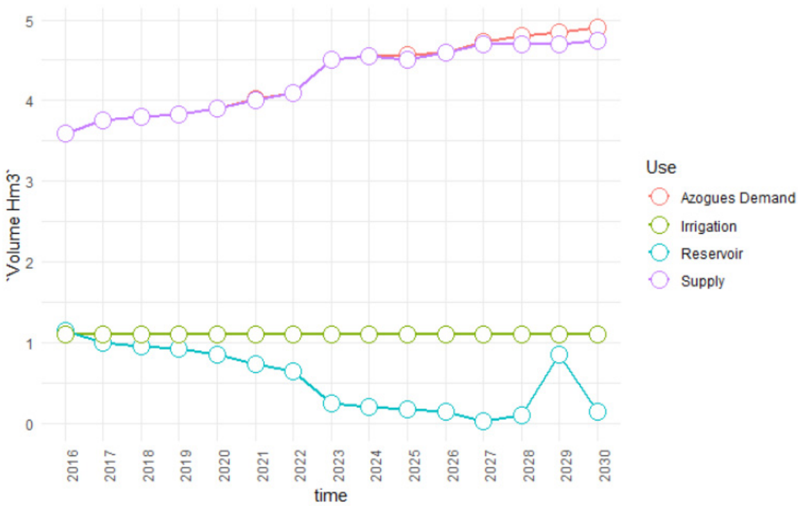

Figure 8: Simulation for 2030 year.

6 CONCLUSIONS

The proposed methodology is based on the use of decision support systems (AQUATOOL-SIMGES) to allow decision-makers to detect characteristics and improve aspects of a basin from the point of view of water management, the importance of the use of these methodologies allows us to understand the behavior of a basin that has undergone changes in land use of great importance and that has affected its hydrological response. In the Tabacay river basin, the amount of water is relatively low, and without proper management, it can be seen as for the present time, and the population suffers from failures in the endowment they require. With scenarios that are very likely to be met and if the same management system is followed by 2030, the city will suffer from severe drought problems, but if action plans are applied, such as those treated in this research, this risk of running out of water can be reduced. The scenarios are proposed until the year 2030 and with the management systems this horizon is reached with the reservoir yielding at its maximum; for this reason, it is necessary to analyze other variables to the system such as water quality and variations in meteorological variables due to climate change.

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IMPACT OF WATER ABSTRACTION ON THE WATER LEVEL OF LAKE ZIWAY, ETHIOPIA

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ABSTRACT
Significant change has been observed in the water level of Lake Ziway in Ethiopia which hinders its services for a wide variety of ecosystems. However, the contribution of water withdrawal and its impact on the lake water level variation has not been quantified yet. In this study, we conducted a water abstraction survey (WAS) to estimate actual water withdrawal from the lake. Then, we applied a water balance model coupling with simulated river inflow from rainfall-runoff model output data to evaluate the isolated impact of water withdrawal on the lake water level from 1986–2000 at monthly time steps. The amount of water withdrawal from the lake for irrigation water use is 37×10^6 m^3 per year. This led to 0.36 m drop in the lake level which corresponded to 18 km^2 reductions in the lake surface area. This consequently resulted in a reduction of mean annual lake volume by 162×10^6 m^3 from 1986–2000, which accounts for 23% of the total lake inflow from rivers.The results indicate that abstraction from the lake is a significant contributor to the drop in water level of Lake Ziway. This calls for serious action on the management of water abstraction from the lake.
Keywords: Lake Ziway, water level, irrigation water abstraction, impact, surface area.

1 INTRODUCTION

Lake Ziway provides a wide variety of ecosystem services with significant contributions in the livelihoods of many people in the area. The lake is a vital source of water for irrigation, domestic, and fish supply for market in the country. Furthermore, the lake and its basin are the focus of the Ethiopian government to stimulate large scale export-oriented irrigated floriculture and a number of irrigation schemes. However, recent expansion of intensive water abstraction activities from the lake are leading water level drops. Hence, this will consequently damage the hydrological and ecological integrity of the lake [1].

Significant change has been observed in the water level of different Rift Valley Lakes in Ethiopia, as a result of natural processes and human activities over the past decades. For instance, Seyoum et al. [2] showed that water level of Lake Abiyata significantly changed as a result of human activities. They reported 70% (4.5 m) reduction in lake height between 1985 and 2006. A rise in the size and water level of Lake Awassa and Beseka was also reported in literature with the main cause of its variation is uncertain [3]. Jansen et al. [1] indicated annual average water level of Lake Ziway approximately decreased by 0.5 m as a result of recent expansion of irrigation activities around the lake and its tributaries. The authors also showed that this drop result in a tremendous decrease in the discharge of Bulbula River which in turn result in a reduction in size of Lake Abiyata by more than 40% of its size in 1999.

The reduction in water level of Lake Ziway is mainly attributed to both natural and anthropogenic factors. Ayenew [4] estimated annual water abstraction for irrigation from the lake to be 28×10^6 m^3. However, recent studies reported that dramatic increase in water abstraction for horticulture and floriculture even doubles this value [1], [5]. The estimate of these studies was only from a dominant crop in the study area and results vary among

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different studies. However, site-specific water abstraction surveys need to be performed to estimate actual water withdrawal. Desta et al. [5] assessed water abstraction of Lake Ziway by considering pump capacity and operation hour for all users. Then, they multiply these values by the number of pump to estimate the amount of water abstraction. However, it is unlikely to assume constant pump capacity and daily working hour for all water users in the study area. Therefore, a systematic study that takes in to account the spatial and temporal water abstraction is required to estimate actual irrigation water abstraction.

Irrigation water abstraction for flower farm, diversion schemes and smallholder farmers are the major water user of Lake Ziway. However, much of the water abstractions from the lakes have not been quantified, as a record of water abstraction rates are not available. Furthermore, water users abstract free of charge from the lake without awareness on water conservation. This consequently may result in overexploitation of the lake water resources, which in turn result in partial or complete loss of the lake storage over time.

Several studies at global and local scales have indicated lack of data as a major challenge in the estimation of actual water abstracted for irrigation [6]. As such most of previous studies estimate irrigation water demand from a crop that requires the highest amount of water using national statistics, reports and climatic database [7]–[9]. However, recently remote sensing and field survey techniques are commonly applied by researcher to estimate irrigation water abstraction. The spatial and temporal coverage obtained from remote sensing data provides improvement in estimating water requirements. Note that field survey provides actual amount as it is based on actual measurement at field level.

The hydrology of many lakes has been relatively well documented, for instance that of, Lake Victoria [10], Lake Malawi [11], Lake Tana [12]–[15]. However, the hydrology of Lake Ziway is not well documented in scientific literature as compared to other lakes. Among the literature, on the hydrology of Lake Ziway [2], [3], [16]–[18] most of them focused on the water budget of the lake under the natural conditions. However, there is no study that quantitatively estimated actual water abstraction from the lake and its impact on the water level based on WAS.

The actual magnitude of water withdrawal and its impact on the water level from available studies are uncertain. The absence of such knowledge in the study area will hinder effective water management of the lake. Therefore, the objective of the present study is to estimate actual water withdrawal from the lake and evaluate its impact on water level using water balance modelling approach. Therefore, this study will provide information on the contribution is water abstraction to the observed drop in water level. Such information can be used by decision-makers, planner and water sectors for better management of water abstraction around the lake. Results of such analysis are of relevance to the scientific community to show the potential use of WAS to improve estimation of actual water withdrawal.

2 STUDY AREA

Lake Ziway is located in the Central Rift Valley (CRV) lakes basin of Ethiopia with a lake surface area covering 450 km^2. It is situated between 7.43°–8.58°N latitudes and 38.2°–39.25°E longitudes. Lake Ziway receives most of its water from Meki and Katar rivers, which drain the western and eastern plateaus, respectively. The two rivers account a total catchment area of 7020 km^2. The outflow from Lake Ziway water is discharged into Bulbula River, which in turn flows to Lake Abiyata.

The climate in Lake Ziway is sub-humid to humid climatic, with mean annual temperature ranges from 13 to 27.5°C. The mean annual rainfall varies from 454 to 995 mm, with the highest rainfall occurring from June to September and lowest from October to January. Water abstractions from the lake for agricultural and domestic water demand account for the major water uses in the lake. The dominant land covers around the lake include agricultural cultivation, wetlands and water bodies (Fig. 1). Fig. 1 shows the location of Lake Ziway including contributing catchments.

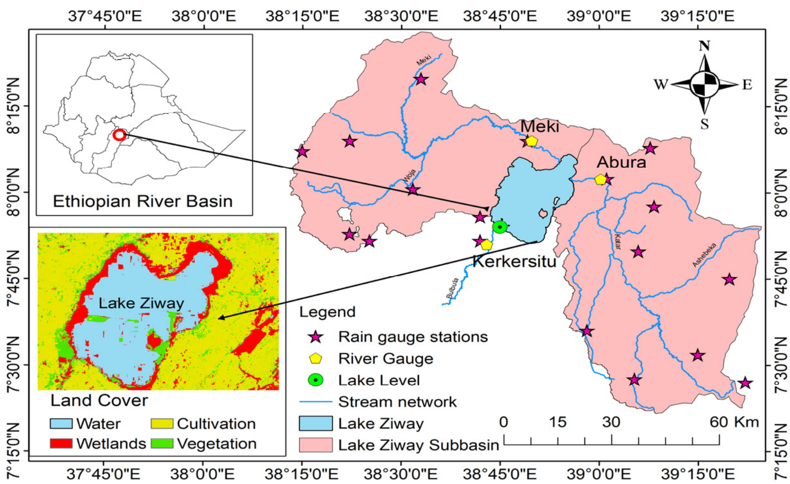

Figure 1: Location of Lake Ziway showing its catchment, major feeding rivers (Meki and Katar), rain gauge stations, and land cover classification around the lake from Google Earth image.

3 DATASETS

In this study, we used climate, hydrological and water abstraction data sets. The observed climate data sets were obtained from the National Meteorological Agency of Ethiopia and Climate Hazards Group Infrared Precipitation (CHIRP) satellite-only product at (daily temporal and 5.5 km spatial resolutions) extracted from http://chg.geog.ucsb.edu/data/. CHIRP covers regions that are situated between 50°S–50°N latitude and all longitudes [19], [20].

Lake Ziway water level, outflow (at Kerkersitu) and river discharge (at Meki and Katar Rivers) data were obtained from the Ethiopian Ministry of Water, Irrigation and Electricity of Ethiopia. The lake level–area–volume bathymetric survey conducted by the Ministry of Water, Irrigation and Electricity of Ethiopia in 1984 and 2013 were used for water level simulation, with a reference datum level of 1,635 m above sea level.

Water abstraction data around Lake Ziway was collected from water abstraction survey at field level for 15 days from 20 October 2018 to 5 November 2018. This period was selected because the problem associated with water resources in the area usually occur in the dry season. This is mainly water user start to irrigate more water during this period and feasible for field measurement. Although, the field survey was conducted during dry season we interviewed the user there seasonal water use for accurate water abstraction estimation.

The field survey was performed with a GPS device, bucket, measurement tape, current meter, and stopwatch. In addition, the data was upgraded by additional data obtained from water and agricultural offices of the localities in the study area. The facilities for water abstraction include individual farmers pumping points, water diversion schemes, flower farms, and domestic water supply owned by individuals, community and private sectors. We also surveyed seasonal pump and/or scheme operation, crop types, command area and irrigation scheduling for season irrigation pattern throughout the year.

4 METHODS

This study is based on the assessment of existing and satellite hydro-meteorological dataset, water abstraction survey, and review of published studies. We applied the hydrological model output coupling with water balance modelling and field surveys. The hydrological model output was based on calibrated and validated results from Goshime et al. [21].

The methodologies followed in this study are: First, we estimated water abstraction for all abstraction points based on Water Abstraction Survey (WAS). Next, we evaluated the water balance components of the lake under the natural condition on a monthly time steps. Then, the implication of existing water abstraction on the water level was evaluated using a water balance modelling approach. The simulated lake level for the natural condition was used as a reference to evaluate the impact of water abstraction on the water level and volume. The natural period run from 1986 to 2000 as major water abstraction was insignificant around the lake and at upstream catchments during this period. Furthermore, this period also represents a year before construction of Lake Ziway outflow regulation at the head of Bulbula River.

4.1 Impact of water abstraction

A record of water abstraction volume is not available at abstraction points in the study area. Hence, we measured the amount of water abstraction for selected abstraction points and managers were interviewed based on our data collection format. The amount of water abstracted was measured using a bucket with a known size. The time which is elapsed to fill the bucket was recorded and was used to estimate the capacity of the pump in volume per unit time. The equation reads

$$Q_{abs} = Qd \times n \times h, \quad (1)$$

where Q_{abs} is the amount of water abstracted (m^3), n is a number of pumps used by the user, Qd is the diverted discharge of the pump (m^3s^{-1}), and h is abstraction operation duration (s).

We measured the water abstraction for the pumps which were under operation during our field survey. However, the characteristics of all pumps were recorded and used to extrapolate using the sampled abstraction rates, pump type and size. The rate of water abstraction was assumed to be constant throughout the year. However, we estimated the monthly seasonal water abstraction based on irrigation pattern and pump operation condition. Hence, this monthly estimated water abstraction amount was used constantly throughout the simulation period.

4.2 Lake water level simulation

The inflow and outflow water balance components of the lake were expressed using the following relationships at monthly time steps including water abstraction

$$\Delta V = R(t) - E(t) + Q_{in}(t) - Q_{out}(t) - Q_{abs}, \quad (2)$$

where ΔV is the change in lake water volume, R is rainfall over the lake surface and E is evaporation from the lake surface, Q_{in} is surface water inflow to the lake, Q_{out} is surface water outflow from the lake, and Q_{abs} is water abstraction from the lake. All terms are in m^3 $month^{-1}$ unit.

In this study, lake areal rainfall is estimated from bias-corrected CHIRP rainfall estimate using rain gauge dataset as a reference. For a more detailed analysis of a bias correction approaches refer Goshime et al. [21]. Lake open water evaporation was estimated from three representative stations (i.e. Ziway, Ogolcho and Arata) which are located close to the lake using Penman [22] method.

The surface inflow to the lake from Meki and Katar river gauge stations simulated using Hydrologiska Byråns Vattenbalansavdelning (HBV) hydrological modelling output based on our prevouis studies, see Goshime et al. [21]. The ungauged inflow contribution was estimated using the area–ratio method. Lake Outflow discharge available at the Kerkersitu station was directly used in the water balance.

After all water balance terms estimated a spread sheet water balance model is developed to simulate lake volume as follows:

$$V_{lake}(t) = V_{lake}(t-1) + \Delta V, \quad (3)$$

where V_{lake} (t) is the lake volume at time t, V_{lake} is lake volume at a previous time (t-1), and ΔV represents a change in lake volume as estimated using eqn (2). The lake volume was then converted to lake level using the bathymetric relationships.

4.3 Impact of water abstraction

To evaluate the impact of water abstraction, two scenarios were built: the baseline natural (BS) and existing development (ED). The BS is the natural simulated water level from 1986–2000 without water abstraction whereas ED represent the existing water abstraction to irrigate a total of 2,000 ha withdrawing water from the lake. For this, first we assessed the lake water balance without and with water abstraction component (Q_{abs}) included in eqn (2). Then, we simulated the lake volume (corresponding lake level) for the baseline natural condition and existing development using eqn (3). The isolated impact of water withdrawal from the lake on the water level will be estimated from the net difference between the simulated for natural and existing condition. Further, we applied a steady state threshold water level below which the lake water might not satisfy the water need of all users. This level is assumed to represent the level at which the impact of water abstraction is minimal and hence all water use including fishing and shipping water requirement will be fulfilled.

In this study, we also assessed the effect of water level change on the lake water quality variation based on temporal lake water chemical characteristics from published articles [23]–[25]. We selected to use different anions (Cl^-, F^-, $SO4^{2-}$) and cations (Na^+, Ca^{2+} and Mg^{2+}) including salinity level [23]. We compared the range of minimum and maximum water quality parameters and the corresponding temporal water level variation. The sampled points were considered to represent both the dry (October–March) and wet (July–September) seasons of the years to consider for low and high water level, respectively.

5 RESULTS AND DISCUSSION

5.1 Water abstraction

The estimated amounts of annual water abstraction for surveyed water sectors are given in Fig. 2. The water uses from individual smallholder farmers were summed up into three administrative districts. The figure shows that Sher Ethiopia flower farm, Meki–Ziway pump irrigation and smallholder individual farmers at three districts were the major water users from the lake. The survey shows that water abstraction for irrigation accounts for 97% and only 3% accounts for domestic water use. We surveyed a total of 856 pumping stations of the individual farmers, seven flower farms, four irrigation schemes, and one water supply facility. The domestic water supply in Ziway town was estimated to be 1.26×10^6 m^3 per year over the study period (personal office communication).

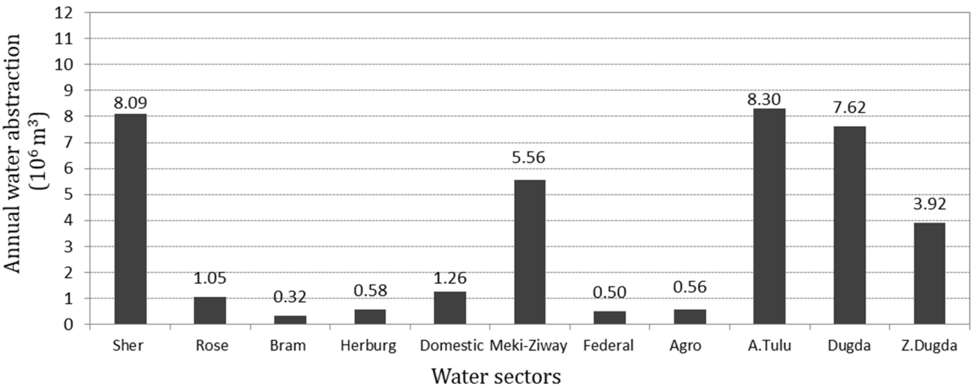

Figure 2: Annual water abstraction amount for the existing situation for all considered water sectors. The total annual water withdrawal makes 38 x 10^6 m^3 per year.

The amount of annual water withdrawal from the lake for irrigation and domestic purpose revealed 38×10^6 m^3 volume of water to irrigate 2,000 ha of agricultural lands for three seasons each year. This value is slightly lower than estimated in Desta et al. [5] (41×10^6 m^3) but higher than in Ayenew [4] (28×10^6 m^3). The difference on the amount of estimated water abstraction among the studies arise from the methods and assumptions applied to estimate. In this study, we used more precise data from water abstraction survey whereas previous studies simply applied from a highest crop water requirement in the area.

5.2 Lake water balance

The monthly average simulated water balance components of Lake Ziway from 1986 to 2000 for the natural condition are presented in Fig. 3. The figure illustrates that lake inflows mostly occur during the wet season (i.e. June–September). Lowest contribution to the inflow occurs from November to March. The lake outflow due to evaporation was greater than the river outflow. The larger outflow through Bulbula River occurs from September to January while lower river outflow occurs from February to July. Overall, our result revealed that rainfall, river inflow and evaporation constitute 33, 60 and 83% of the annual water balance of the lake, respectively. This indicates that the river inflow contributes the major Lake inflow and evaporation over the lake surface accounts the major lake water loss.

The results of annual lake water balance for the natural condition (1986–2000) for Lake Ziway are given in Table 1. The finding of this study was compared with other previous studies [1], [4], [5], [18]. We note that our estimates of the annual water balance components are comparable with most of the studies. Results of this study revealed that water balance closure error of Lake Ziway is 67 mm from 1986–2000, which accounts for 2.9% of the total lake inflow from rainfall and river inflow. The source of this error can be attributed to uncertainty in the estimation of any of the water balance component in addition to our assumption of negligible groundwater components.

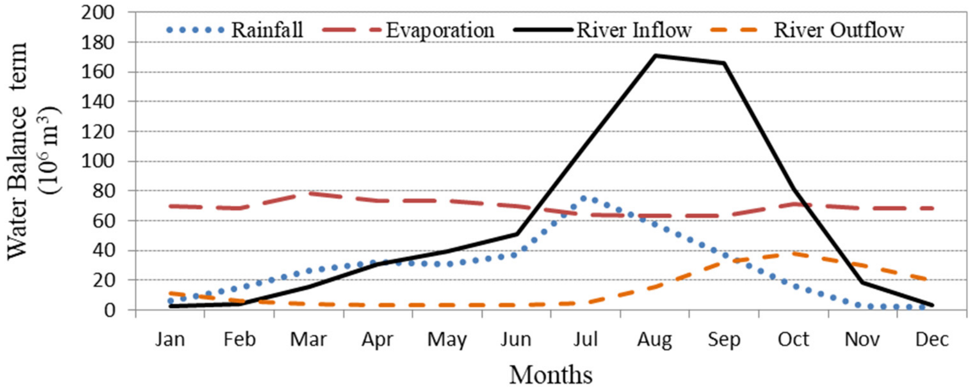

Figure 3: Mean monthly water balance of Lake Ziway from 1986 to 2000.

Table 1: Annual water balance terms of Lake Ziway for the natural condition for 1986–2000 (all unit expressed in 106 m^3).

	Inflow				Outflow		Water Abstraction	
Water Balance	R	Q_M	Q_K	Q_U	Evap	Q_{out}	Irrigation	Domestic
This study	338	233	380	81	832	171	37	1.26
Vallet-Coulomb et al. [18]	335	273	418	50	832	157	–	–
Ayenew [4]	323	265	392	48	890	184	28	–
Jansen et al. [1]	327	274	411	–	774	185	27	1.31
Desta et al. [5]	356	262	394	–	854	–	41	–

Note: R = rainfall on the lake; Q_M = Meki river inflow; Q_K = Katar river inflow; Q_U = inflow from ungauged catchment; Evap = evaporation from the lake surface, Q_{out} = lake outflow in the river outlet.

5.3 Lake water level simulation

After all water balance components estimated, we developed a water balance model to simulate the lake water volume using eqn (3). The simulated lake volume was then transformed into a lake water level using area–elevation–storage bathymetric relationships. The simulated lake levels were compared with observed lake levels. Fig. 4 shows the simulated and observed lake levels for 1986–2014 on a monthly time step. The simulated monthly lake levels reasonably fit the pattern of observed water level up to 2000. However, for a recent period (after 2000) the simulated lake level significantly deviated from the observed counterparts. The deviation between the simulated and observed levels beginning from the end of 2000 attributed to an error in any of the water balance terms and human activities such as pumping water abstraction for irrigation, which are not incorporated in our model simulation.

We also refer to previous studies that indicated increased irrigation water abstraction during recent periods in the Central Rift Valley lakes basin [5], [26]. Additionally, future climate change projections such as increased air temperatures and decreased precipitation might also lead to decline in lake water levels as well as severe water scarcity problems. Hence, the time series prior to the year of the deviation (i.e. 1986–2000) was considered as

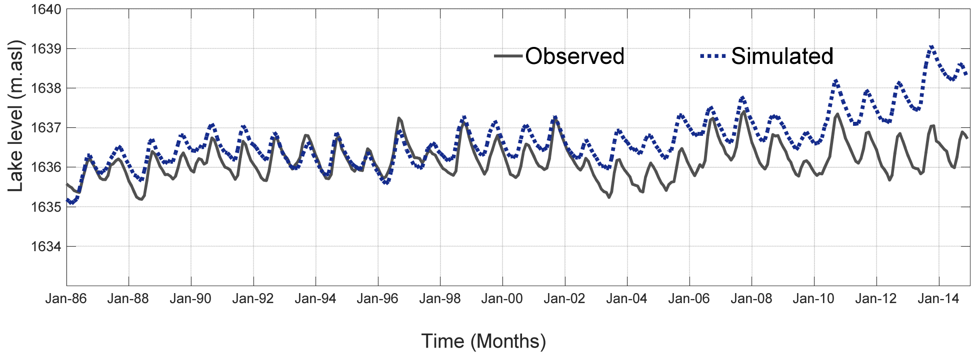

Figure 4: Comparison of observed and simulated lake level for the period 1986 to 2014.

the baseline natural period to evaluate the impact of water abstraction on the water level due to it represents natural flow condition to occur with minimum human influences in the lake and its tributaries.

The comparison of simulated lake water level for natural condition (BS) and the simulated including water abstraction for existing development (ED) from 1986 to 2000 are shown in Fig. 5. The constant line represents the steady state restriction water level (1,636 m.asl). The figure shows that the simulated lake level for existing water abstraction was below the natural baseline water level over the simulation period. This clearly indicates that the influence of water abstraction on the water level of Lake Ziway is substantial. The disagreement was significant after 1990 onwards, which possible due the cumulative effect of water abstraction and variation of climatic regions over the study area. This is especially significant when expressed by the periods of time when the lake levels below the restriction water level. For the existing water abstraction, the lake water level drops below the steady state at about 67% of the time.

The summary of the average annual water level, surface area and volume for natural level and with existing water abstraction condition are presented in Table 2. The result indicates the mean annual lake level, volume and surface area decreased during water abstraction for existing development. For existing water abstraction, the average annual water level of the

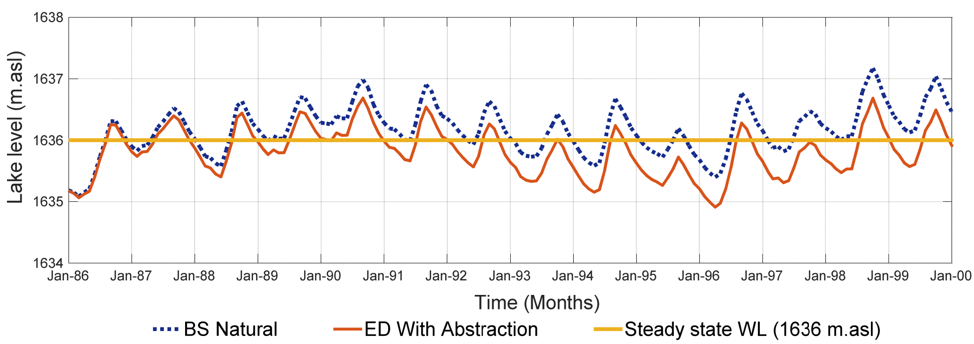

Figure 5: Comparison of simulated lake level for natural condition and existing development around Lake Ziway from 1986 to 2000.

lake lowered by 0.36 m from the baseline natural condition, with result reduction of 18 km^2 of the lake surface area (Table 2). This consequently will result in 162×10^6 m^3 reductions in the volume of the lake from 1986–2000, which accounts for 11% of the average lake volume from the baseline (Table 2). The decrease in water level of the lake in some dry years even drops up to 1.08 m from the natural water level. Hence, this will likely to have significant impact on the ecology of the lake and reduce its services for a wide variety of ecosystems. Lake Ziway supports the largest fish stock in the CRV basin and serve as a principal source of commercial fishing in Ethiopia [27], [28]. Hence, the reduction in water volume will hinder its potential as a freshwater fishery which in turn reduces the main economic income of the country. The impact also goes to reduce its service for food and shelter for a wide variety of endemic birds and wild animals [28].

Table 2: Summary of lake level simulation result for natural and existing development for 1986 to 2000.

Scenario	Water level (m.asl)	Area (km^2)	Volume (10^6 m^3)	WL change (m)	Area change (%)	Volume change (%)
BS	1636.18	442.24	1529.50			
ED	1635.82	424.35	1367.49	-0.36	-4.0	-10.6

Note: BS = baseline natural; ED = existing development.

To further evaluate the effect of water level change on water quality of the lake, we reviewed Vallet-Coulomb et al. [18] and Legesse and Ayenew [23], which they compiled from different sources [25] (Table 3). We assessed the variation of chemical characteristics and the corresponding mean annual water level for natural condition for dry and wet seasons. We note that the lake chemical characteristics values obtained during wet season increased than dry season mainly as a result of inflow from rain that might carry high concentration of solutes. Atmospheric deposition, which includes wet rain and dry dust are the main sources of chloride and sodium concentration in the water system. Table 3 shows the concentration of chloride water ranges from a minimum of 0.26 mmol l^{-1} to a maximum of 0.51 mmol l^{-1}, with mean annual water level of 0.58 m fluctuation. The variation in the concentration of chloride will affect the quality of the lake water for drinking, treatment and irrigation water use. The concentration of fluoride and $SO4^{2-}$ showed slight temporal variation as compare to chloride ion (Table 3).

The sodium concentration of the lake water also increased from 2.4 to 4.2 mmol l^{-1} for dry and wet season, respectively. This mainly indicate that rain contribute to the formation of this chemical. The sodium concentration combined with Mg^{2+} and Ca^{2+} determines the suitability of the lake water for irrigation water. Therefore, any variation in the concentration of these cations due to water level change will likely to affect its vital source for irrigation water. Furthermore, for 1988 to 1994 the salinity level fluctuated from 311 to 618 mmol l^{-1} and pH varied from between 7.3 and 8.7 for approximately 0.2 m average water level change. The salinity content of the water plays important role in the usability of the lake water for irrigation and drinking purpose. Overall, this study showed that water level change clearly reflected in the temporal variations of the chemical concentration of the lake water (Table 3). This is especially significant with increasing flower farm activities around Lake Ziway due to the fertilizer used in the farm like nitrate, sulfate, and organic waste. Similar findings were also reported in other studies [24], [29]–[31].

In this study, we focused on the impacts of direct water abstraction from Lake Ziway on the water level. Desta et al. [5] reported that a number of human-induced impacts, such as

Table 3: Temporal chemical characteristics of Lake Ziway, data from various sources.

Period	Anions (mmol l^{-1})			Cations (mmol l^{-1})			Water level (m.asl)	Salinity	pH
	Cl^-	F^-	$SO4^{2-}$	Na^+	Ca^{2+}	Mg^{2+}	BS	mg L^{-1}	(-)
Dry season									
Mar 1991	0.32	–	0.16	2.87	1.12	1.3	1636.18	400	8.5
Dec 1992	0.34	0.07	0.03	2.39	2.00	1.2	1635.15	311	8.7
Nov 1994	0.31	0.07	0.02	3.18	1.28	1.1	1636.38	618	–
Dec 1998	0.26	0.05	0.03	2.35	1.72	1.2	1636.42	–	7.9
Oct 2001	0.27	0.04	0.07	2.42	1.92	1.2	1636.56	–	7.9
Wet season									
Aug 1988	0.51	0.11	0.06	4.18	1.72	1.4	1636.13	579	7.3
Jul 1993	0.35	0.07	0.03	3.96	2.00	1.3	1635.87	439	8.2
Sep 1995	0.37	0.10	0.14	3.04	1.68	1.4	1636.74	–	–
Aug 1999	0.32	0.07	0.04	2.96	1.72	1.4	1636.87	–	9.1

Note: Cl^- = chloride; F^- = floride; $SO4^{2-}$ = sulfate; Na^+ = sodium; Ca^{2+} = calcium; Mg^{2+} = magnesium.

sediment loads due to deforestation, soil erosion, uncontrolled water abstractions from the lake and its feeding rivers are main causes for the lake water level reduction. Our result also share the view of their studies that water abstraction contributed to the observed drops in Lake water level. Hence, if the current water abstraction situations continue without intervention, the lake will lead to vulnerable to excessive water scarcity problem as that has been observed in Lake Alemaya [32]. Therefore, consideration should be given to determine how the water is appropriately utilized. This requires integrated management of water abstraction among all water sectors in the study area.

6 CONCLUSION

In this study, we evaluated the actual water withdrawal from the lake and its impact on the water level using a water balance modelling approach. The study was unique as we applied field water abstraction survey coupling calibrated hydrological model output and water balance model. The bias-corrected CHIRP rainfall dataset was used as input in a rainfall-runoff simulation where the simulated river inflow served as input to the water balance model. A water abstraction survey (WAS) was conducted to estimate actual water withdrawal from the lake.

This study indicated that an accurate estimate of actual water withdrawal and its impact on the water level can be estimated using WAS and water balancing approach, respectively. As a result of 37×10^6 m^3 annual water withdrawals from the lake for irrigation, the mean water level and volume of Lake Ziway drop by 0.36 m and 162×10^6 m^3, respectively. This will cause the water level to be lower than the steady state level over 67% of the time and the mean lake area to reduce from 442 to 424 km^2 (i.e. 18 km^2). Hence, this study indicates that water abstraction directly from the lake has a significant impact on the water level, volume and surface area of the lake. The water level change also further reflected in the temporal variation on the water quality of the lake. Therefore, we suggest the need for integrated water abstraction management among all sectors towards achieving sustainable water use around the lake including future climate change condition.

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EVALUATION OF THE SUSTAINABILITY OF THE VALLE DE BRAVO RESERVOIR, MEXICO, AS A WATER-SUPPLY SOURCE

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ABSTRACT
The reservoir of the Valle de Bravo (BVR) dam shows acute symptoms of progressive cultural eutrophication that distances it progressively from its function as a supply source. The reservoir and the city of the same name are tourist attractions, so that, as demotechnics progress, the environmental deterioration reduces the basin capacity to provide environmental services and sustain the economic and social development of its own inhabitants. The BVR provides drinking water to the Metropolitan Area of the Valley of Mexico (MAVM: 22 million inhabitants), through the Cutzamala System (CS), hence, since 2003 there is a Strategic Plan for the Environmental Recovery of the Basin of Amanalco-Valle de Bravo (SPERBAR), whose effectiveness is evaluated in this study, reviewing the concerning scientific and technical literature, with the objective to know what we can expect from the increases in population, pollution, sedimentation and the change of the reservoir use, respect to its sustainability as a supply source. The growing environmental impact exceeds the efforts to retain the resilience of the aquatic ecosystem. The participation of experts has not been sufficient to clarify the situation, control eutrophication and mitigate its impacts, since economic interests are imposed on the use of the reservoir, suggesting that the principles and objectives of sustainable development could not be transposed onto the specific context of tourism. The situation demands a different approach in water management and an inclusive legislation that meets the objectives of the sustainable development of all the interests at stake. Some works and actions are recommend.
Keywords: watershed, reservoir, eutrophication, management, policy, sustainability.

1 INTRODUCTION

The CS supplies drinking water with conventional treatment to the MAVM (22 million people), which receives many resources as contributes 23% of the Gross Domestic Product (GD; [1]). The Demotehnic [2] into the MAVM, amplifies the environmental problems in its reduced area, deteriorating long stretches of the rivers Pánuco, Lerma and Balsas borned at the Mexican central plateau. Together with aridification, desertification and aquifers over-exploitation, already limits water availability here and in broad zones of the centre, north, and northwest of the country [3], VBR included.

Known before 1979 as Miguel Aleman Hydroelectric System (MAHS), the CS came into operation in 1982, contributing 14.7 m^3s^{-1} (24%) to the water supply system of the MAVM, currently composed of four sources: aquifers (66%), Lerma System (8%), superficial springs (2%) and CS [4], [5]) (Note: CNA is called Conagua since 2000, but they are the same entity). The VBR and its watershed are part of the CS. It is 615.5 km^2 and includes 61 springs and the smaller San Simon basin, which feeds three ones (Fig. 1).

The inhabitants and beneficiaries of the reservoir have expressed to the authority their concern about the recurrent appearance of eutrophication symptoms. Thus, the National Water Commission and the Mexican Institute of Water Technology (IMTA), since 2003 have guided the SPERBAR, in order to review and update the proposed projects (including those in the *2008 Environmental Program*), update the original database and generate indicators on the impact of fragmentation and forest felling, erosion and proliferation of irregular

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garbage dumps, and polluting effluents from people and livestock [6], [7]. The *Consensus Matrix of Priority Problems* included in the SPERBAR, made with 63 representatives of the basin organizations, includes: water quantity and quality loss (37); forest degradation (15); inadequate/inapplicable legislation, social participation and environmental culture (8); soil degradation (5); social and economic lags (3); insufficient environmental monitoring (3); anarchic urban growth (1).

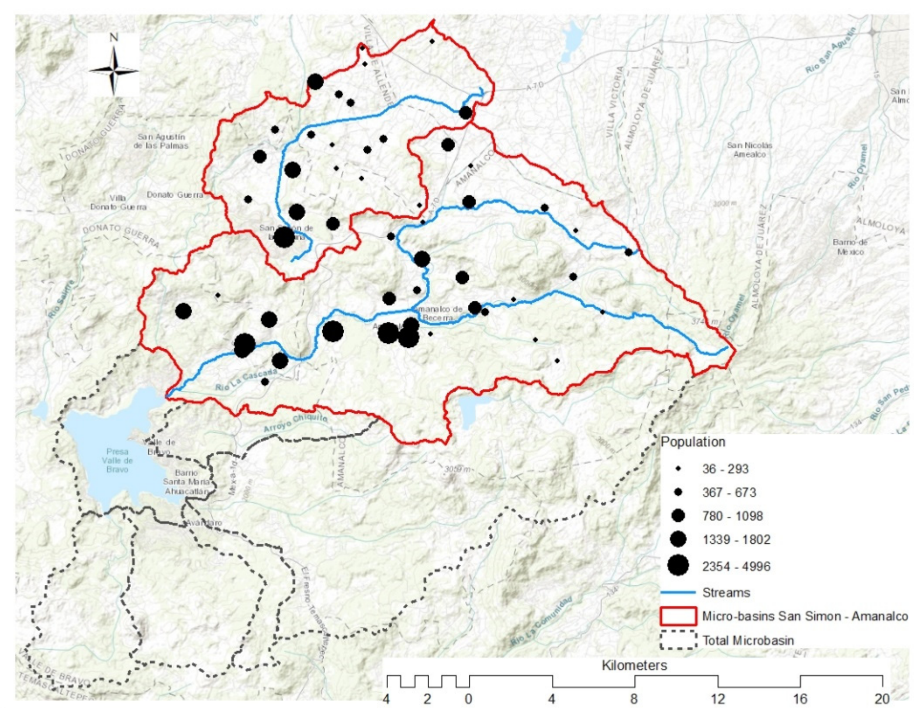

Figure 1: Valle de Bravo micro-basin location and its population density.

About water quantity and quality loss, the CNA and the IMTA studied the main contributor to the reservoir (Amanalco river), to 1) diagnose through the river's response to the effects of soil conservation jobs in the watershed, carried out since 1992 [6]–[8]; 2) know the reservoir limnology [9]; 3) control the discharges to the reservoir and the phytoplankton toxic potential (Phycotoxin was detected in 1998: discussed later in the paper); 4) conserve springs [6], [7]; and 5) evaluate the efficiency of the municipal wastewater plant (done by IMTA in 2013: discussed later in the paper). Including 1) identify, locate and prioritize the main factors of ecosystem disturbance; 2) evaluate the river-reservoir system relationships, and the environmental quality of water; 3) develop indicators of the basin water quality; and 4) suggest restoration and conservation measures of water quality and quantity.

Therefore, the general objective of this study is to evaluate the sustainability, in the context of Sharpley [10], of the VBR as a source of supply for the MAVM, fulfilling the following particular objectives: 1) update the knowledge on the reservoir condition; 2) assess the impact coming from its watershed; 3) prepare a diagnosis on its trophic evolution; and 4) suggest mitigation measures to maintain its current use.

2 STUDY AREA

Valle de Bravo dam (VBD) is located in the Watershed IV: Río Balsas, with coordinates 19º 21´30" N and 100º 11´00" W (Fig. 1). It was completed in 1944 with 526 km^2 of total catchment area; 148 m length, 56 m height and 457 hm^3 capacity at the Maximum Extraordinary Water Level (MEWL), at 1,833 m altitude. The reservoir had 1,700 ha, 21 m average depth, and 39 m maximum depth near the curtain [11]. It provided 10.8 of the 15.6 $m^3 s^{-1}$ required by the MAHS in the El Durazno Plant turbines [12]. Currently it sends 6 $m^3 s^{-1}$ to Los Berros drinking water plant. The municipal effluents must comply with certain mandatory sanitary. By 1997, a peripheral sewage collector and a 150 L s^{-1} treatment plant were added [13]–[15].

The sub-basin gives its name to the CS (Table 1). VBD is located at the confluence of several micro basins, being Amanalco River its principal affluent, which micro-basin is 35 km long, 7 km wide and 286 km^2 area, extending from 3,250 to 1,820 m altitude, with 2,510 m average. The terrain is steep, especially between 2,375 and 3,250 m altitude. The watershed/reservoir areas ratio is 30:1.

Table 1: Characteristics and graduation of the Balsas River basin and smaller units [8].

Unit	Name	Area (km^2)	Precipitation (km^3)	Runoff (hm^3)
Basin	Balsas River	116,912	109,890	29,005
Sub-basin	Cutzamala River	12,353	11.61	6,547
Micro-basin	Amanalco River	233.6	0.222	126.14
Nano-basin	Garrapata Creek	60.63	0.057	37.1
Nano-basin	El Faro Creek	8.47	0.008	4.22

3 METHODOLOGY

The information available in the Water Knowledge Center (CENCA: http//:cenca.imta.mx), of the IMTA was gathered including scientific papers, technical reports and thesis made in the study area, mostly unpublished but containing enough field data to address the issue. Following to Hodren et al. [16] the considered section of the Balsas river basin was graduated in subordinate units (Table 1). Then, the loss of quality and quantity of water is analyzed with a Systems Approach [17], [18]. The previous assessments are applied to weigh the interactions between the compartments identified in the watershed-reservoir ecosystem. Finally results are applied to improve the planning and integral resources management, with measures that protect them and make their use more efficient [8], [19], [20].

4 RESULTS

4.1 Biophysical environment

4.1.1 Amanalco River

Its watershed is located at west of the Mexico State, adjacent to Nevado de Toluca National Park. Includes the entire municipality of Amanalco, most of Valle de Bravo and smaller portions of Donato Guerra, Villa de Allende, Temascaltepec, Villa Victoria, Almoloya de Juárez and Zinacantepec (Fig.1).

Its Physiography shows hills with plateaus. The bedrock is 10 to 50 cm deep. Humic andosol of medium texture covers 74% of the area and Arctic acrisol in second term [21]. The river borns near the watershed edge, in the nano basins of two creeks: La Garrapata to the North, arising from a deforested area with grazing practices and seasonal agriculture on steep slopes; and El Faro to the South, arising from a forest subject to management and grazing. Both streams converge near the municipal head and in the vicinity of the wetland La Laguna, a useful trap of sediments and agrochemicals that was drained to be incorporated into agriculture.

Following the climatic classification of García [22], in the sub-basin are the Köppen climate types: (C (E) w2) above 3,200 m altitude (eastern part); (Cw2) from 2,200 to 3,000 m altitude; and ((A) Cw1) below 2,200 m altitude. Also, a climate type (A) C (W1) (W) is reported, slightly varying to (A) CW2 (W) (i') g in reservoir surroundings: semi-warm and sub-humid summer rains, 800 to 1,200 mm average annual precipitation, 5 to 10% of total rainfall in winter, with 2,000 mm evaporation and 18–22°C average temperature. The P/T ratio is between 43.2 and 55.3. Dominant winds flow from north-northeast and northeast with maximum speed of 20 km h^{-1} from November to May, most frequently in March [5], [23].

In upper zones the main vegetation is pine-oak forest interspersed by secondary vegetation and seasonal agriculture that changes to irrigation in middle and lower zones [5], [21]. Also important are forestry, livestock and aquaculture, highlighting Amanalco Municipality as the main trout producer nationwide, with 65 farms producing 500 to 900 tons yearly, which generate 533 T of suspended matter; 91 T of ammonia; 3.75 T of nitrates; 4.8 T of phosphates; and 10.5 T of total phosphorus [12], [24].

The river crosses over 3,000 ha of irrigation and 7,500 ha of seasonal crops, where about 5,600 T yr^{-1} of fertilizers are applied, partly assimilated by the crops, partly washed by runoff and infiltration, and partly removed by wind in the dry season. Around 1976, the river received domestic drains of 35,000 fixed and 15,000 floating people, plus diffuse contributions from livestock. Currently, this population has doubled. Table 2 shows the phosphorus (P) and nitrogen (N) loads in the reservoir tributaries around 1992. By 1993, the calculated erosion was 44.7 T ha^{-1} yr^{-1} (Table 3), mainly generated by seasonal agriculture. The reservoir capacity decreases 1.28 hm^3 yr^{-1}, average rate, due to alluvium [8].

Table 2: P and N loads from the influents to the VB reservoir [9].

River	Flow (hm^3 yr^{-1})	P load (T yr^{-1})	%	N load (T yr^{-1})	%
Amanalco	90	26.518	57	161.84	58
Molino	58	0.81	2	29.968	10.8
Santa Mónica	4.2	0.266	0.69	3.06	1
Gonzalez	20.3	0.22	0.5	9.876	3.6
Carrizal	12.1	0.121	0.3	9.379	3.4
Rainfall	14.5				
Total		27.935	60	214.143	77

Table 3: Volume loss rate of VB reservoir from 1940 to 1993.

Year	Volume (hm^3)	Difference (years)	Loss rate (hm^3 yr^{-1})
1944	410	0	-
1973	405	29	0.16
1993	364	20	2

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Two hundred and eigth physicochemical samples of forty variables were evaluated from 1984 to 1996 (river 156, reservoir 49, other 13). Largest Pearson correlations ($p < 0.05$) emphasize natural relationships, i.e. hardness is determined by magnesium (0.93); salinity by sodium (0.85); alkalinity by bicarbonate (0.84); carbonate increases as reservoir volume decreases (-0.88). And reveal human interference, i.e. detergents (MBAS), providing P, are linked to domestic drains (0.85), whose organic waste increases CO_2 by microbial activity. Phosphorus grows as reservoir volume does (0.80), due to leachates of dumps and fertilizers come into the runoff [8].

The springs presented higher content of nitrate derived from the subsoil, and lower of ammonium derived from fertilizers. At the micro-basin lower half, eleven extreme observations (EO), detected in several creeks measure intermittent human impact due to domestic effluents from the watershed and urban areas. One EO comes from a highly mineralized spring. Their averages exceed total average of each variables by 57 times for NH4, 51 times for Mn, 26 for total N, 21 for MBAS, 8 for P and 4 for CO_2.

The multivariate statistic defined an altitudinal gradient in the micro-basin. Natural leachates predominate in high and middle zones, but contaminants grows in lower parts as human settlements increase. So that, P and NH_4 start to increase disproportionately from the upper-middle zone, especially between Amanalco de Becerra (middle zone) and San Bartolo (lower-middle zone), where La Laguna wetland was drained. Ca and Mg bicarbonates predominate in highlands water, where the lower temperature and pH dissolve Si. But downstream, increasing temperature and pH decreases dissolved CO_2 and increase carbonate, which predominates in the lower parts and in the reservoir, favoured by a greater evaporation. Mg and Ca salts increase at the lower parts due to soil leachate, agricultural lime, streams confluence and evaporation.

4.1.2 Municipal treatment plant

The municipal treatment plant (MTP) efficiency was evaluated by the IMTA in 2013 (Proyect TC-1339.3 unpublished) to prevent incidents to pouring treated water into a supply source, focussing on emerging and unregulated compounds that can affect the man and wildlife health [25]. Eight hundred molecules were detected, near 75 resisted the treatment, few of which exceeded the limits allowed, and rains and the reservoir dilute their effect. It was assumed there is no health risk in the short term if raw or treated wastewater of the plant is accidentally consumed. It was suggested to improve the plant efficiency regard pesticides and solvents dangerous to aquatic environment.

4.1.3 Valle de Bravo reservoir

The original volume was 437 hm^3 with 17.3 km^2 area at the Maximum Ordinary Water Level (MOWL), with 7.3 km maximum length, 6.3 km max. width, and 35 m max. depth. In 1991, it was 335 hm^3 and the outputs were: extraction 153.8, evaporation 27.8 and filtration 21.6 hm^3. During 2002–2005, the volume was 347.9 hm^3, 89% of its maximum capacity [26]. Around 2015, sedimentation reduced 21% of the reservoir max. capacity, keeping 361 hm^3. The previous minimum volume was recorded in mid-July 1990 with 210 hm^3. A max. level of 428 hm^3 (without discounting the azolve, we assume), was achieved in 2008 stopping extractions and transferring water, since December 2006, from the Colorines dam, covered with water lily [9], [14] and 2015 [24], [27].

Aquatic vegetation: around 1987, the water lily density was 67 kg m^{-2} and biomass 121,800 T, with an average of 50,000 T in the dry season (March), and a minimum during rains, but with greater coverage. The lily contained 94.9% humidity, 0.086% phosphorus, and 1.48% nitrogen in average [9]. A *Hydrilla* sp similar plant, develops well on euphotic zone soil. Microcystin-LR was detected in June 1999, with values of 2,551 mg kg^{-1} (dry basis weight). In July 2001, it was 3,761 µg g^{-1} [28]. In July 1998, a bloom of *Anabaena spiroides* did cover 60 to 70% of the reservoir area, and the detected anatoxin-*a* indicates the presence of its toxigenic strains.

Between July 2000–July 2001, euphotic zone reached 4.3 m; 40% of 68 phytoplanktonic taxa were dominant, notably Chlorococcales and cyanobacteria. *Snowella septentrionalis* highest density was observed in April, and *Microcystis botrys*, *M. flos-aquae*, *M. wesenbergii* and *Mougeotia* sp. in October, at the beginning and end of stratification, respectively. These pulses coincided with the periods of N limitation. Dominance of these species and a highly fluctuating Shannon–Wiener diversity index (0.45 to 2.35 bits), point to disturbed and eutrophic conditions [29]. In 2008, an increase of planktonic diatoms biomass and a significant decrease of harmful algae, as Nostocales, were observed, both related to a water quality improvement [27]. We note the last study coincides with the maximum water level reached by pumping.

Aquatic fauna: Between September 1969–September 1970, twenty genera and six species of Hemiptera (9), Coleoptera (6), Ephemeroptera (5), Odonata (4), Plecoptera (1) and Trichoptera (1) were identified, the latter in places near the streams mouth. Also abundant were the paclifer *Cambarellus montezumae*, largemouth bass *Micropterus salmoides* and bluegill moray *Lepomis macrochirus* [30]. Ichthyofauna populations, as rainbow trout, charal, white fish, common carp, israeli carp and gilthead carp, and green mojarra, African mojarra and bluegill mojarra, introduced around 1980, have declined due to toxic conditions by mixing [9].

In 2006, the average density of zooplankton (847 ind L^{-1}) doubled its total abundance compared to November 2004–October 2005 period. The rotifers *Anuraeopsis*, *Keratella*, *Polyarthra* and *Trichocerca* (80% of total numerical abundance) dominated as in temperate lakes. The abundance of dominant rotifers depended on the availability of food and 70% of its variation was explained by temperature, dissolved hypolimnetic oxygen and pH [31]–[33].

Limnology: the reservoir temperature is 17.5–23.5°C It stratifies in summer with an average stratification period of 241.4 ± 30.1 days The epilimnion is 7 to 8 m thick. Dominant wind blowing strongly in dry season (December to May), promotes the mixing (monomictic) of the whole water body (holomixis) suffocating and intoxicating the aquatic biota and fertilizing the water with N and P compounds, favouring the massive growth of blue-green algae (cyanophytes) throughout the water body. The rest of the year, the moderate wind apparently causes an upwelling of nutrients to the limnetic zone, favouring phytoplankton grow near the dam curtain [26], [29], [34], [35].

In 1992 oxycline did not show anoxia, at 2001 it was totally anoxic [26]; transparency oscillated between 1.5 m in the littoral, up to 2.5 m in the limnetic zone; euphotic zone was 3.4 to 5.2 m thick; Chlorophyll *a* had a maximum of 52.8 mg m^{-3} in February in front of Carrizal River mouth, a minimum of 10.5 mg m^{-3} in July near the curtain; with 29.2 mg m^{-3} annual average. The reservoir was eutrophic with the P trapped in sediments as the main limiting factor of productivity [9]. We think this conclusion opposed to the high COD rates associated with the high nitrification rates observed.

The reservoir primary productivity from 1998 to 1999, was performed by genera as *Anabaena*, *Microcystis*, *Nostoc* and *Oscillatoria*, and the N/P ratio of 0.98 to 5.68 pointed to a N limitation. In April, a ratio of 28.32 indicated P limitation [31], the rest of the year the presence of N-fixing algae, such as Anabaena, Microcystis and diatoms, indicate sufficiency of P. Diatoms dominated in cold and dry months. In 2001 to 2002, chlorophyll averaged 21 µg L^{-1} with frequent blooms up to 88 µg L^{-1} limited by N during stratification

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[36]. This alternating control of primary productivity is recurrent in lakes of Mexican highlands, and points to a summer maximum primary productivity P-limited [37].

4.1.4 Reservoir management

The change from MAHS (before 1982) to CS (now) implied a change in the reservoir Hydraulic Retention Time (**T**), that is, the lapse to empty the reservoir by outflow [19]. Considering the original volume at the MOWL, outflows changed from 10.8 to 6.5 m^3s^{-1}, and **T** from 1.32 to 2.13 years (62% larger), i.e. 9.72 months more to renew the water. Around 1990, **T** was 2.18 years [9], that is, 10.3 more months. Besides this, surface water is (or was) extracted when the reservoir stratified [35], involving 109 to 140 hm^3 $year^{-1}$, or 78 to 91% of the total extractions (153 hm^3 $year^{-1}$), and between 30 and 39% of the reservoir volume (361 hm^3). We think, this action exposes the hypolimnion. No data could be found on the quality of the water transferred from the Colorines dam to the VBD.

4.2 Social environment

4.2.1 Demography

From 1970 to 2010 the population of VB municipality almost doubled (190%), and may reach 100,000 inhabitants in 2020 (Table 4). This growth of 350% in the micro-basin can exceed 2,000% if tourism is included. From 1990 to 2000 agricultural and urban land grew by 200% and 167%, proportionally increasing pollutants and sediments loads to urban and agricultural sewages. This growth has not stopped [38]–[40].

Table 4: Evolution of population and land use in the VB Municipality.

Año	Agríc. (ha)	Incr. %	Urban (ha)	Incr. %	Popul	Incr %	GDP 3^{rd}	Incr. %
1970					35,000	0		
1990	4,930	0	1,350	0	36,135	3		
2000	9,865	200	2,250	167				
2010					66,599	190	7,000	0
2015							12,000	41
2020					100,000	286		

PROCUENCA [41], an escrow of VB micro-basin sponsored by 14 companies as Conagua, BANCOMER and the State of Mexico government, says "most of the 120,000 watershed permanent inhabitants live in poor communities pressing natural resources through activities of primary sector as agriculture". But the municipal govern [21] says "tertiary sector occupies 68% of the workforce, tourism included, and enters more money into the Municipality and State coffers through the touristic amenities". These amenities are settled on the reservoir banks, where the floating population generate garbage and waste, especially on holidays. The escrow found twelve (35%) highly contaminated and 5 (15%) contaminated (fecal coliforms) in 34 samples taken by themself in August 2016 in Amanalco river, revealing unhealthy conditions due to the outdoor fecalism (including livestock), and domestic sewage from settled communities along the main road which runs parallel the river. Thus, the efforts made in the aforementioned SPERBAR apparently have not had an effect, since from 1992 to 2005 the N and P discharges have grownby 276% for P and 203% for N [26], almost the same as population did (Table 4), and the reservoir deteriorates more and more.

4.2.2 Watershed management policies

The Valle de Bravo Trust ($74.6 million MN) was temporarily created in 2005 [42], with contributions of the National Commission of Natural Protected Areas of Environment Ministry (SEMARNAT-CONANP: $31.9 million), the state government ($20.6 million) and Televisa Foundation ($21.4 million), to acquire properties in the margins of the "Valle de Bravo Water Sanctuary" protected wetland area [43], via law, public interest, and Bank interest (about $726 thousand NM). The Sanctuary approaches the reservoir in steep areas and does not include urbanized, current or planned shores. The properties would be donated to the Federation because "the temperate environment is threatened by soil erosion and degradation, forest fires, urban development, extensive cattle ranching, illegal logging and expansion of the agricultural border".

The Trust has expropriated for conservation purpouses, about 79 ha of the San Juan Atezcapan ejido, paying compensation of $20 per m^2 [44], [45]. However, the case shows that the land adjacent to the reservoir is marketed by real estate agents that quote between 300 and 400 USD m^2 [46], stimulating within the basin the properties supply offered for "real estate developments" (e.g. El Financiero [47] and Trovit [48]).

5 DISCUSSION

The biological and physicochemical data from studies carried out by official, academic and private entities showed recurrently the increasing pollution in the contributors and in the VB reservoir, culturally eutrophicated in a short time: In the 80s it was qualified as oligotrophic, but in 2003 and 2004, it had bad appearance and biological, physical and chemical parameters typical of eutrophic conditions [24].

Althought the *Microcystis aeruginosa* populations did not exceed 5% of the total phytoplankton abundance when analized, its proliferation can explain the closure of the reservoir to navigation from 2011 to 2012 (below) [49]. So, it was recommended in 1998 (Project TC-9815 IMTA unpublished) to control it, if necessary, with calcium hydroxide, but we think this method would increase water costs, as well as dissolved Ca, hardness and alkalinity in the reservoir.

Vollenweider equation [19] shows that dissolved solids concentration depends on **T**/z′ ratio. The only factor can reduce solids concentration is z' (mean depth), but less volume reduces depth, and concentration increass, especially due to silting, and/or to a very dry season, and/or if agriculture decreases inflows, or a combination of these three factors, as occurs in BVR. Since **T** has almost doubled, part of the waste from the previous season remains in the reservoir, adding self year after year to the waste coming from the micro-basin, accumulating self inexorably in the water and sediments.

When the reservoir belonged to the MASH, the extraction was higher and the volume lesser, favouring the solutes and pollutants washout. Pollutants were also less due to a smaller population, lesser the agricultural area and larger the tributaries contribution, however, this led to the bowl invasion with constructions below the MOWL. The washout could be effective again when sediments reduce the volume to an adequate level, but the micro-basin receives from 2.5 to 3 million people annually [21], [39], in hotels and own houses, surpassing 25 times the fixed population. Although their greater influx is temporary, the garbage and waste produced in holidays remains in the ecosystem lands and water, and in the treatment plant at best. The problem is usually attributed to the upper micro-basin population while tourism is promoted downstream, bypassing the quantity, not quality, of sewage drains, as evidenced by the following notes from a local newspaper and the CNA.

Teorema Ambiental (2012). (Environmental Theorem). Valle de Bravo, Mexico. June 29, 2012 [50]: "The Ministry of Communications and Transportation, at the request of the

Conagua, kept the place closed to the navigation ... due to a persistent bad smell and bad taste of the water ... attributed to the algae *Anabaena* ... it is necessary to develop and promote sustainable tourism in the region, because the boatmen ... were more affected … The Citizen Observatory ensures that ... Conagua and the municipality of Valle de Bravo, must immediately carry out a comprehensive management and sanitation program".

CNA: Press Release 139-12, Friday, July 6, 2012: "Cutzamala System water is suitable for human consumption because meets... Mexican standard. On Friday 6, Saturday 7, and Sunday 8, from 10 am to 5 pm, the navigation of the vessels … in the eastern area of Valle de Bravo dam in the State of Mexico will be allowed, informed … (Conagua), ... Given the weather conditions and the … decrease of geosmin, … the General Directorate of Merchant Marine, the Communications and Transportation Ministry, and the State of Mexico, allow the navigation of motor boats, yacht type".

In the present context, the only sustainable tourist is one who does not eat nor drink and, therefore, does not require agricultural land, nor drainages nor trash dumps. This problem has not been prioritized, as evidenced by the result of the survey carried out for the SPERBAR: only one of the 63 representatives pointed to the anarchic urban growth, but no one complained about the tourist increase.

We can see the weak side of the reservoir sustainability as supply source in Table 4, looking at the tourism income. The VB tertiary sector contributes 93.7% of GDP, and represents 33% of the State of México GDP, reaching 12,000 million pesos in 2015, 41% higher than sector GDP during 2010 [39]. This growth of 8.2% yearly exceeds the 7% proposed in the UN Objective 8.1 for Sustainable Development for developing countries, confirming the incompatibility between objectives 8, 7 and 15 and, in this particular case, 11 (e.g. Hickel [51]).

This money has causes and consequences, i.e. the cost of clean and move the water of the CS is \$6.145 m^3 pesos [52], without include the costs of unsuccessful studies, actions and works from both public and private sectors to prevent the environmental degradation, as we have seen so far. Similar situations happen in other national water bodies, that could be exacerbated by the official boost to tourism without sustainable planning, if it exists.

The parallel increase of the population and the consequent and irreversible water contamination could not be stopped despite the efforts of: 1) the authorities responsible for planning and manage natural resources, 2) the non-governmental organizations interested in environmental conservation (for purposes whether altruistic or metallic), 3) the citizens, and 4) the interaction between the three. The basin participants (8), in the SPERBAR who think that the main problem is that the legislation, the social participation and the environmental culture are inadequate and/or inapplicable, are right. Although the properties offered into the micro-basin are not on the reservoir shore they are into the micro-basin fluvial corridors, so the perspective is worrisome, unless the Valle de Bravo Trust purchases the lands offered and uses them for conservation.

6 CONCLUSIONS

The main problem in the basin and the reservoir is the conflict that exists in the very definition of sustainable development: economic growth and sustainability [51], reflected in the scheduled use and the actual use of the reservoir.

Five (maybe six) steps were done, consciously or not, favoured eutrophication: 1) build the dam in a micro-basin where prevailing nutrient-rich volcanic soils; 2) change dam use, from hydro-electric generation to supply, increasing **T** and the load of suspended and dissolved substances; 3) extract epilimnetic water, thinning the epilimnion and exposing dirty hypolimnetic water, reinforcing the eutrophication; 4) pour to the reservoir the treatment plant effluent to maintain its level. This last water with high N and P load; 5) stimulate tourism into the micro-basin. The effect of importing water from the Tilostoc dam is in doubt. So, biodiversity has declined in favour of a few species eutrophication resistant, despite previous recommendation of discharge the treated wastewater outside the reservoir [8].

It is needed to know if the zooplankton food is produced into the reservoir (autotrophic) or comes from external sources (heterotrophy). This last case would implies extra income of organic matter from the micro-basin, which the waterbody could not depurate, aggravating the problem of hypolimnetic anoxia during winter mixing (e.g. Jasser et al. [53]).

As expected, the flocculant applied in the drinking water plant has grown in same proportion as N and P loads in the river discharges. Therefore, the recommendation that gave rise to the limnological studies in the reservoir no longer valid: reduce the flocculant applied in the plant [34], with the discomfort of the original inhabitants due to the discharge of the plant residuals in the surrounding lands.

It is necessary to improve the weighting of the problems generated in the site and the planning of the works and actions, as well as the prioritization, without simulation, of the economic benefits in favour of groups that have been marginalized for a long time [54]. Null result in conservation works and actions devalue social participation in water management and show that image and funds of institutions can be misused.

Must be emphasized that priority should be focused on redistributing the local population towards alternative income sources outside the micro-basin, and to control the agricultural frontier and its corresponding increases in drainages and sediments.

If the demotechnics does not stop, the work and actions to conserve the quality and quantity of the water in the VB micro-basin will be increasingly expensive and unsuccessful, and it is neither ecologically nor socially fair to invest so much money and labor in a conservation task that is doomed to fail to maintain the high water supply of a hydraulically almost unsustainable megalopolis due, in part, to the problem of the VBR discussed here, as well as to the desiccation of the sources of the Lerma River (with its social and economic consequences), and the sinking of Mexico City due to the overexploitation of the aquifer [55].

Other tourist sites in the country, such as Acapulco, Gro., Patzcuaro, Mich. (Project HC9825, 1998 unpublished [56]; and Cancún, Q. Roo (IMTA, 1998 unpublished), show similar results, sugesting that the principles and objectives of sustainable development cannot be transposed onto the specific context of tourism [10], adding to the worldwide environmental deterioration [57], characteristic of *Anthropocene* [58]. This requires check the preponderant economic development model [59], to achieve real sustainability in the face of the compromised situation between economic growth and the ecology [51], and apply a different approach to water management that includes the social aspects concurrently to the biological, ecological and hydrological aspects (e.g. Harper et al. [18]).

If this happens in such conspicuous systems as VB, under the gaze of national and international community, what can be expected from inconspicuous systems, such as subsurface waters under the effects of "fracking" [60]? This document is an example of what could be called "forensic sustainability", a necessary approach in the region to assess the state of natural resources and plan their conservation or recovery.

7 RECOMMENDATIONS

The floating population should be controlled by limiting land speculation and the development of tourism infrastructure, especially on the banks and within the reservoir, rivers and streams and on the surrounding hillsides and hills within the basin, at least to reduce to 3% GDP [51]. This would be more feasible also reducing, or at least controlling, the irrigated land. The correct function of the municipal treatment plant (MTP) and the peripheral wastewater collector should expand their capacity to serve the floating population during holidays. In addition, their water should not be poured into the waterbody but outside the dam, at least during the holiday season.

The water extraction from the epilimnion should be avoided and doing a intake scheduled management so that the hydraulic retention time can be shortened, at least in the rainy season.

The reservoir sediments must be removed by means of a low-impact dredging or through the deepest window of the intake. Given that there is no heavy industry in the region, sediment can be apply to fertilize the soils in the upper part of the basin affected for bad agricultural practices.

The sediments and agricultural pollutants must be retained *in situ* restoring both the wetland called La Laguna and the riparian vegetation of the river and its tributaries, and build manmade wetlands (e.g. Shutes [61]).

Determine the environmental flows of the tributaries to plan the allocation of volumes of water to progressively restore the ecosystem (e.g. Tharme [62]). Floating restaurants are a great attraction, but it is imperative that they be equipped with dry latrines and the excretions be stored in tanks and then handled in an environmentally safe manner.

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THERMAL SPRINGS AND SOCIAL DISTRIBUTION OF GROUND WATER

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ABSTRACT

Thermal springs are an essential source of water for certain towns. Since human beings depend on water, different ways to distribute it were developed. In Mexico, aqueducts became an important means to conduct water to society once the Spaniards decided to found new settlements in America, and through the years knowledge in architecture and urbanism have contributed to improve tunnels, water boxes, thermal baths, fountains and modern water infrastructure. A good example is the city of Aguascalientes – which means "hot waters" in English – located in the central part of the country. Hot springs have been used as a source of water since the 16th century, but nowadays water tunnel distribution systems show deficiencies in response to urban growth. The main objective of the paper is to analyse social ground water distribution in the city of Aguascalientes, from the Ojocaliente thermal baths being built in 1831 to modern day drinking water distribution. So, it's through an historical analysis of Aguascalientes City, the use of a survey and a qualitative statistical method that we can understand urban morphology and the way inhabitants in a Mexican city perceive social ground water distribution. The way drinking water used to be distributed into the city is described in the paper. Also, the use of a correspondence analysis will be helpful to understand the perception that people have that water coming from taps isn't clean now. This situation has given advantages to distribution of bottled fresh water recently. Social ground water distribution in Aguascalientes has contributed to shape the city since the 19th century, even though recently drinking water distribution is bottled and expensive. Also, publicity made abroad related to unclean water management, like: Don't drink the water! has an impact on tourists and city visitors who distrust Aguascalientes ground water quality.
Keywords: water distribution, hot springs, society, historic water supply buildings.

1 INTRODUCTION

The main objective of this paper is to accomplish an analysis of social ground water distribution, including historic water buildings in the city, since the Ojocaliente thermal baths were built in the year of 1831. In fact, when the first settlements occurred during the 16th century the thermal springs were used to take water from this source and it was distributed since then – by irrigation ditches – to the main square of the small village, and also nowadays thermal waters from such source is still distributed through a complex built environment. So, it's been more than four centuries since social thermal water distribution has taken place in Aguascalientes.

Thermal springs and social distribution of ground water is barely analysed by researchers in Mexico, but in this paper it will be explained, starting from simple irrigation ditches to water supply buildings and distribution of drinking water to the population of the town. A qualitative progress in the way water was distributed occurred during the 20th century. Therefore, instead of using donkeys or mules to pull the fresh water tanks on wheels, small water companies preferred to use fresh water trucks during the second half of the 20th century, and also water distribution was improved during the beginning of the 21st century.

Hence, people's opinion on fresh water distribution nowadays was useful to understand if public image about water depends on publicity or to appreciate what they know about water quality.

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2 METHODOLOGY

The first step in the methodology applied in this article was the use of an historical analysis about social distribution of ground water, in order to understand the qualities of the social problem. Afterwards, a survey and a qualitative statistical method were very useful to understand urban morphology and the way inhabitants in a Mexican city perceive the use of ground water distribution. So, it was convenient to design a survey including opinions of people, using direct questions about historical use of water and nowadays opinions about bottled water distribution. The survey included a questionnaire plus the following categories with statistical validity: Age; gender; educational level; origin; trust in city's tap water; water supply system evaluation; disappearance of public drinking fountains; conscious about *El Cedazo* water tunnel; awareness about water distribution to old orchards; reasons of consuming bottled water and reasons people don't drink tap water. Next step was operating the survey at public places. Downtown is the most visited place in the city, and also it was easier for the surveyors to find people willing to answer the survey there. At the time doing the survey, a good spot to find respondents was a touristic bus stop. Also, some other good spots were outside the main museums or outside the main historic buildings of town. Five surveyors applied 150 questionnaires apiece. The total amount of questionnaires was 650, and they were completed during the first week of August. But, a sample of 125 questionnaires was chosen using a random method. This is, 25 questionnaires respectively. After obtaining the results, a qualitative statistical method was used. The categories of the questionnaire and the variables obtained were used in multiple correspondence analyses. The correspondence among variables helped clarified configuration of interactions. The Burt's matrix was successfully used to obtained valid relationships. In Fig. 1 we can observe an illustration of how a Burt's matrix runs. It's through categories of the questionnaires' data and the order of variables that we can obtain a correspondence analysis. A complete explanation of how to obtain a Burt's matrix can be examined in Acosta Collazo [1].

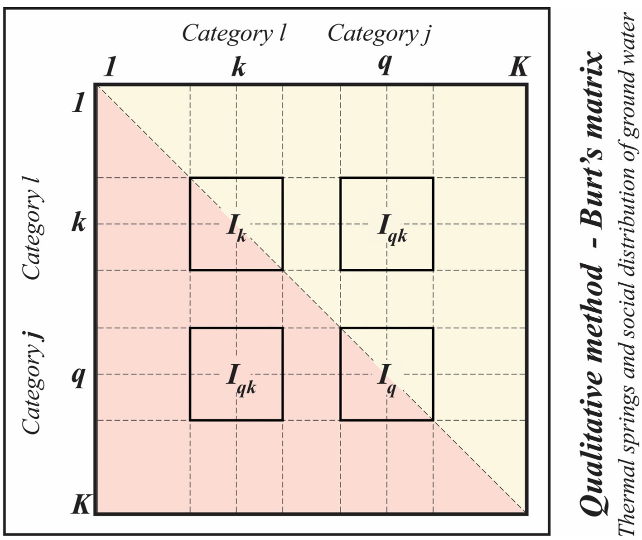

Figure 1: Qualitative method based on a multiple correspondence analysis, specifically a Burt's matrix. Accordingly, an interaction of variables in categories of a survey. *(Source: Author research design, August, 2019 and a reinterpretation of a figure exposed by Josse et al. [2].)*

3 HISTORIC WATER SUPPLY BUILDINGS IN AGUASCALIENTES

In order to cover the distance from the water thermal main sources (Ojocaliente) to the main fountains in the city centre, water ditches were used at the beginning. Culture of high society during the 19th century in Aguascalientes included taking baths and swimming at Ojocaliente Thermal Baths, but poor people decided to take baths in the open water ditches; consequently, such water wasn't that clean because it had been used by humans at the thermal springs before flowing into the water ditches. Ruiz López talks about this situation in her studies about poor people between the years: 1871 and 1942 in Aguascalientes City, and the way reach people tried to civilize them [3].

The water is warm at the main source of the thermal springs in Ojocaliente Baths. The average temperature is about 40°C (104°F). In regular conditions it's too hot for swimming pools and baths, so in most of the cases the baths and the citizens at home combine hot water with cold water to regulate the temperature. Also, there used to be a well-known baths named *Los Arquitos* in the city, and the hot water system included water tanks to regulate the temperature of water coming from Ojocaliente hot springs and baths. Also, the neighbourhoods near the Ojocaliente thermal springs use subsoil water and it's also hot. For this reason, some people in their houses prefer to connect their water pipes with spring water directly to showers in order to avoid heating it with boilers. As a result, they save energy and money. Most of the citizens say it's worth it. So, living in houses around Ojocaliente thermal springs, and also in some areas of the city centre, has advantages over the rest of the city.

Fig. 2 shows part of a restoration project of the Caracol water box done by the author of this article in the year of 2001. It's situated by Ojocaliente thermal springs, but in this case the water was collected by natural subsoil filtration, so the water wasn't as hot as in the thermal springs. This water box was the source of a distribution system to the southern part of the city during the late 19th century, and also at the beginning of the 20th century. Also, this water was conducted through a subsoil tunnel directly to several fountains and to the old orchards situated in that area.

The objective of explaining how this water box used to function is to show the importance of this building for the history of water distribution in Aguascalientes. Even though, it looks like a simple cylinder shaped building, with a distinctive beige patina, the way it conducted water was remarkable and also complex. The building had a spiral stone staircase. After the making of the project the cylindrical building was actually restored – including its staircase.

The water box had an entrance below from water filtration underneath the building and also from a water table filtered by sedimentary rocks (see Fig. 2), composed of petrosilex material. In fact, this is the main reason the place was named *El Cedazo* (a water filter). Furthermore, petrosilex is a type of sedimentary rock that was used in prehistoric times for making tools. In fact, near the water box was discovered several decades ago a prehistoric place, and after getting through with the restoration of the building local tourism agencies had artists reconstruct prehistoric animals like sabre-toothed tigers, mammoths, glyptodonts, giant armadillos, American mastodons, etc. in fiberglass, to recreate the way the place looked like before human history, several thousand years ago.

Guzmán Gutiérrez and Acosta Rincón mention: in the year of 1974 the palaeontologist Walter W. Delquest described new species of animals like the antelope that lived in the Cedazo river in Aguascalientes, and named it *Tetrameryx mooseri*, honouring Oswaldo Mooser Barandun [4] the scientist who did a great job doing paleontological research in Aguascalientes. The recreation of prehistoric animals and the importance of the water box restoration became an attractive site to visit during the last decade.

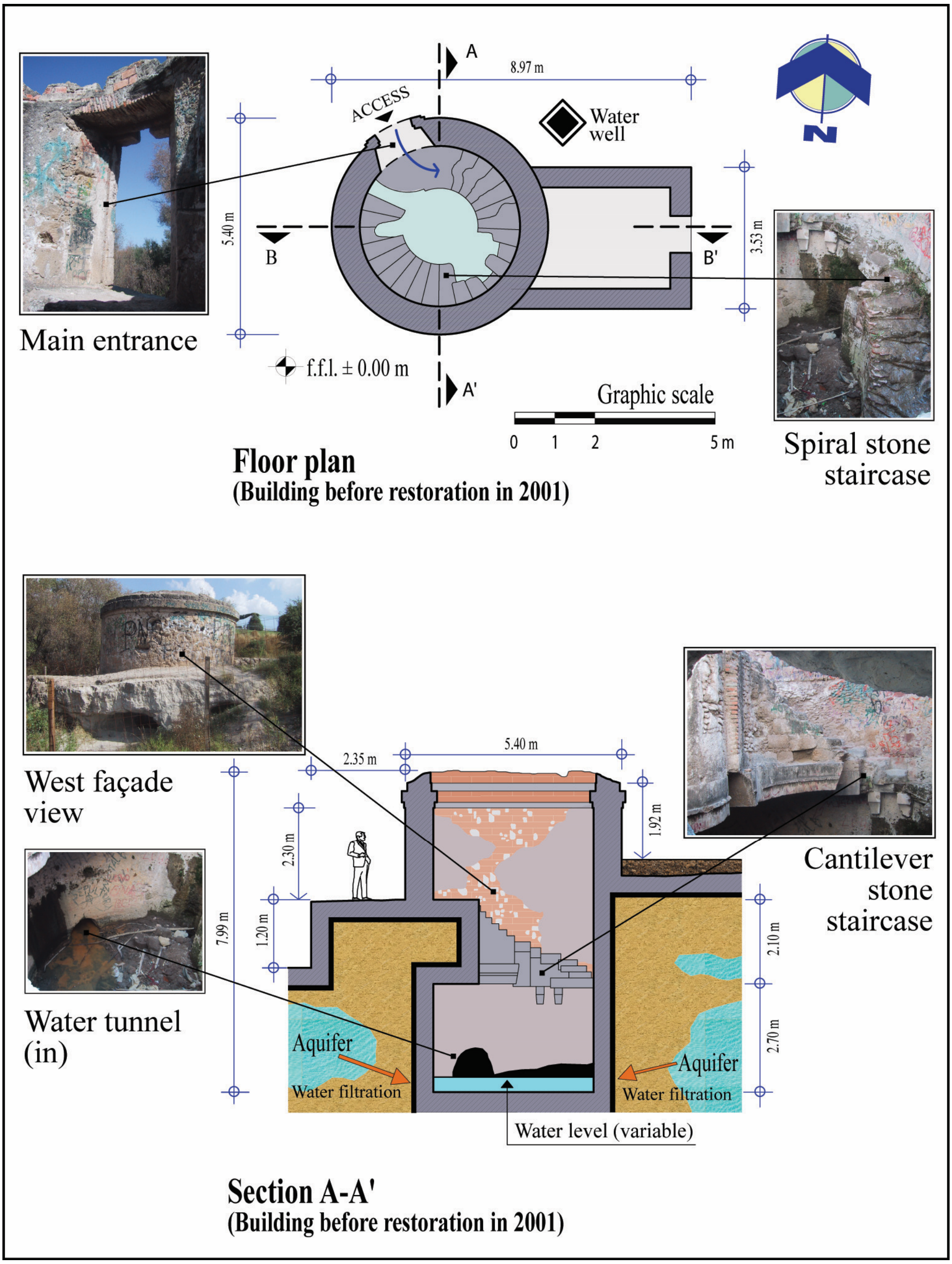

Figure 2: The *Caracol* water box. Floor plan and Section A-A′. *(Source: Restoration project, photos and drawing by Alejandro Acosta Collazo originally in 2001. Drawing edition: Alejandro Acosta Colunga, August 2019.)*

The *Caracol* somehow functioned like a water filter and then the water was conducted through a tunnel (out) that can be seen in Fig. 3. During the restoration project it was discovered a well-constructed tunnel with stonewalls. The masonry construction was made with a material named “matacán”. The stone looks like “tepetate” (Nahuatl tepetate), which is found near volcanic regions in Mexico, so the material doesn’t absorb water. The tunnel coming out from the *Caracol* building was named *El Cedazo* tunnel, and it distributed ground water to old orchards and fountains in the city of Aguascalientes.

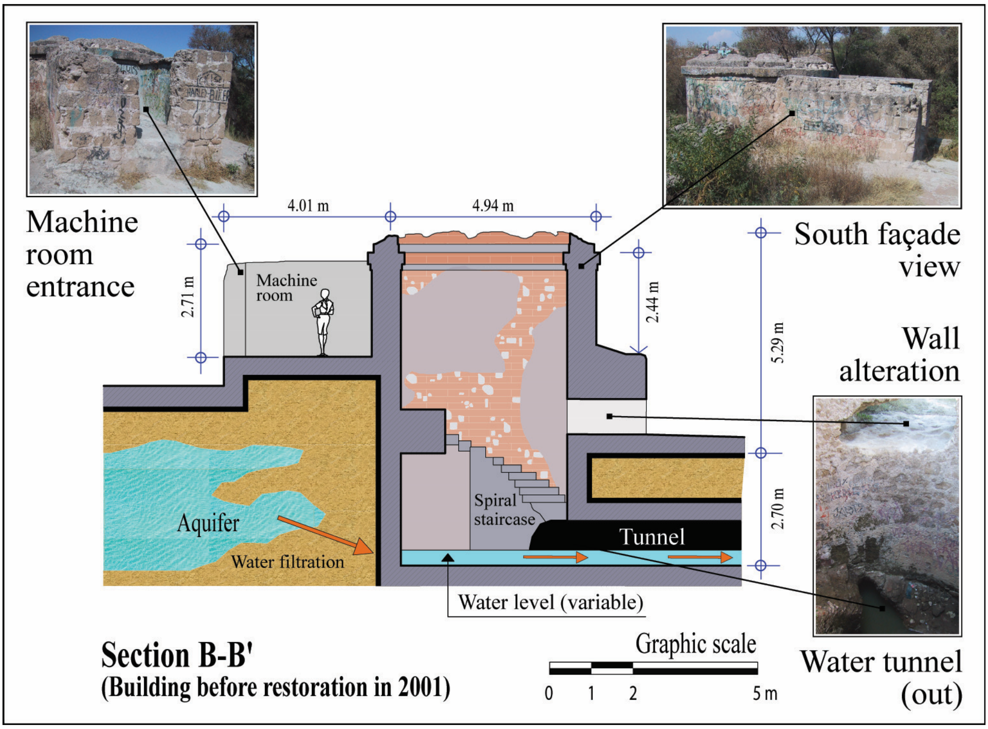

Figure 3: The *Caracol* water box. Section B-B′. *(Source: Restoration Project, photos and drawing by Alejandro Acosta Collazo originally in 2001. Drawing edition: Alejandro Acosta Colunga, August 2019.)*

In addition, the idea of building tunnels for water distribution came from Europe to Mexico since the 16th century, but it was during the late 19th century that it became more common. This was also a result of the Industrial Revolution, since it increased production processes, for example the water wheels could power mills. Lacoste says hydraulic revolution became so important that cities started to build water tanks and water tunnels from places away up yonder [5]. Moreover, the social hygiene movement helped improve urbanism at the same time. So, water tunnels became popular and also a very efficient way to maintain the water properties and temperatures similar to its natural sources. The water tunnel system became also useful during the *Cristiada* War. It was very common to use the water tunnels to escape from one place to another. The *Cristiada* War took place in Mexico from 1926 to 1929. During this war the government decided to promote a religious intolerance against people during the period of the president Plutarco Elías Calle, whom emphasized separation of church and state. So, some priests, social leaders and religious people, as well as some owners of haciendas, decided to build tunnels to communicate churches, haciendas and key houses with exits – around the city – to scape. Nowadays there's confusion between the two types of tunnels, but water tunnels used to be stone masonry tunnels. The case of *El Cedazo* tunnel had a pointed roof, masonry walls; also it was narrow – the whole way – and had a small channel on the floor.

The types of tunnels used to scape during the *Cristiada* weren't as good in construction quality as the water tunnels. The *Cristiada* tunnels were wide and high enough to make people fit – even when riding horses. Nowadays there's not a complete register of such tunnels system. The history of architecture of Aguascalientes registers that one of the most important architects at the beginning of the 20th century: Refugio Reyes drew a plan of the city of Aguascalientes including the whole tunnels system, but the plan hasn't been found in historical archives yet. The fact is that in several constructions in the city centre several tunnels entrances have been found, but none of them are well preserved. In addition, somehow different parts of the tunnels were torn down or demolished on purpose.

From the 16th century to the middle of the 19th century (before the building of *El Cedazo* tunnel) fresh water was distributed to fountains so people could pick it up and take it in wood buckets to their houses. In fact, most of the people paid water takers whom took carried water on donkeys where people needed it for a few coins.

During the 19th and 20th centuries, some farmers preferred to have donkey wheels to lift subsoil fresh water. This system was known as *norias* in Mexico. A *noria* had a rim with wood buckets. Sometimes the *norias* had an adjacent aqueduct to distribute water to the population of a city. In Guanajuato city there used to be a well-known *noria* named *Noria de Ángeles*.

4 SOCIAL DISTRIBUTION OF FRESH WATER

There was another type of fresh water distribution, based on subsoil filtration in Aguascalientes. Consequently, some water boxes were built to collect water in tanks for selling it to people. *Sandovales* historic water supply building is a good example of it. It's located in the north-western side of the city, specifically over the main aquifer in the valley of Aguascalientes state. Because of the decreasing level of water tables this type of water boxes became useless recently. It was in the middle of the 20th century when Sandovales water supply building was constructed, and the owners installed a water pump to lift subsoil water to tanks (see Section A-A′ in Fig. 4). The water used to be very clean at this place and it was coming out from a natural source. So, when the tanks were filled up the fresh water was poured in wheel tanks. At the beginning water carts were pulled by donkeys, but in 1960 the system changed to water trucks, as we can observe in Fig. 4.

A few months ago, the author of this article was hired to design a restoration project of *Sandovales* historic water supply building. One of the main problems to solve was to find out about the spatial changes from the original project, including its adaptations to newer technologies. In fact, this water box was built during the first half of the 20th century. The main changes discovered were the renewal of lines of pipes used in the water box, due to the different types of water pumps acquired by the owners after using the building for several decades.

The population of the city radically increased during the second half of the 20th century and more fresh water was required. Several companies decided to establish in the city and definitely they wanted to distribute fresh water – and also selling it – to the people. Besides *San Lorenzo* Water Company, *Sandovales* Water Company turned out to be essential in the northern part of the city as a water distributor.

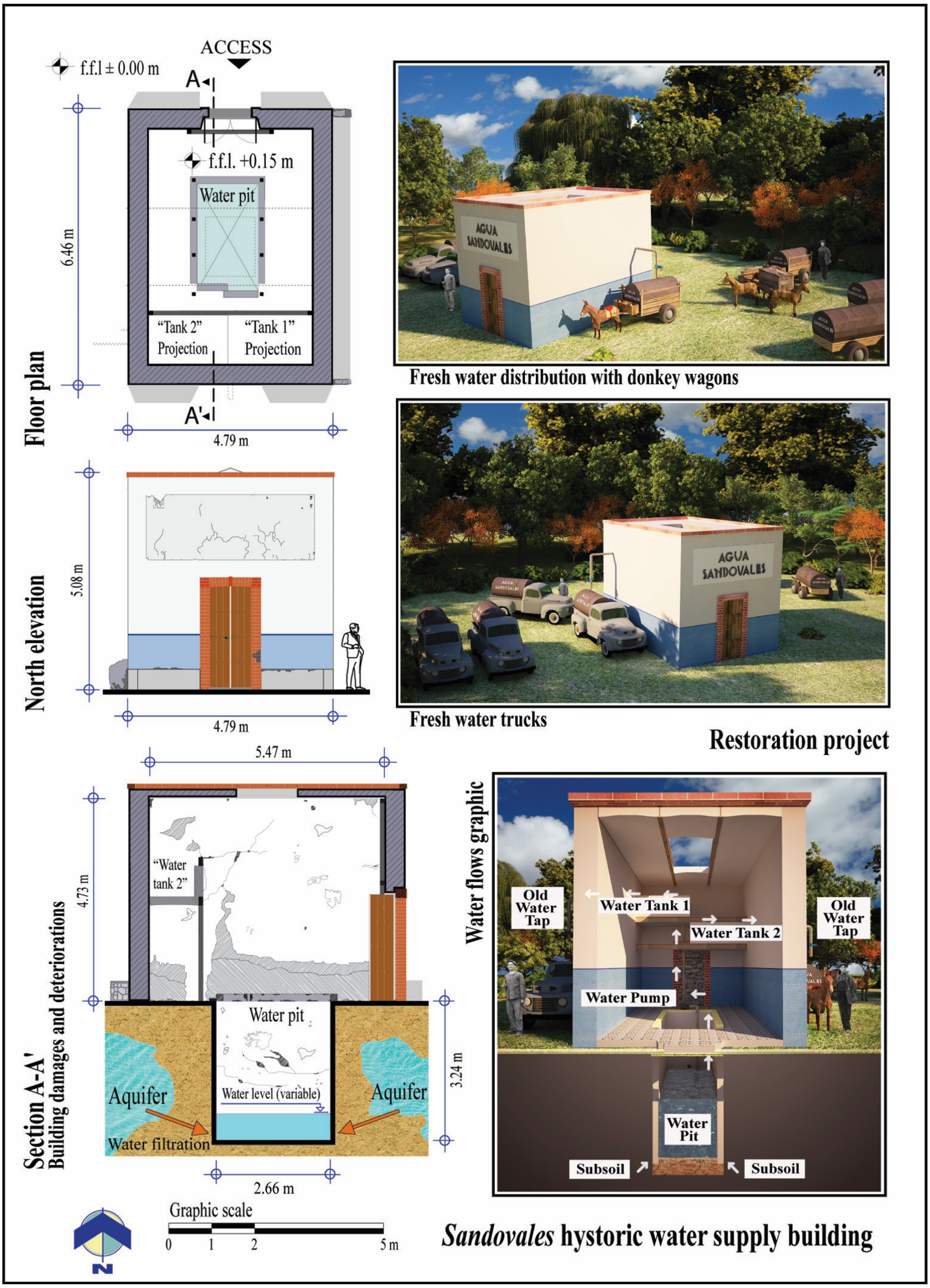

Figure 4: *Sandovales* historic water supply building in Aguascalientes, Mexico. *(Source: Drawing and renders by Alejandro Acosta Collazo, Alejandro Acosta Colunga and Fernando Jesús May Vázquez, August 2019.)*

At first, Sandovales Water Company started distributing fresh water using donkey wagons (see Fig. 4), but during the 1960s they changed them for water trucks. In fact, the water box building had somehow a small size (width = 4.79 m, length = 6.46 m) and it was 5.08 m height. But, a bigger building wasn't necessary because water was like a raw material for the company, and it was taken from the subsoil. Comparing the water boxes mentioned in this paper: *Sandovales* and *El Caracol*, we can observe similar architectural dimensions, also the way they filtered ground water, but the distribution of it was different. El Caracol had an adjacent water tunnel (*El Cedazo*), nevertheless Sandovales water box needed carts to distribute the water to the population. This is a functional response to the moment of time and the geographic place. This means at the end of 19th century motorized vehicles were limited – in quantity – in Aguascalientes. But during the second half of the 20th century they became very popular – over some other means of transportation.

In Sandovales water box the water was pumped up from the subsoil – through a water pit – and poured in tanks. Then using gravity – and through a pipe with a water tap – they filled up the tanks on donkey wagons or water trucks. Also, the time frame between the natural filling of the water pit, with a convenient level, and draining the water tanks was approximately 30 minutes. Thus, the water vehicles could leave the place every 15 minutes because the building had two water tanks and also two water taps.

Urban growth has changed quotidian life in the city since the beginning of the 20th century, but it was in the middle of the century that increasing population started causing urban problems. Population statistics specify that in the year of 1950 the population of Aguascalientes State was: 188,057 people [6], and at the end of the millennium it was close to 1,000,000 people. The biggest city in the state is Aguascalientes City and it involves 85% of Aguascalientes State population. Nowadays the city is becoming a million people city.

One of the problems of Aguascalientes growth is pollution and it has affected water quality for several decades. For example, in the year of 1994 a city trash deposit close to *Parque México* (Mexico Park) was made in the northern side of the city, but it's had a significant impact on the water table, caused by leaching, for the last 25 years. Thus, rain water passed through the trash carrying minerals to ground water. Leaching damages part of the reservoirs of Aguascalientes valley main aquifer. Tiscareño Silva also says leaching from decomposed trash could damage part of Aguascalientes Valley main aquifer due to soil subsidence [7].

Also, the water table tended to fall during the last years because of excess subsoil water extraction. This is somehow due to Aguascalientes urban growth. Thus, the more population live in the city the more fresh water is needed.

El Caracol and Sandovales water box are not functional any more as a result of changes of water table level. This means both buildings are abandoned somehow now.

For the purpose of writing this research, a surveyed was applied recently, to understand the perception of historic use of water and nowadays social distribution of fresh water. The following categories and variables were used: Age (young 13–17, adult 18–60, elderly 60+); gender (male, female); educational level (basic education, graduate, post-graduate); origin (Mexican, foreigner); trust in city's tap water (yes, no); water supply system evaluation (good service, bad service); disappearance of public drinking fountains (water system obsolescence, sanitation control procedures); conscious about *El Cedazo* water tunnel (yes, no); awareness about water distribution to old orchards (though irrigation ditches, people using water buckets, through pipelines in public streets); reasons of consuming bottled water (the water is clean, it's more practical, flavour) and reasons people don't drink tap water (the water is unclean, because of advertisements).

5 RESULTS

The lack of fresh water in several residential areas of Aguascalientes City is evident, mainly in the eastern neighbourhoods. In some cases the city hall provides only one day of water out of seven every week. *El Hidrocálido* – a local newspaper – mentions that some people collect rainwater in buckets, during rainy seasons, to use it for bathrooms [8]. This situation becomes more critical every year. Avelar González mentions that extracted water from the water tables has multiplied five times in the last 50 years, so scarcity of fresh water will become a problem to deal with, in the near future [9], especially in semi-arid lands like Aguascalientes.

Nowadays, there's a particular perception of fresh water and its social distribution that will be explained based on the survey designed for this paper.

It's important to mention that, for practical reasons, it was convenient to use only one average resulting table with 25 questionnaires. This means the final table was the average of the five surveyors' results. Thus, five surveyors applied 120 questionnaires apiece. The total amount of questionnaires was 600, during the first week of August. But, a sample of 125 questionnaires was chosen using a random method (25 questionnaires respectively). This means the final table was the average of the five surveyors' random results.

The average table (not included in this paper) was used to develop a Burt's matrix, and involves all the categories and the 26 variables of the questionnaire. In order to create the matrix shown in Table 1 a transposed matrix (not included in this paper) was done, and the result (Burt's matrix = $Z'Z$) was the average matrix times the transposed matrix.

The results demonstrated that in the category of trust in city's tap water, the people with more participation were adult females and 87% mentioned they didn't trust in city's tap water. But 48% of people with basic education also said they didn't trust in city's tap water, similarly, 36% of people (graduated) thought the same way.

In the category: Water supply system evaluation, the people who participated were basically adults (92%), and 78% of them were happy with the water system. Although some of them asked the surveyors if there was another variable (other than good service or bad service) because some of them thought the service had a more or less quality.

The awareness of people about historic water systems in the city had to do with the disappearance of public drinking fountains. 76% of people thought public drinking fountains had disappeared because of sanitation control procedures, which is in some measure correct.

In the results of the survey, the conscious about *El Cedazo* water tunnel was basically negative. Thus, 92% of the people denied understanding the presence of the historic water tunnel. Therefore, this situation should be a concern in the accomplishments of Aguascalientes preservation programs.

The classification: Awareness about water distribution to old orchards in the city, was more related to historical facts, specifically if people knew if water was distributed through irrigation ditches, or if people used water buckets in the past to flood the orchards, or the city hall used pipelines in public streets to distribute the water. 84% of the people mentioned that distribution to orchards was done through irrigation ditches.

Consuming bottled water is a concern of the author of this paper because it looks like nobody knows if tap water in the city is really clean, but bottled fresh water distribution companies say it isn't. So, 52% of the adult people said they consumed bottled water because it was clean and 40% because it's more practical. People are always in a rush, and acquiring bottled fresh water means less time consuming.

The reasons people don't drink tap water have to do with a healthy perception. Since tap water is distributed sometimes through rusty pipelines they think it's unclean. 80% of the people said the main reason for not drinking this type of water was because it's unhygienic and only 12% mentioned the reason was the advertisements.

Table 1: Data obtained from 650 questionnaires applied in public spaces of Aguascalientes City, and converted in matrixes to develop a Burt's matrix. *(Source: Author research design, August, 2019.)*

Burt's matrix = Z'Z			Age			Gender		Educational level			Origin		Trust in city's tap water		Water supply system evaluation		Disappearance of public drinking fountains		Conscious about *El Cedazo* water tunnel		Awareness about water distribution to old orchards			Reasons of consuming bottled water			Reasons people don't drink tap water	
			Young (13-17)	Adult (18-60)	Elderly (+60)	Male	Female	Basic education	Graduate	Post-graduate	Mexican	Foreigner	Yes	No	Good service	Bad service	Water system obsolescence	Sanitation control procedures	Yes	No	Through irrigation ditches	People using water buckets	Through pipelines in public streets	The water is clean	It's more practical	Flavour	The water is unclean	Because of advertisements
			a1	a2	a3	b1	b2	c1	c2	c3	d1	d2	e1	e2	f1	f2	g1	g2	h1	h2	i1	i2	i3	j1	j2	j3	k1	k2
Age	Young (13-17)	a1	2	0	0	0	2	2	0	0	2	0	1	1	1	1	1	1	0	2	2	0	0	2	0	0	1	1
	Adult (18-60)	a2	0	23	0	8	15	11	12	0	23	0	3	20	18	5	4	19	2	21	21	1	1	13	10	0	20	3
	Elderly (+60)	a3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gender	Male	b1	0	8	0	8	0	4	4	0	8	0	2	6	8	0	1	7	2	6	8	0	0	4	4	0	8	0
	Female	b2	2	15	0	0	17	9	8	0	17	0	2	15	11	6	4	13	0	17	15	1	1	11	6	0	13	4
Educational level	Basic education	c1	2	11	0	4	9	13	0	0	13	0	1	12	8	5	3	10	2	11	12	1	0	9	4	0	12	1
	Graduate	c2	0	12	0	4	8	0	12	0	12	0	3	9	11	1	2	10	0	12	11	0	1	6	6	0	9	3
	Post-graduate	c3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Origin	Mexican	d1	2	23	0	8	17	13	12	0	25	0	4	21	19	6	5	20	2	23	23	1	1	15	10	0	21	4
	Foreigner	d2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trust in city's tap water	Yes	e1	1	3	0	2	2	1	3	0	4	0	4	0	3	1	0	4	0	4	4	0	0	2	2	0	3	1
	No	e2	1	20	0	6	15	12	9	0	21	0	0	21	16	5	5	16	2	19	19	1	1	13	8	0	18	3
Water supply system evaluation	Good service	f1	1	18	0	8	11	8	11	0	19	0	3	16	19	0	3	16	2	17	19	0	0	9	10	0	15	4
	Bad service	f2	1	5	0	0	6	5	1	0	6	0	1	5	0	6	2	4	0	6	4	1	1	6	0	0	6	0
Disappearance of public drinking fountains	Water system obsolescence	g1	1	4	0	1	4	3	2	0	5	0	0	5	3	2	5	0	0	5	4	1	0	4	1	0	3	2
	Sanitation control procedures	g2	1	19	0	7	13	10	10	0	20	0	4	16	16	4	0	20	2	18	19	0	1	11	9	0	18	2
Conscious about El Cedazo water tunnel	Yes	h1	0	2	0	2	0	2	0	0	2	0	0	2	2	0	0	2	2	0	2	0	0	1	1	0	2	0
	No	h2	2	21	0	6	17	11	12	0	23	0	4	19	17	6	5	18	0	23	21	1	1	14	9	0	19	4
Awareness about water distribution to old orchards	Through irrigation ditches	i1	2	21	0	8	15	12	11	0	23	0	4	19	19	4	4	19	2	21	23	0	0	13	10	0	19	4
	People using water buckets	i2	0	1	0	0	1	1	0	0	1	0	0	1	0	1	1	0	0	1	0	1	0	1	0	0	1	0
	Through pipelines in public streets	i3	0	1	0	0	1	0	1	0	1	0	0	1	0	1	0	1	0	1	0	0	1	1	0	0	1	0
Reasons of consuming bottled water	The water is clean	j1	2	13	0	4	11	9	6	0	15	0	2	13	9	6	4	11	1	14	13	1	1	15	0	0	13	2
	It's more practical	j2	0	10	0	4	6	4	6	0	10	0	2	8	10	0	1	9	1	9	10	0	0	0	10	0	8	2
	Flavour	j3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Reasons people don't drink tap water	The water is unclean	k1	1	20	0	8	13	12	9	0	21	0	3	18	15	6	3	18	2	19	19	1	1	13	8	0	21	0
	Because of advertisements	k2	1	3	0	0	4	1	3	0	4	0	1	3	4	0	2	2	0	4	4	0	0	2	2	0	0	4

6 DISCUSSION

The water supply buildings shown in this paper were in harmony between water distribution and built forms; also they were good examples of Viceroyalty water boxes in Mexico. But social water distribution has changed in the last decades and people have forgotten what water historic buildings were made for. People now are more worried if there's no water from pipelines. Also, watching TV has changed the perceptions of people, specifically on the way we have to consume products like bottled fresh water.

After analysing the results of the survey applied for this paper, we can observe that most of the people don't trust in city's tap water, so they prefer to drink bottled water. Similarly, a couple of tourists – in a Mexican tourist group – mentioned they preferred bottled fresh water and mentioned, in their countries, every once in a while, they had watched advertisements saying "don't drink the water in Mexico". In addition, even more educated people in Mexico don't trust in tap water, accordingly with the foreigners' perception.

Even though a company administrates social ground water distribution – by pipelines in streets – it was demonstrated in the survey that most of the adult people (78%) think they get a good service.

The answers about water distribution to old orchards in general were reasonable. This means people are aware of this type of water distribution. In fact, nowadays irrigation in the countryside is still through water ditches.

Even though city orchards are disappearing due to urban growth they used to be an essential aspect of the city image during the 19th century and in the early 20th century.

The correspondence analysis allows a comparison among all variables resulting in interesting discussions. For example, a few people think that nowadays water supply system is good, and also think disappearance of public drinking fountains had to do with water system obsolescence. This means they prefer to practice renovation beliefs over a preservation culture.

7 CONCLUSIONS

History of ground water distribution is related to historical thermal water distribution in Aguascalientes (a hot waters city). De Groot says that it seems that historians wish to mark history out, to control and boundarise it, but it is in the transformations and transgressions of the historical that culture's desires, innermost workings, and underlying assumptions might be seen [10], so describing history of unique buildings should be related to scientific basis. This is the case of *El Caracol* or *Sandovales* water boxes, and the restoration projects made to understand the original spatial functions of the buildings.

There's still job to do, registering and drawing the complete tunnels system in Aguascalientes. Also preservationists should prevail over renewal ideas about historical buildings.

Also, the survey and the qualitative statistical method used in this paper (Burt's matrix) showed interesting results. For example, in the category: Water supply system evaluation, most of the people who participated in the survey were happy with the water system currently. This result was a surprise, due to the negative perception of local news.

It was remarked in this article – through research – that historic water boxes didn't function anymore because of nowadays low level water tables, and because of subsidence problems. So it looks like we – as researchers – need to share this type of knowledge among society. Accordingly, science could contribute to veracity of press news as long as they consult science. This means there should be more interaction between news and science.

In addition, the fresh water companies have changed the perception of tap water quality in Mexico for the last two decades. Most people had an embracing image about bottled water, especially if global enterprises distributed it.

Besides, in Mexico we have a problem with sugary drinks, because most of the people drink them to hydrate. This is common in young and adult people. For example, it's usual that construction workers drink sugary drinks instead of water, this means about half a gallon a day. Then it becomes a healthy problem, so obesity and diabetics are very excessive in Mexican population.

Education (public or private) should contribute to understand the use of water and the consequences of consuming sugary drinks or bottled water. Also, science and ethical news could help with it. Additionally, subjects about sustainability should be included in schools in order to understand the way we have historically used water, and what we are doing with it nowadays.

Finally, water is a common element that connects species throughout millenniums, including prehistoric and the whole history of human beings, and there's still a lot to do in order to preserve it.

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GROUNDWATER MOBILE APP DEVELOPMENT TO ENGAGE CITIZEN SCIENCE

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ABSTRACT

Public domain borehole information in South Africa is generally stored in the National Groundwater Archive (NGA) and the Groundwater Resources Information Project (GRIP) databases of which both are centralized databases. The GRIP database is updated by the Department of Water and Sanitation, but only covers one of the nine provinces. The NGA on the other hand covers the entire country, however there is a backlog of borehole information that needs to be captured, and it has limited time series data. The reason for the poor time series data is twofold: (i) groundwater monitoring is expensive due to the distributed nature of the resource (the NGA consists of approximately 280,000 boreholes over an area of 1,225,986 km^2); and (ii) consultants tend not to upload data to the national databases as the data is seen as a competitive advantage. During the recent drought experienced in the Western Cape Province (2015–2018), citizens of local communities took to social media, reporting on rainfall and groundwater levels within their communities. With the dams drying up people started targeting groundwater with approximately 30,000 boreholes being drilled. This led to the development of a mobile app for both citizens and groundwater professionals. This app allows logging of borehole information via smart phones. One of the main challenges with populating databases is the verification of data. The mobile app introduces a type of block chain approach where all data is accepted, but marked as low confidence until verified by a trusted user. The vision for the app is a "live" hydro census and even if only water levels are captured, it would improve groundwater management by applying data mining techniques for trend analysis in future.

Keywords: citizen science, borehole database, mobile app.

1 INTRODUCTION

Public domain borehole information in South Africa is generally stored in the National Groundwater Archive (NGA) and the Groundwater Resources Information Project (GRIP) database of which both are centralized databases. The Limpopo GRIP database is regularly updated by means of a term contract set up by the Department of Water and Sanitation (DWS). The NGA is known for a backlog of borehole information that still needs to be captured and the GRIP database should ultimately also form part of this database.

The NGA database relies on users to upload captured borehole information to the database, but this is not happening for various reasons. The flow of data for the current situation is depicted in Fig. 1, where the partially filled arrows refer to the partial transfer of data. The partial transfer of data between the NGA and GRIP databases relates to the reluctance of users to transfer data for the following reasons:

- The GRIP users and administrators want to keep the GRIP database separate and don't want merging of data with the NGA due to the fact that they perceive the NGA data to be substandard.
- Third parties are reluctant to upload data, due to the fact that data has monetary value and if a person has a dataset which someone else does not, it is to that person's advantage.

The partial data transfer between the NGA and the users is mainly due to system and institutional constraints from the DWS. System constraints refer to the capability of the

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system to automatically send all query results to the users. Chemistry related queries are performed by a person rather than the system and users don't always get a response when querying chemistry data. Institutional constraints refer to backlogs that exist due to not having enough capacity to capture data. The combined borehole distribution of the NGA and GRIP databases is presented in Fig. 2.

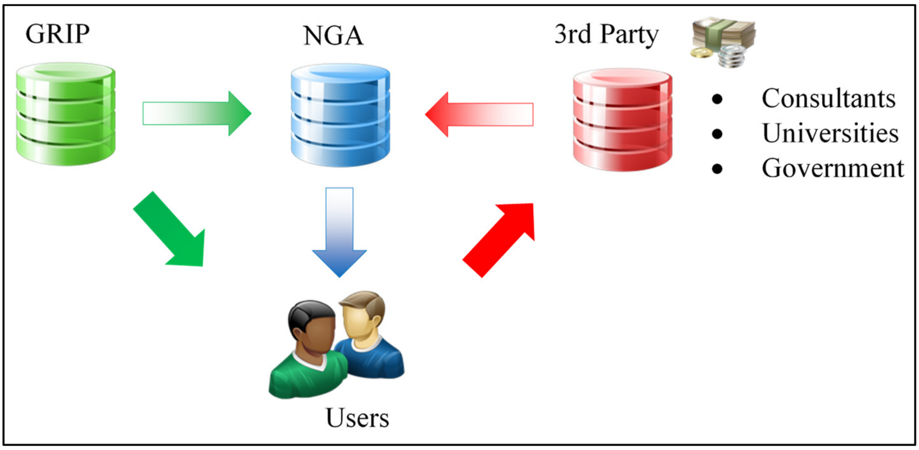

Figure 1: Current data flow between entities.

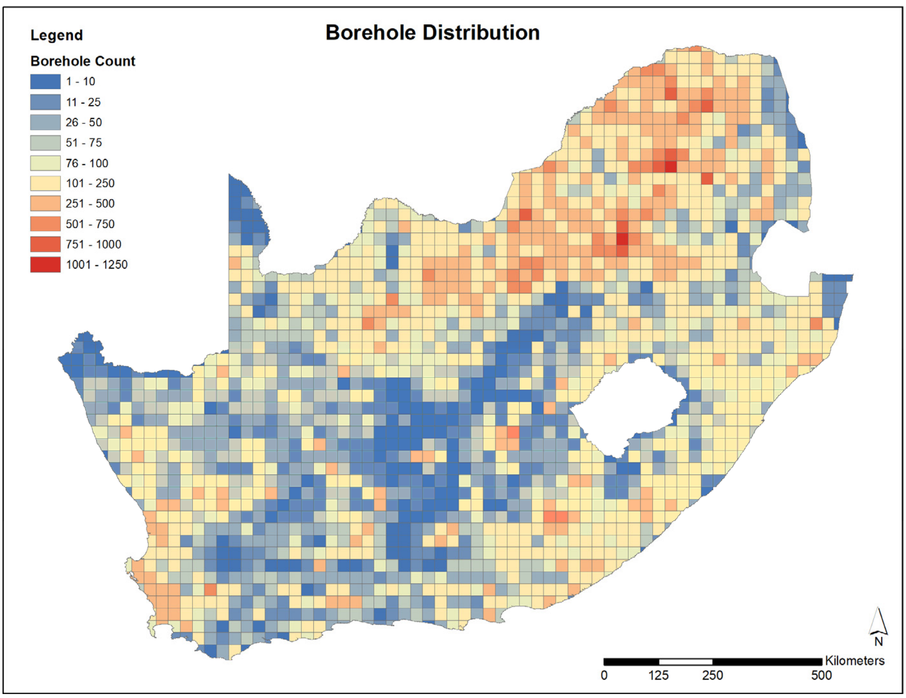

Figure 2: Borehole distribution of the NGA and GRIP databases [9].

2 CITIZEN SCIENCE

Citizen science is defined by the Oxford dictionary as the collection and analysis of data relating to the natural world by members of the general public, typically as part of a collaborative project with professional scientists. Other aliases for "citizen science" include "amateur science", "crowd sourced science", "volunteer monitoring" and "public participation in scientific research" [1].

2.1 Background

Some of the first citizen science projects started with bird counts in the early twentieth century [2]. The phrase "citizen science" itself was coined in the mid-1990s. Irwin, a sociologist, defined it both as "science which assists the needs and concerns of citizens" and as "a form of science developed and enacted by the citizens themselves" [2]. From Irwin's definitions it is clear that the citizens should have vested interest in the relevant project.

2.2 The smartphone era

With the advent of mobile communication technologies such as smartphones, citizen science has become increasingly popular. Apple opened the door to this disruptive technology at the time in 2007, with the launch of the iPhone. Consumers and scientists alike, embraced this new technology and today a world without smartphones is unimaginable. The worlds of scientists and citizen science are now converging, with scientists harnessing the power of citizen science with newer and smarter technologies [3].

The fact that a smartphone can take a photo and associate a global positioning system (GPS) coordinate and a time stamp with it allows for the collection of both spatial and temporal data, which prove invaluable in many scientific fields especially in the environmental sciences. Current day smartphones phones have an array of onboard sensors that can be used in various applications. Newer Japanese models are even fitted with radiation detection sensor [3]. Scientist are continuously developing new techniques to harness the power of the onboard sensors.

Concerns regarding the use of technology in citizen science projects have also been raised. Not all groups have access to this type of technology and therefore are excluded. The steadily increasing number of smartphone apps can also prove overwhelming for users unfamiliar with these tools [4].

2.3 Suitability and success factors

Both the suitability of the project and success factors should be considered when embarking on a citizen science project. Six broad areas to review the suitability [5] is presented in Fig. 3 and the associated questions to be answered for each of these areas is given in Table 1.

In addition to the six broad areas defined a decision framework [5] exists to evaluate each considered project in terms of its potential to succeed as a citizen science project. The decision framework considers basic questions like online surveys, safety in making observations, are sensors required and the spatial scale of the project. Once these questions have been answered, the decision framework categorizes the project based on spatial and temporal requirements. Lastly, for each type of category, questions regarding access to sites, site types and protocols result in the final recommendation regarding potential of the project.

Six success factors for citizen science were identified by Pocock et al. [5] and are depicted in Fig. 4. Although the aforementioned work was focused on coastal and ocean research, these principles are generic and applicable to all citizen science efforts. Most of these factors are interrelated at some level as illustrated in the short discussion that follows.

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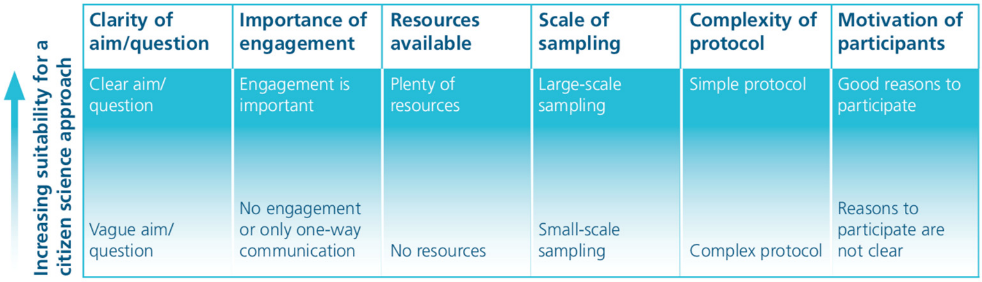

Figure 3: Suitability criteria for a citizen science project [5].

Table 1: Questions asked with respect to suitability criteria [5].

Suitability criteria	Typical question to be answered
Clarity of the aim	Do you have a precise and clearly-defined aim for your citizen science project?
Importance of engagement	Can you extend your engagement activity into meaningful and relevant citizen science or should you simply undertake excellent engagement for its own sake?
Resources available	Do you have sufficient resources available to ensure you can support your volunteers for the entirety of the project?
Scale of sampling	Do you need many people (or volunteer time or commitment) to achieve your aims?
Complexity of the protocol	Is your protocol practical for volunteer involvement? Are you expecting too much from the volunteers?
Motivations of participants	Does your project resonate with potential volunteers, and are there clear and appropriate triggers for people to make records?

Figure 4: Factors of success in citizen science [4].

First and foremost, clear goals should be set for the project. Keep the project focussed and avoid the "big bang" approach, where it is attempted to collect all possible types of data just because it can be done. This in turn relates to the engagement of citizens – if the collection process is long and tedious, people will lose interest.

Reliable data is a prerequisite for an improved database and an improved database will contribute to the science through proper analysis of the acquired data. Data quality and verification underpin reliable data and most data quality problems can be addressed if they are properly anticipated. The simplest measure is training and communication to the network of people participating in the data collection.

2.4 Growth in citizen science

Significant growth of the citizen science projects has been recorded over the last decade (Fig. 5) as indicated by the SciStarter [1] repository, which keeps track of citizen science projects. The field of citizen science is largely decentralized, which makes the tracking of these projects difficult [2]. Some academics fear that the public is getting fatigued by all the options, and noted that participation in some projects has declined [2].

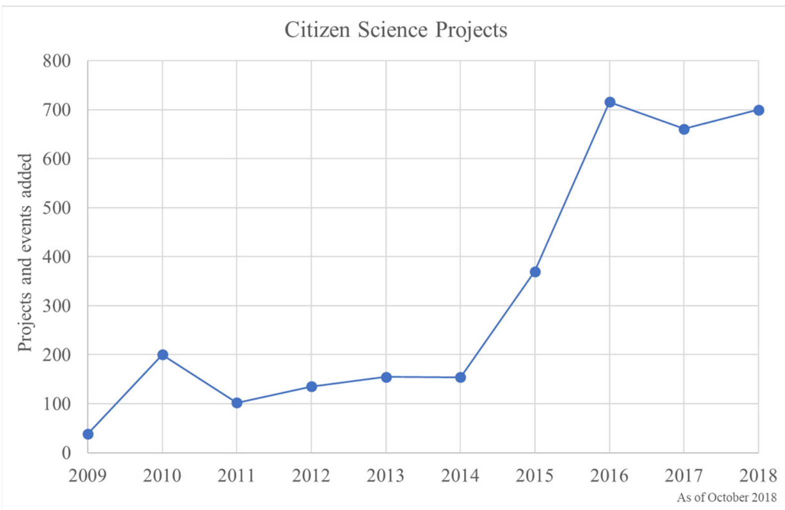

Figure 5: Factors of success in citizen science. *(Source: Adapted from Garcia-Soto et al. [4].)*

3 HUMAN BEHAVIOUR DURING A WATER CRISES

3.1 Setting the scene

In 2018, the City of Cape Town experienced its worst drought in over a century. The historic dam levels from 2016 are presented in Fig. 6. The water crisis peaked during mid-2017 to mid-2018 where water levels hovered between 15 to 30% of total dam capacity. In late 2017, the first mentions of plans for "Day Zero" were made (indicated as the estimated cut-off level in Fig. 6), a shorthand reference for the day when the demand for water to meet essential needs exceeds the supply [6].

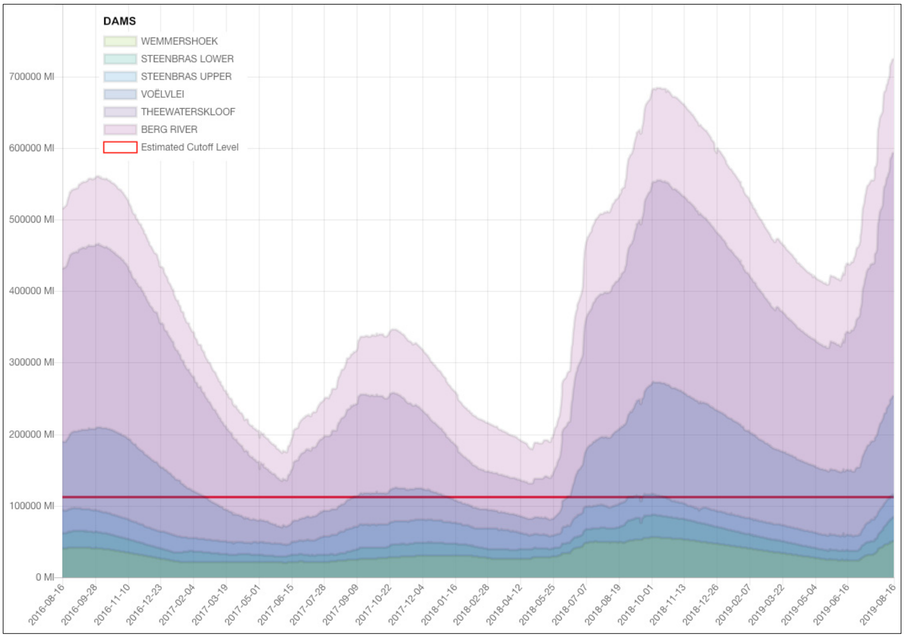

Figure 6: Historical dam levels for the Cape Town region in South Africa [8].

"Day Zero" would herald the start of Level 7 water restrictions, where municipal water supplies would largely be switched off and residents would have to queue for their daily ration of water, making the City of Cape Town the first major city in the world to potentially run out of water [7].

3.2 Response to water crises

During the ongoing drought people resorted to groundwater as a source of water. This resulted in an estimated 30,000 boreholes being drilled in and around the Cape Town. In general, a water use license is required for water use in South Africa under the National Water Act (No. 36 of 1998). However, the water law makes provision for water-use that is termed "Schedule 1" use. Schedule 1 water uses are generally low-volume, low-impact activities that are consistent with domestic use, livestock watering, recreational use and the use of water for emergencies.

This water use is permissible and does not require licensing or registration. The concern from a water management point of view is the question: Is 30,000 boreholes in close proximity to each other still a low-impact activity? A further concern is that since no licensing and registration is required for Schedule 1 water-use, the positions of the majority of these boreholes will not be known, unless the drilling contractors and consultants provide this information to the authorities.

3.3 Water status reporting on social media platforms

As people were affected more and more by the water shortage, they took to social media platforms and started reporting rainfall and to a lesser extent water levels in the areas where they lived. The data resolution obtained in certain areas were astonishing – people had a vested interest to report on the status of water as this could assist in management.

The problem with social media platforms is that the data is highly distributed and is cumbersome to collate for management purposes. This response from the public sparked the development of a borehole mobile app to assist with borehole identification and monitoring to enable better water management in future. The following quote from John Thorson never held truer than during the time of drought:

> *"Water links us to our neighbour in a way more profound and complex than any other."*

4 BOREHOLE DATA CHALLENGES

Some inherent challenges exist with respect to the existing borehole data and the borehole entity itself when it comes to measurements.

4.1 Current status of national borehole databases

The summary statistics of the national borehole databases is presented in Table 2 and the spatial distribution is shown in Fig. 2. It should be noted that the parameters presented in Table 2 is an abbreviated list of parameters available in these databases. The following observations are made from Table 2:

- 46% of boreholes have one or more water level;
- 14% of boreholes have one or more electrical conductivity (EC) measurements;
- 6% of boreholes have one or more chemistry datasets;
- 28% of boreholes have yield values;
- 38% of boreholes have water strike data;
- 50% of boreholes have borehole logs.

Table 2: Summary statistics of national borehole databases [9].

Count	Description	NGA	GRIP
Borehole	Total borehole count in each database. Roughly 11% of the GRIP boreholes are also present in the NGA database.	276,333	26,912
Water level	The number of boreholes that have one or more water levels associated with it.	129,615	10,333
Electrical conductivity	The number of boreholes that have one or more EC measurements	33,153	7,884
Chemistry (major anions and cations)	The number of boreholes that have one or more chemistry analysis associated with it (2008 data as no new chemistry data could be obtained).	12,173	7,050
Yield	The number of boreholes that have one or more yield values associated with water strikes.	75,327	10,002
Water strikes	The number of boreholes with one or more water strikes associated with it.	112,880	2,386
Borehole logs	Total number of boreholes with a borehole log.	147,837	3,403

It is clear that these databases are sparsely populated and have poor temporal data (not presented here). Monitoring programmes are expensive to operate and the majority of boreholes are located in rural areas, as these are used for water supply where no surface water infrastructure exists.

The DWS in South Africa does have a dedicated borehole monitoring network that collects long-term borehole data, but these monitoring points only make up a fraction of the total number of boreholes and were chosen as "representative" points of various aquifers in South Africa. Groundwater data is however highly variable over short distances, making the selection of representative points an impossible task.

4.2 Borehole localities

Although military development of the GPS started in the late 1950s, GPS technology only became available to the public in the 1990s. The borehole positions captured in the NGA before GPS availability was done by assigning the borehole to the relevant farm or plot centroid. The result of this, is that a few of the 276,333 records will be located in the field as the associated coordinate is the farm or plot centroid. It is therefore not uncommon to obtain multiple boreholes assigned to the same position (Fig. 7), with a small offset to prevent duplicate coordinate positions in the database.

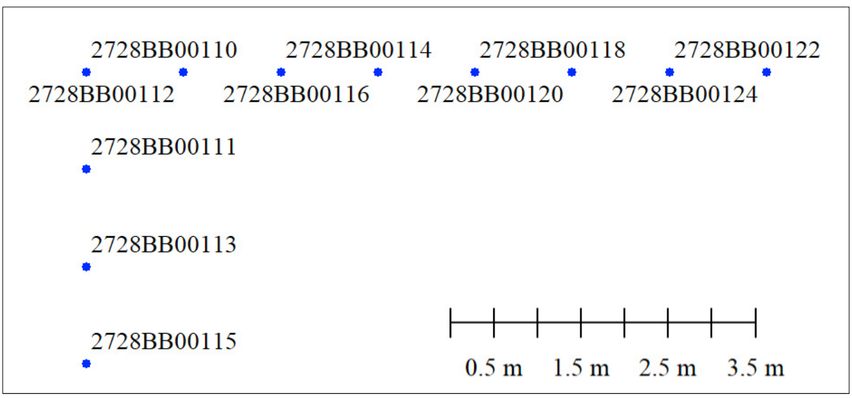

Figure 7: Boreholes with offset to prevent duplicate coordinates.

Unfortunately, the fact of the matter is that some of the boreholes present in the NGA, will never be located. This does not mean that these boreholes should be removed, as associated data like geological logs do provide information on the surrounding area even though the exact position is unknown.

4.3 Borehole parameters

From a citizen science point of view, to identify a borehole position and take a photo is elementary. However, borehole measurements require specific equipment and training. The solution to this challenge is to present the public with selection lists to give an indication of the status of the borehole if they are not equipped to perform proper measurements. The critical data captured remains the borehole locality, so that the position is known and the site can be revisited in future to carry out proper measurements.

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5 METHODOLOGY

The methodology consists of evaluation of the project in terms of its suitability as a citizen science project and the selection of an appropriate platform for the development.

5.1 Evaluate the suitability and potential

The project potential as citizen science project, was evaluated by applying the suitability criteria and decision framework described by Pocock et al. [5]. The aforementioned is no guarantee to success of the final project, but merely provides guidance to success factors to be considered based on lessons learnt from other citizen science projects.

5.2 Software solution

The decision between custom software development and an off-the-shelf solution, is one that could be detrimental to the success of the project. Both these approaches have pros and cons to be considered. Table 3 provides a comparison of the key features to be considered in the context of the aforementioned solution types.

Table 3: Comparison of custom development vs. off-the-shelf software solution.

Feature	Custom development	Off-the-shelf solution
Cost and time	Generally, cost more and development time is longer.	Cheaper in comparison to new software development, but at the cost of functionality.
Maintenance	Done by developer or 3rd party if source code is available.	Maintenance generally done by seller and included in licensing.
Solution maturity	New software is subjected to testing and teething problems with new developments is common.	Generally, a stable solution as it has already matured over time.
Operating system compatibility	As operating systems change on target devices, the developer or 3rd party needs to ensure compatibility. This could also be part of product maintenance and updates.	From a commercial product point of view, this will form part of the product life cycle and likely be included in the maintenance.

When considering the comparison in Table 3, the ESRI App Studio® for ArcGIS® is consider a favourable solution, for the following reasons:

- GIS is ESRI's core business and App Studio® allows mobile development that integrate directly with existing data and maps.
- App Studio® provides the ability to build a 100% custom app, use templates or use existing apps e.g. Survey123 to be modified according to the developer's specification by the use of an extensive library with tested source code, which dramatically reduces development time.
- App Studio® further allows the deployment of the app to multiple mobile (and desktop) operating systems, making use of a single code base.

The proposed development platform has obvious advantages that relate to the success of the project, but the six success factors presented by Garcia-Soto et al. [4] should form the cornerstone of the design and implementation as far as possible.

5.3 Online database

The mobile app will require an online database to present users with existing borehole positions and related data. The ESRI solution already provides this functionality and facilitates seamless integration with the App Studio® solution. Both the GRIP and NGA databases form the basis of the online borehole database as these databases, even though poorly populated in certain respects, form a good basis to start from.

6 RESULTS AND DISCUSSION

6.1 Suitability and project potential

The suitability of the project for citizen science was evaluated making use of the criteria described by Pocock et al. [5] and the evaluation results are presented in Table 4.

Table 4: Suitability criteria.

Criteria	Suitability
Clarity of the aim	☺
Importance of engagement	☺
Resources available	😐
Scale of sampling	☺
Complexity of the protocol	☺
Motivations of participants	😐

The results for resources and participant motivation warrant some explanation:

- Resources available – since an online database is used, there are certain costs associated with storage and use. Currently the development of the application is done within the realm of an academic license of a university. The development costs associated with the ESRI products used (App Studio® and ArcGIS® Online) are covered by an academic license. With the final release of the product a custodian needs to be appointed which will assume the responsibility of system, associated maintenance and license costs.
- Motivations of participants – the challenge with a borehole is that special equipment is required for measurements. The public, however, have the ability to obtain the GPS location, take a photo and answer some basic questions in the form of selection lists. The project will resonate with the general public for typical reasons like a sense of jeopardy ("my water resources are under threat") or being part of a narrative ("I'm taking part with others"). In contrast to the public participants, professional participants will gain the most value from the project and motivation is a non-issue.

The project potential as citizen science project was also evaluated by applying the decision framework suggested by Pocock et al. [5]. The evaluation of the project potential was done considering only the general public, with no measuring equipment. The result indicated that the project has very good potential for a mass participation citizen science approach.

6.2 Implementation of mobile app

The high-level implementation design of the mobile app is depicted in Fig. 8 and two user types are distinguished in the design namely "general public" and "professionals". The major distinction between these two user types is the ability to perform proper borehole measurements. All available data capture fields are visible to users. Users registered as professionals will be able to capture all fields as opposed to the general public users who is only presented with the ability to enter data through selection lists to determine the status of the borehole. The latter is implemented, not to overwhelm the general public users to keep their interest in locating boreholes.

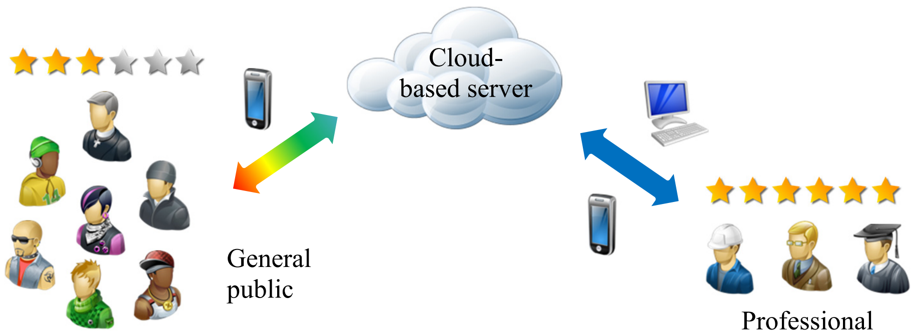


Figure 8: High level implementation of mobile app.

Reliable data which relates to an improved database are two of the identified success factors. The app implements the functionality where users verifies each other's data. Each user is issued a user rating with registration and is issued a one-star rating. Data captured by a one-star user implies the data is low confidence until verified by a user of a higher rating. Multiple verifications lead to an increase of the star rating of a particular user.

One of the challenges of the existing NGA database is that users query the database, but seldom upload newly acquired data, due to the fact that the data has monetary value and they see this a competitive advantage in the groundwater industry when it comes to tenders.

The premise of the mobile app system is that only users who contribute to the database will have access to bulk downloads of data. This process is managed by means of a virtual credit system which is transparent to the users. Each user receives a number of credits during data update transactions and these credits are exchanged for download transactions. The credits have no monetary value, but rather transactional value.

A summary of how the success factors specified by Garcia-Soto et al. [4] were implemented or considered is presented in Table 5.

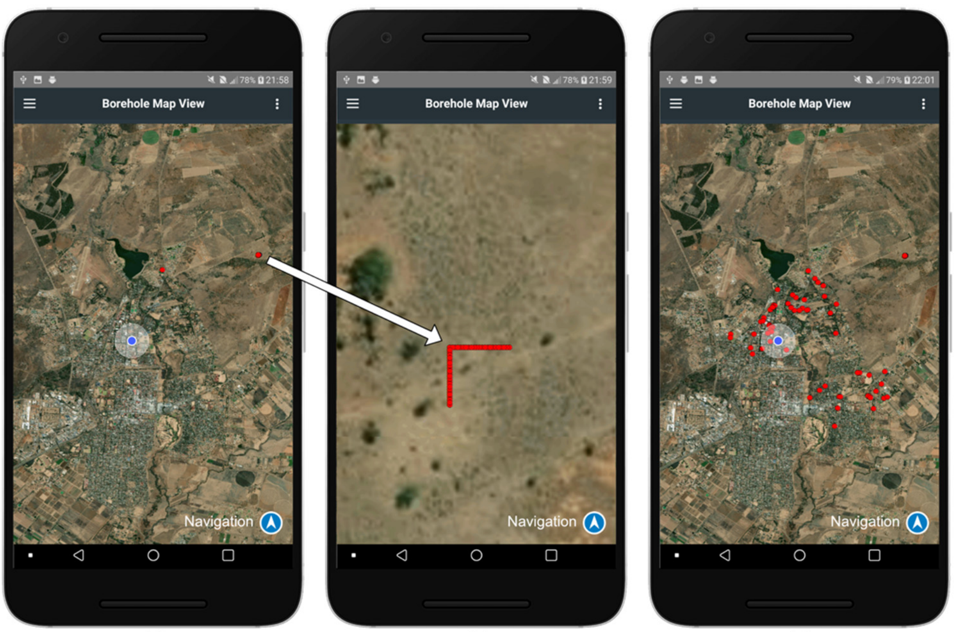
6.3 Pilot study area

The mobile app was tested on a pilot study area (Potchefstroom, South Africa), by making it available to people interested in participating. The user group consisted of ordinary citizens living in Potchefstroom, university students and a local environmental consultant.

At the start of the pilot, the available data from the online database (mainly NGA data as GRIP does not apply to the study area) amounted to 46 boreholes. The spatial distribution of

Table 5: Summary of success factors considered.

Success factor	Implementation/consideration
Clear goal	Determine borehole localities regardless if other borehole parameters can be measured by specific user.
Engagement of citizens	Engagement of geohydrologists is a non-issue, however, to keep the general public interested, outside the realm of a water crises, rely on factors like being part of a narrative: "I'm taking part with others".
Reliable data	Data verification is achieved by users, for users through a rating scheme.
Improved database	By capturing actual borehole positions and associated data will result in an improved database.
Contribute to science	An improved database with both spatial and temporal data will support future data mining for trend analysis to be used in management.
Good communication	Training of users is funded by the Water Research Commission of South Africa – Project K5/2827.

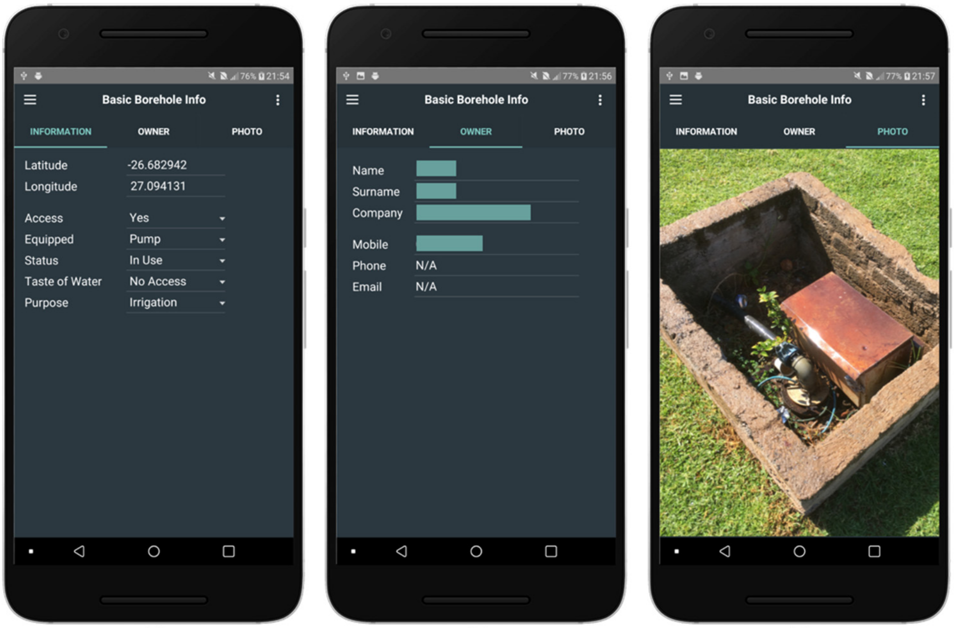


(a) (b) (c)

Figure 9: Map view of pilot study area. (a) Boreholes before pilot study; (b) Boreholes assigned to same location; and (c) Status at time of publication.

these 46 boreholes are shown in Fig. 9(a) and 9(b) respectively, and it is clear that the majority of the boreholes were historically assigned to the farm centroid at the time.

At the time of the publication and additional 63 borehole positions were recorded which totals 109 boreholes in the area as shown in Fig. 9(c). The borehole additions from the



(a) (b) (c)

Figure 10: Basic borehole information. (a) Locality and status; (b) Owner; and (c) Photo.

different users were 33 from the general public, 19 from the student group and 11 from the local consultant. None of the existing boreholes (before commencement of the pilot study) were verified by any of the participating users. The consultant provided water level readings where the boreholes were not equipped. The general public users together with the student group only provided basic information as shown in the example shown in Fig. 10.

As mentioned earlier, even if only the borehole position can be verified, it is considered valuable information since locating a borehole in the field for hydro-census purposes is time consuming. Once the localities are known, professional users can carry out proper measurements to be used for management purposes and all users contributing to the database have access to this information.

7 CONCLUSIONS AND RECOMMENDATIONS

Both the assessment of the suitability and project potential were considered favourable, before the commencement of the actual software design. By choosing the App Studio® mobile application development environment from ESRI, a geo-enabled cross-platform native application could be built from a single code base.

The results from testing the app in a pilot study area, showed that borehole positions nearly doubled from what was on the existing database and 52% of these added borehole positions came from the general public. When considering the exiting boreholes before the pilot study, 96% of the boreholes were assigned to the same locality, making it impossible to locate them in the field. By having the public identify boreholes not in the database, could result in consolidating the "new" position with that of a "misplaced" borehole if enough information can be gathered to support this association. This however was not the case with the pilot study. The pilot study is considered a success when considering the addition of new borehole localities that is verifiable in the field.

It is recommended to also include rainfall monitoring in the app as farmers in South Africa tend to keep meticulous rainfall records as their livelihoods depend on this.

ACKNOWLEDGEMENT

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STORED WATER QUALITY IN HOUSEHOLD ROOF TANKS OF VILLAS IN SELECTED AREAS OF SHARJAH, UNITED ARAB EMIRATES

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ABSTRACT

Water quality control is crucial throughout its supply, distribution, and storage to safeguard consumers and mitigate the spread of water associated diseases. The aim of the current study is to comprehensively assess water quality in private villa household water storage tanks in random areas of Sharjah, United Arab Emirates. The study explores the variation in physico-chemical, as well as microbiological, water quality parameters, the factors contributing to the quality of stored water, as well as the most common water tank cleaning practices by the owners. Forty-four water samples were collected from water storage tanks, and analyzed for a variety of water quality parameters. Results demonstrate that overall physico-chemical quality of stored water is acceptable except for operational parameters such as electrical conductivity and chlorides in 50% of investigated samples; yet, such parameters do not pose major health hazards. However, residual chlorine levels were below minimum requirements set by water quality authorities in 93% of the samples, which may pose a risk of water re-contamination. The microbiological quality was satisfactory in terms of total coliforms yet total bacterial counts and occasional presence of fungi and molds suggest poor hygienic conditions and highlight the need for tank cleaning. Household water tank owners rarely clean their tanks thus it is highly recommended to promote such measures and educate tank owners about the importance of regular tank cleaning and maintenance.

Keywords: water quality assessment, water storage tanks, water guidelines, United Arab Emirates.

1 INTRODUCTION

Water-related diseases are considered to be a major cause of global morbidity and mortality as more than 3.4 million people die annually from such diseases, and most of the sufferers are children [1]. Absent, inadequate, or inappropriately managed water and sanitation services expose individuals to preventable health risks. Thus, safe drinking water is a necessity and it can be achieved only if it is well controlled throughout all its phases of supply, distribution, storage, and end use.

Various researchers studied previously water quality in water storage tanks and highlighted the importance of tank cleaning and maintenance. In Nyankpala, Ghana, 120 water samples were collected and analyzed from different types of water storage tanks. Generally, the physico-chemical quality of stored water was good since parameters measured well with World Health Organization (WHO) recommended limits. However, color, turbidity, and total iron levels recorded in stored water in metallic containers were higher than WHO drinking water guidelines. Also, stored water analyzed from all types of storage facilities recorded coliform bacteria, probably resulting from unhygienic water-handling practices as such containers were rarely cleaned and were unprotected from faecal contamination. Water stored in earthen pots recorded the lowest level of coliform bacteria (total coliform (TC) 0–315 CFU/100 mL, faecal coliform (FC) 0–78 CFU/100 mL) while

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water stored in polyethylene tanks recorded highest levels of coliform bacteria (TC 0–714 CFU/100 mL, FC 0–250 CFU/100 mL) [2].

Another water quality study of household storage tanks was conducted in Tiquipaya, Bolivia. No significant difference in physical and chemical water quality between polyethylene, fiberglass and cement water storage tanks were noted but there was a difference in microbial *E. Coli* contamination ($p = 0.082$). This was possibly linked to the black color of polyethylene tanks which increased water temperatures to 33.7°C compared to temperatures ranging between 20–23°C for other tanks. Also, tank age was found not altering water quality; however, cleaning frequency may have contributions to microbial water quality [3].

Several sources of water from household storage tanks were also investigated in Gaza Strip. The presence of biological contamination was detectable in 75.7% of water storage tanks. With reference to chemical investigations, pH was mostly below the acceptable level, with values ranging from 4.4 to 6.3 [4]. Furthermore, 100 water samples were collected and analyzed for major anions, cations, and heavy metals to assess the effect of the residential storage tanks on the quality of drinking water in Al-Karak Province, Jordan. Results showed higher ionic concentrations in comparison to source waters which could be due to the hot and dusty summers in the region. Increased levels of heavy metals were also found in the drinking water [5]. A study conducted in the unincorporated neighborhoods in El Paso County, Texas revealed low chlorine levels and high bacteriological contamination in drinking water storage tanks due to the improper maintenance measures. The study encouraged educating such communities about proper storage of drinking water as well as about the risks of unsafe water use [6]. Another study was conducted by Sule et al. [7] to assess the physiochemical and bacteriological quality of household water storage tanks in Ilorin, Nigeria. As the sources for each water storage tank were different (municipal water, wells, borehole) the results varied as well. For instance, pH readings varied from 6.53 to 7.45, and many bacterial counts were positive showing different species, including *E. coli* and *Pseudomonas aeruginosa*, while, only 40% of the samples had suspended solid readings within the limits according to WHO standards.

In the United Arab Emirates (UAE), municipalities assure that the water produced and distributed to consumers is subject to continuous monitoring and is always safe, and regulate as well as highlight the importance of water storage tanks proper installation, maintenance and cleaning. However, a good quality potable drinking water may be subject to recontamination by not following the Municipality regulations for water storage and water tanks cleaning. The responsibility to keep the water up to the standard lies with all the residents, landlords and property owners [8].

In this regard, studies conducted and published in UAE related to household water storage tanks and water quality seem very limited. In a single preliminary study conducted by Amiri et al. [9], water samples collected from eleven houses from both ground and roof level water storage tanks were assessed for microbial quality however, physico-chemical analysis was not considered in the study. The study revealed that 54.5% of the samples were positive for coliforms; yet, none of the samples were contaminated by *E. coli.* Total bacterial count (TBC) results revealed that eight out of the eleven sampled houses exceeded acceptable TBC standards.

The main aim of the current research study is to comprehensively assess the water quality in household water storage tanks related to stand-alone villas in random areas of Sharjah, UAE. The study explores the variation in physico-chemical as well as microbiological water quality parameters, the factors contributing to the quality of stored water as well as the most common water tank cleaning practices by the owners. Such a study may serve as a measure to promote the importance of cleaning and proper maintenance of storage tanks at the household level as well as increase the confidence of the consumers towards the quality of stored water.

2 MATERIALS AND METHODOLOGY

2.1 Sample and data collection

Twenty two household water storage tanks of stand-alone villas were randomly selected throughout Sharjah City and suburbs, and the tanks were sampled in duplicates in two sampling rounds. The first sampling round was conducted in the Fall season, while the second round was completed in Winter. A custom-designed water sampler and sterile 250 ml glass bottles were used to collect water samples properly from depths at middle of tanks to avoid any possible cross-contamination. Collected water samples were cooled to 4°C and transported to the University of Sharjah (UoS) laboratories within allowable holding times to be analyzed for a series of physico-chemical and microbiological parameters.

At time of sample collection, a questionnaire was distributed to the house owners to collect necessary information related to the specifications of the tanks (age, dimension, material, presence of cover, etc.), use of stored water, as well as tank maintenance and cleaning measures. Additionally, field observations related to the tank status and surroundings were recorded.

2.2 Analytical procedures

Collected samples were analyzed on-site for water temperature. At the University water lab, samples were analyzed for the parameters listed in Table 1, which also specifies the adopted analytical reference methods [10].

Table 1: Analytical parameters and reference methods.

Parameter	Method principle	Reference method
pH (@ºC25C)	Electrometric	SM 4500-H+
Electrical conductivity (uS/cm @ 25°C)	Electrochemical	SM 2510 B
Total hardness (mg/L as $CaCO_3$)	Titrimetric	SM 2340 C
Turbidity (NTU)	Nephelometry	SM 2130 B
Sulfates (mg/L SO_4^{2-})	Turbidimetric	HACH 8051
Nitrates (mg/L NO_3-N)	Colorimetric	HACH 8039
Phosphates (mg/L $PO4^{3-}$)	Colorimetric	HACH 8048
Chlorides (mg/L)	Titrimetric	SM 4500-Cl-B
Free and total chlorine (mg/L)	Colorimetric	HACH 8021 and 8167
Metals – Fe, Cu, Pb (mg/L)	ICP-OES	SM 3120 B
Total coliforms (CFU/ml)	Membrane filtration (M Endo agar)	SM 9221 B-C
Molds and fungi (CFU/ml)	Membrane filtration Spread plate culture	SM 9610 C-D
Heterotrophic plate counts, HPC (CFU/ml)	Membrane filtration Spread plate culture	SM 9215 C-D

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3 RESULTS AND DISCUSSION

Surveys and observations revealed that 90% of investigated tanks were polyethylene plastic while the remaining were glass fiber reinforced plastic (GRP). Water storage tanks' age varied from 2 months to more than 10 years, and they were either located at the ground level or on villa roofs. All investigated water tanks were covered except a single tank. Volumes of tanks varied from 400 till 1200 gallons to fulfill various types of activities and purposes. Owners expressed that they rarely clean their tanks and stored water is used for various domestic activities, such as washing, cooking, cleaning, and irrigation. Table 2 summarizes recorded averages of analyzed physico-chemical water quality parameters. Average results for samples collected during the Fall season are tabulated as A whereas B relates to average results recorded in the Winter season.

As for microbiological parameters, all samples exhibited 0 CFU/100 ml for total coliforms, four samples yielded positive results for molds and yeasts with counts ranging between 4–23 CFU/100 ml, and as for HPC all samples yielded counts exceeding 100 CFU/100 ml. Although, total bacterial counts do not impose serious health hazards to consumers; however, they are an indicator of poor hygienic practices. Water temperature ranged between 28 to 34°C in the Fall season, and from 17 to 26°C in Winter season.

Sharjah households receive their drinking water from three main sources provided by Sharjah Electricity and Water Authority (SEWA), namely desalinated seawater from various desalination plants, water from wells, and desalinated water from Abu Dhabi distribution company. The multiple sources of water cause a variation in the water quality parameters. 84% of pH readings varied from 8.02 to 8.90 units, and all recorded pH values were within minimum and maximum guideline values set by WHO, GSO (GCC Standardization Organization), or WQR (Water Quality Regulations) as shown in Fig. 1(a) [11]–[13]. As for electrical conductivity, GSO and WQR set a minimum level of 100 and a maximum level of 1,000 uS/cm at 25°C. None of the samples' conductivity dropped below 100 uS/cm at 25°C however approximately 50% of investigated water samples exceeded the recommended maximum limit (Fig. 1(b)). This was also linked to higher chloride levels in samples, especially in Fall sampling round (Fig. 1(c)). No major health implications are associated with drinking water with high electrical conductivity or chloride but such parameters are typically controlled to avoid corrosion and to reduce salty taste of water. Two samples (19 and 20) had a significant variation between the two rounds in terms of conductivity and chloride levels as salt removing units were installed in the second round. For turbidity, 7% of the results were over WHO maximum limits. As for hardness, its occurrence in water systems is related to groundwater sources, since as water moves through geological formations it dissolves small amounts of minerals [14]. In the geographical area under study, most of the water supplies are desalination plants which remove hardness. Fig. 1(d) shows that hardness results were below the GSO and WQR acceptable level of 200–300 mg/L as $CaCO_3$ in 18 samples out of 22 in fall season and in all winter season results. However, WHO sets a recommended level of 100–300 mg/L as $CaCO_3$, thus 77% of fall results and 68% of winter results ranged between the limit. As for nitrates and sulfates, all recorded average results were within WHO, GSO, and WQR acceptable levels (Fig. 1(e) and (f)). Phosphate results ranged from 0.01 to 3.19 mg/L.

Chlorine is a well-known disinfectant used in water treatment and maintaining a residual in distributed and stored water in approved amounts assures safe water. Water provided by SEWA is chlorinated and distributed to consumers with a free residual chlorine concentration ranging between 0.2 and 1.0 mg/L. However, recorded results showed very low free and total chlorine levels in the collected water samples, mostly below minimum

Table 2: Recorded averages of analyzed physico-chemical water quality parameters.

Sample ID		Analytical parameters pH (pH units)	Conductivity (µs/cm 25°C)	Hardness (mg/L $CaCO_3$)	Turbidity (NTU)	Sulfate (mg/L SO_4^{2-})	Nitrate (mg/L NO_3-N)	Free chlorine (mg/L)	Total chlorine (mg/L)	Chloride (mg/L)	Phosphate (mg/L $PO4^{3-}$)
1	A	8.21	1227	72	0.49	29	0.45	0.05	0.15	372	0.08
	B	6.83	1231	76	1.34	25	0.60	0.03	0.08	369	0.04
2	A	8.11	1541	237	0.83	198	0.45	0.28	0.53	332	0.08
	B	8.35	1184	152	1.58	110	1.20	0.07	0.11	231	0.08
3	A	8.05	801	172	0.53	190	0.60	0.28	0.28	324	0.06
	B	8.31	1193	224	2.65	90	1.20	0.09	0.11	215	0.10
4	A	8.02	1305	248	0.98	193	0.85	0.38	0.45	328	0.08
	B	8.17	1181	184	0.34	100	1.50	0.09	0.12	223	0.14
5	A	7.88	1605	237	0.16	185	0.80	0.22	0.23	326	0.07
	B	8.15	1192	192	0.83	110	1.70	0.04	0.04	225	0.08
6	A	8.05	1101	185	1.39	70	0.85	0.02	0.04	366	1.58
	B	7.85	802	152	0.35	105	0.90	0.04	0.07	184	0.01
7	A	8.14	1069	55	1.27	55	0.65	0.05	0.36	356	0.50
	B	8.11	1076	168	0.56	95	1.00	0.12	0.12	202	0.06
8	A	8.80	1102	115	0.78	170	0.80	0.01	0.02	330	3.19
	B	8.35	1055	156	0.42	110	2.40	0.10	0.20	197	0.05
9	A	8.70	1134	145	1.17	240	1.00	0.02	0.02	309	0.62
	B	8.25	1136	164	1.25	105	0.60	0.10	0.34	219	0.14
10	A	8.77	934	129	0.64	218	0.85	0.02	0.04	237	1.51
	B	8.20	989	132	0.63	60	0.80	0.02	0.03	219	0.37
11	A	8.85	952	130	2.29	220	1.10	0.03	0.03	243	1.52
	B	8.40	980	156	0.37	55	0.80	0.03	0.08	235	0.16
12	A	9.01	605	85	0.36	19	0.60	0.04	0.05	189	0.07
	B	8.50	974	130	0.55	40	0.70	0.09	0.13	237	0.64

Table 2: Continued.

Sample ID		Analytical parameters									
		pH (pH units)	Conductivity (µs/cm 25°C)	Hardness (mg/L $CaCO_3$)	Turbidity (NTU)	Sulfate (mg/L SO_4^{2-})	Nitrate (mg/L NO_3-N)	Free chlorine (mg/L)	Total chlorine (mg/L)	Chloride (mg/L)	Phosphate (mg/L $PO4^{3-}$)
13	A	8.97	588	74	0.09	22	0.35	0.03	0.04	194	0.08
	B	8.50	980	134	0.24	40	0.90	0.04	0.06	283	0.14
14	A	8.57	1044	152	0.31	31	0.90	0.13	0.18	297	0.25
	B	8.07	1216	184	0.90	105	1.10	0.22	0.23	229	0.09
15	A	8.57	1052	148	0.24	30	0.80	0.15	0.22	294	0.22
	B	8.30	1196	192	0.51	105	1.60	0.07	0.20	231	0.07
16	A	8.65	847	154	0.72	25	0.65	0.00	0.03	278	0.21
	B	8.25	1146	184	0.46	120	1.00	0.19	0.26	217	0.07
17	A	8.73	597	44	0.24	35	1.15	0.07	0.08	117	0.19
	B	8.36	772	88	0.53	40	0.80	0.12	0.14	137	0.29
18	A	8.55	644	76	0.55	30	2.10	0.09	0.09	118	0.19
	B	8.33	713	92	0.48	140	1.20	0.10	0.12	133	0.20
19	A	8.32	1560	50	0.41	203	1.95	0.01	0.03	279	0.15
	B	8.03	67	24	0.13	5	1.20	0.00	0.13	20	1.23
20	A	8.27	766	22	0.51	73	1.40	0.01	0.03	144	0.07
	B	7.19	60	12	0.34	0	0.70	0.00	0.00	20	0.06
21	A	8.58	928	81	0.15	65	1.20	0.16	0.24	230	0.13
	B	6.70	975	108	0.28	60	0.80	0.00	0.02	231	0.25
22	A	8.70	974	84	0.13	60	1.15	0.19	0.26	229	0.10
	B	7.10	1004	110	0.40	55	0.80	0.00	0.01	237	0.12

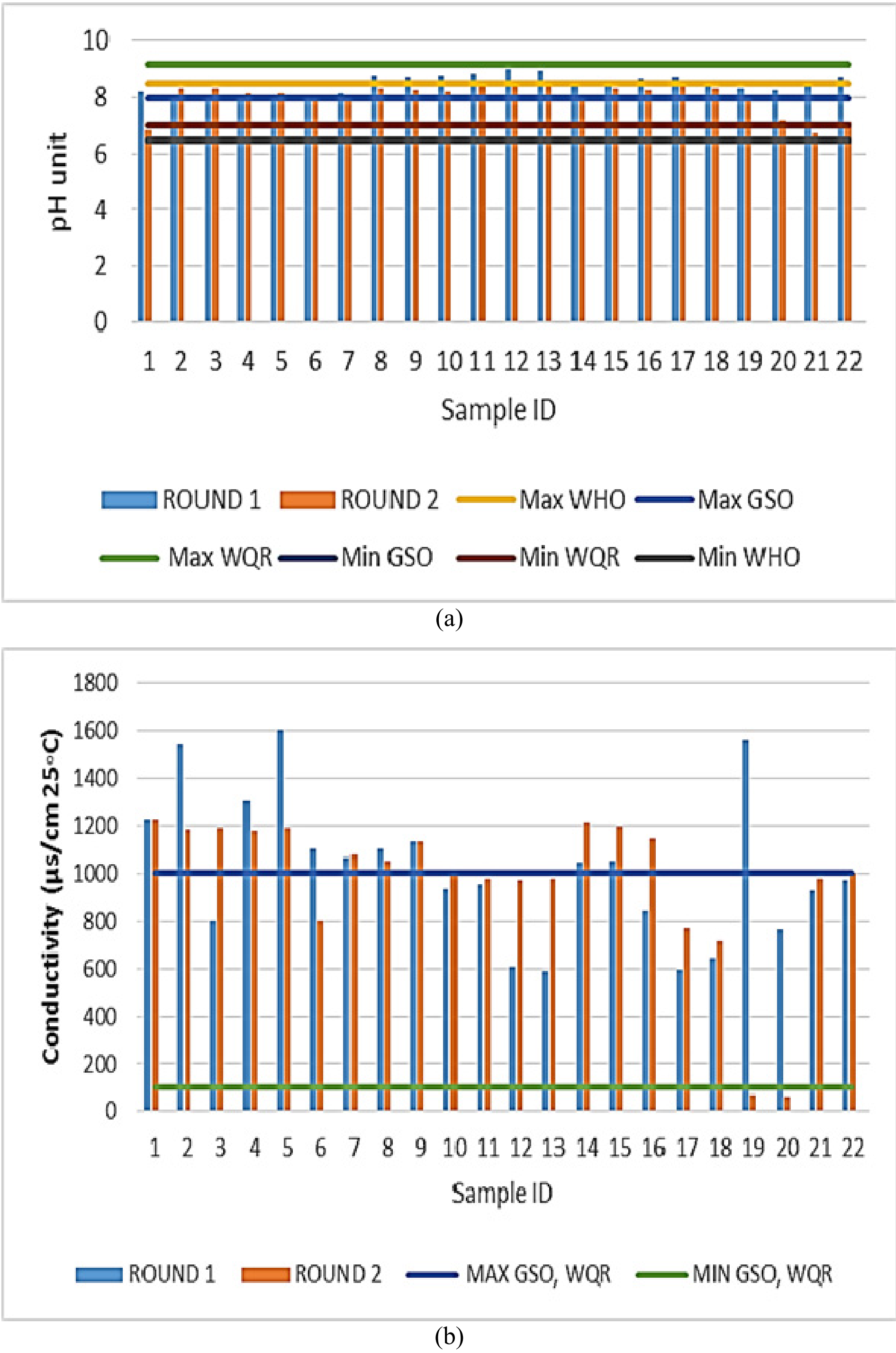
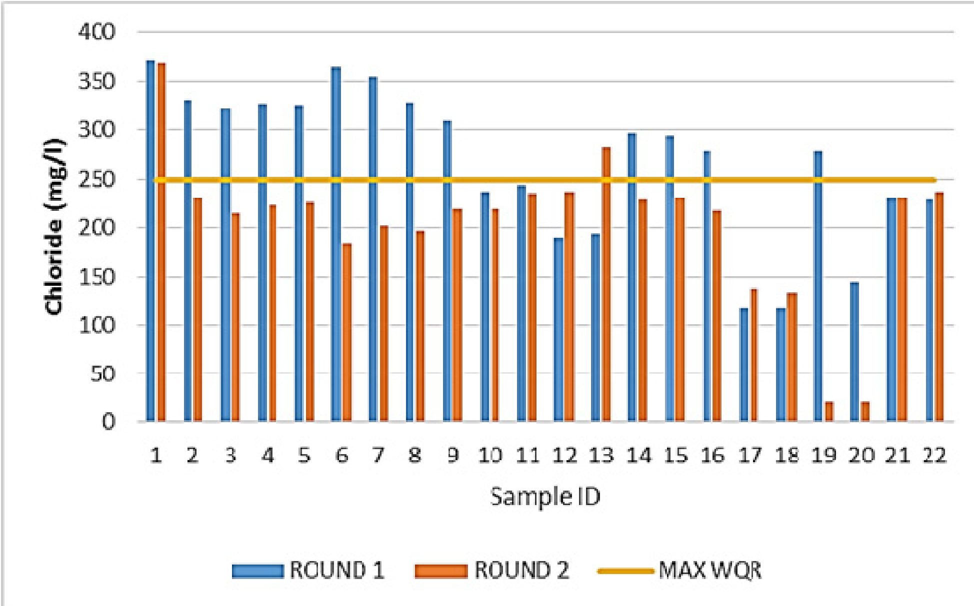


Figure 1: Physico-chemical water parameters compared to GSO, WHO, and WQR drinking water guidelines.



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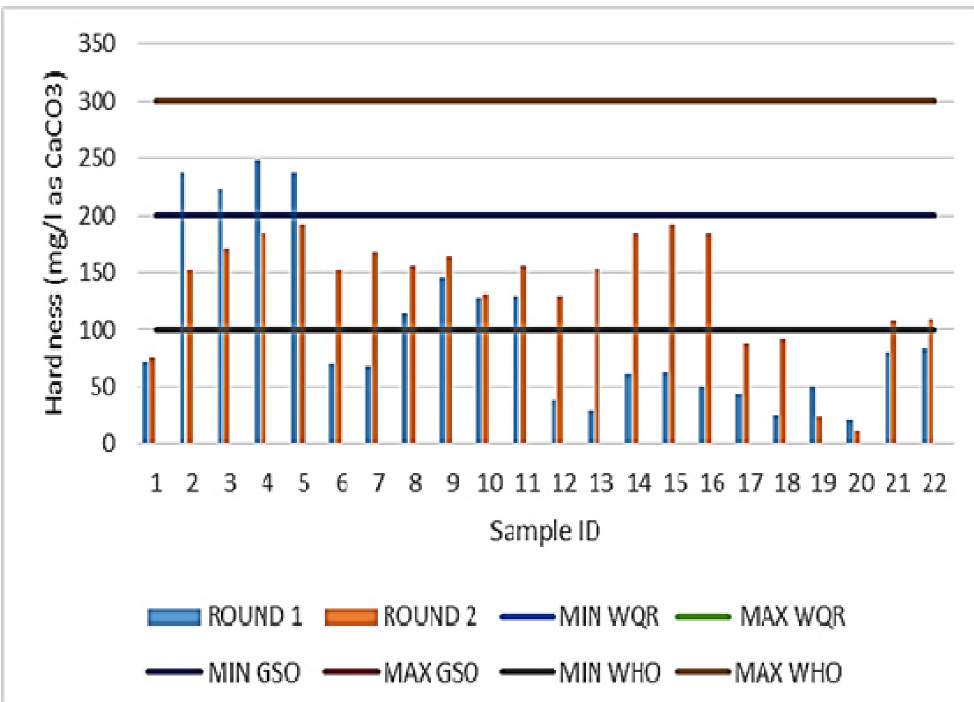

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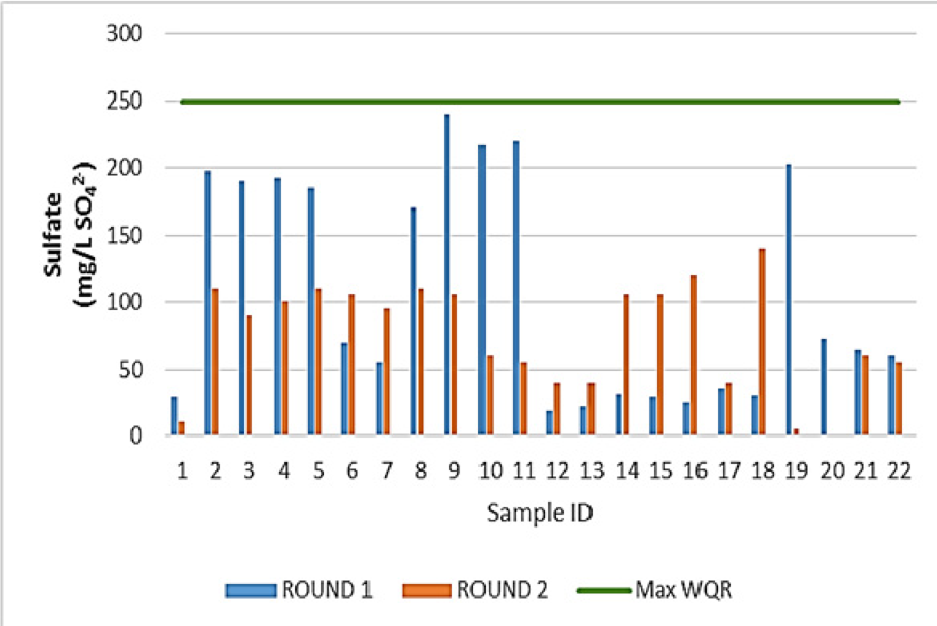

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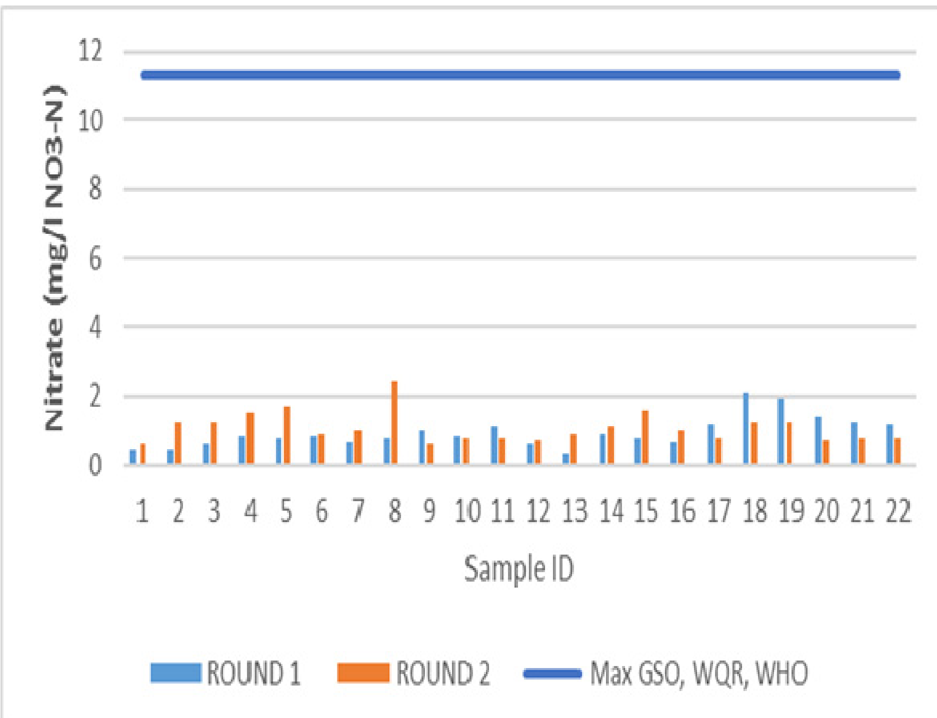

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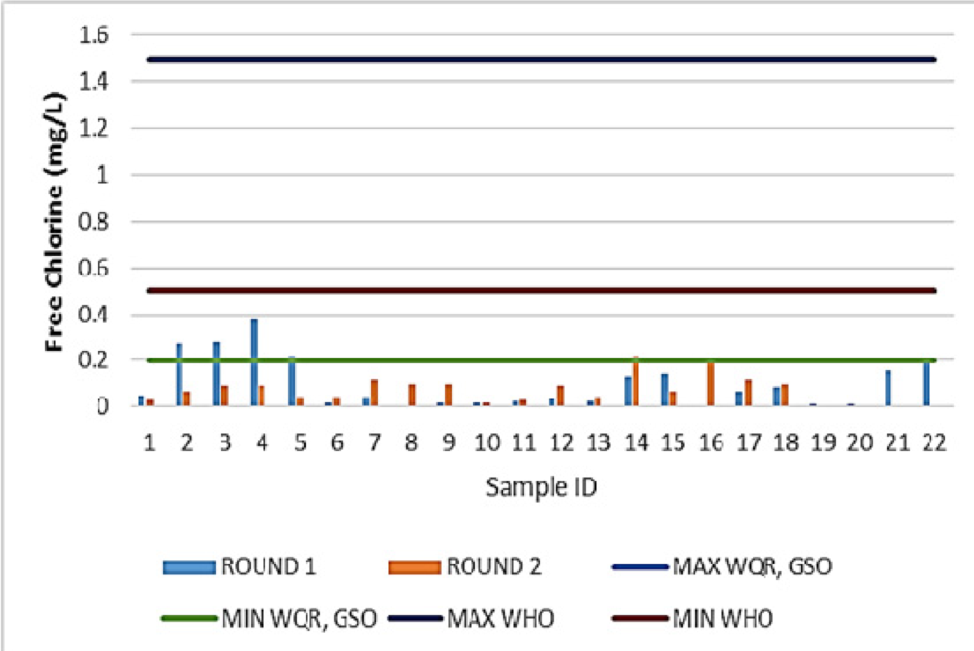

(g)

Figure 1: Continued.

requirements set by WHO, GSO, and WQR (Fig. 1(g)). Possible reasons can be chlorine volatilization especially in hot weather as well as chlorine reaction with chlorine consuming substances in the storage systems. Furthermore, the survey revealed that residents rarely clean and apply additional disinfectants to their water tanks.

Last, heavy metal analysis was also conducted on investigated waters. Iron, copper and zinc were < 0.1 mg/L, thus below WHO, GSO, and WQR maximum acceptable levels for these metals.

4 CONCLUSIONS

Results demonstrate that the overall physico-chemical quality of water stored in household water storage tanks of stand-alone villas is acceptable except for operational parameters such as electrical conductivity and chlorides in 50% of investigated samples; yet, such parameters do not pose major health hazards. However, free and total residual chlorine levels were below minimum requirements set by GSO and WQR in 93% of the samples, which may pose a risk of water re-contamination and may subject the consumers to possible water-related health effects. Microbiological quality of sampled water was acceptable in terms of total coliforms yet total bacterial counts and occasional presence of fungi and molds suggest poor hygienic conditions and highlight the need for tank cleaning, Variations in physico-chemical parameters were observed between the two rounds, possibly because of variations in supplied source water, water temperature, and installation of specific pollutant removal technologies by house owners. The study revealed that household water tanks owners rarely clean their tanks thus it is highly recommended to promote such measures and educate tank owners about the importance of regular tank cleaning and maintenance. As an intervention strategy, information related to basic steps and requirements for households' tanks design material and cleaning were distributed to tank owners and the public in the form of educational brochures to highlight the importance of safe water.

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IMPACT OF NATURAL CAPITAL INVESTMENT STRATEGIES ON WATER QUALITY IN THE NDEMBERA RIVER SUB-CATCHMENT, TANZANIA

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ABSTRACT
Natural capital investment strategies are a highly important tool in the sustainability of ecosystem services – including water and improved community livelihoods worldwide. However, their implications on the quality of water are hardly known in many societies of Tanzania. This paper reports the effect of one of such strategy, called Wetland Friendly Investment (WFI), on the quality of water on small parts of Ndembera sub-catchment of Tanzania, where (WFI) has been implemented for more than a decade. Samples of water were collected from the seven locations in the dry and wet seasons using 1,500 ml plastic tubes. Bottles with samples were labeled, stored in the cooling box and transported to the laboratory for analysis. All parameters were measured using standardized methods. To determine the effect of the strategy, we compared the measured mean difference values of the physicochemical properties of water before and after the introduction of the strategy using a two-way Analysis of Variance (ANOVA). The results showed that there was a statistically significant difference in Total Suspended Solids (TSS) before ($p = 0.0066$) and after ($p = 0.0324$) the intervention. Msugulika stream and the upstream of Ndembera River had the highest value for Ammonia-Nitrogen, with means of 0.3 and 0.23 mg/l in the dry and wet seasons, respectively. The use of agrochemicals was mentioned as one of the contributing factors in the poor quality of water and this could not significantly be reduced by the introduction of the WFI strategy alone. Therefore, more robust actions are required in addressing the issue of the quality of water in the sub-catchment.
Keywords: Ndembera River sub-catchment, physicochemical, wetlands friendly investment, natural capital.

1 INTRODUCTION

More than one billion people are depending on wetlands for ecosystem services – including water, fishing, agriculture, flood control and climate regulation [1]. The quality of water in this ecosystem is of paramount significance for society development. However, the degradation of wetlands is one of the major global problems [2] that has reduced the wetlands area cover by almost 50% in the past century therefore threatening the quality of water worldwide [3]. Various studies in Tanzania has identified changes in land use, over-use of water in irrigation, sedimentation, invasive alien species, and climate change to have contributed about degradation of 90% of the wetlands in the country [3], [4].

In the light of the growing pressure on the wetlands and the services they support, the Government of Tanzania has introduced a number of natural capital strategies – including the strategy called Wetlands Friendly Investment (WFI) in the 2000s [5]. Theoretically, supporting the local community with incentives would make them reduce pressure on these natural systems henceforth provision of the services to the society [6]. The main objective of the strategy was to balance the protection and utilization at the heart of the wise use concept. Despite the introduction of this strategy, little is known on the effect of its implementation on the quality of water in the areas implemented [7].

This study aimed to fill this gap by investigating the effect of the implementation of this strategy on the quality of water in Ndembera area, Tanzania. This area was selected

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because the water in the basin supports many communities in Southern Tanzania, especially during the dry season when there is a water shortage. Data on the quality of water is important for developing proper land use as well as water treatment innovation methods in this catchment and beyond.

2 MATERIALS AND METHODS

2.1 The study area

This study was conducted in the section of Ndembera River Sub catchment which lies between latitudes 7°.57'.09" and 8° 13'.25" S and longitudes 35°05.16" and 35°37.49" E in Iringa District, Ngowi [3] (Fig. 1). It covers about 1,223 km^2 within the Great Ruaha River (GRR). The later drains an area of about 68,000 km^2. The climate is characterized by three distinct climatic zones – the highland, Midland and the lowland zone depending on the topography [3]. The long rain season runs between late March to June and the short ones November to February [8]. It is the only potential river contributing to about 500 m^3 of the total inflow to Ihefu wetlands [8]. The catchment is an important area for natural resources conservation [8]. Agriculture, fishing, and livestock keeping are the main economic activities in the study area.

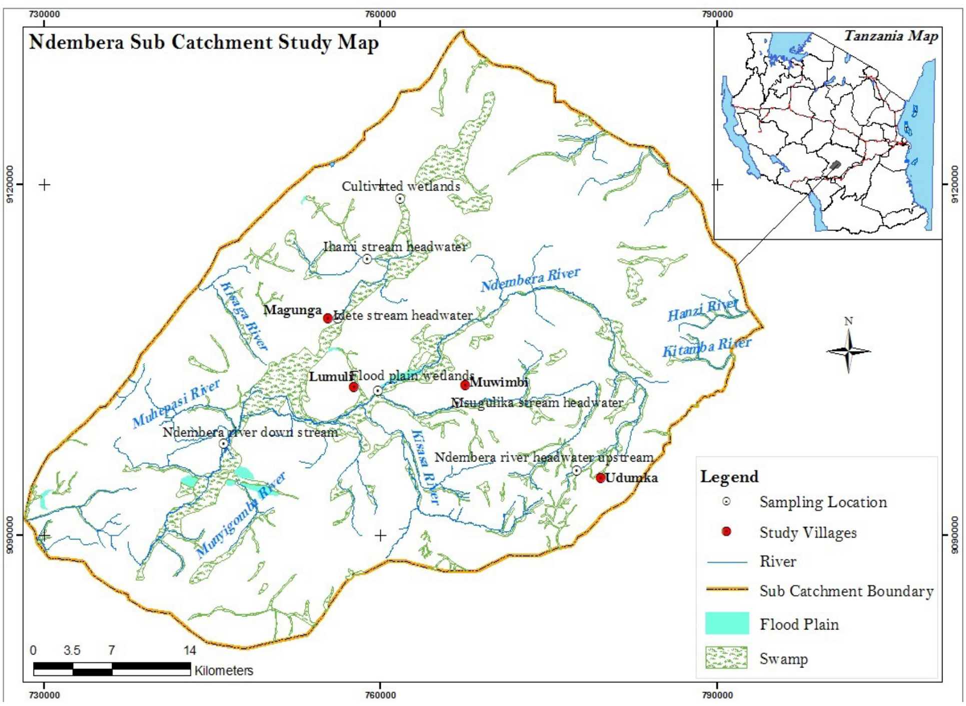

Figure 1: Map of the study area. Modified from Ngowi [3].

2.2 Methods

2.2.1 Sampling locations
Seven locations where the WFI strategy was introduced were selected. They included: cultivated wetlands, Ihemi stream, Ndembera, flood plain wetlands, Msugulika and Idete stream.

2.2.2 Collection of water samples
The water samples were collected from the depth of 15 cm in each of the seven locations in the month of September 2015 which represented the peak of the dry season and February 2016 for the wet season respectively. Water samples were stored in the 1500 ml clean corked plastic bottle that have been pre-washed with Nitric Acid and thoroughly rinsed with distilled water [9]. The sampling locations were selected based on ease of access and in such a way that the samples represent the entire sub catchment. The bottles with the sample were labelled SP_1, SP_2, SP_3, SP_4, SP_5, SP_6, and SP_7 based on the locations and kept in the cooling box, then transported to the laboratory for analysis.

2.2.3 Experimental design
Water quality analysis was carried out using standard analytical methods. Data were subjected to the Complete Randomized Design (CRD). ANOVA for each variable was conducted using MSTAT C software Program [10]. The mean values were separated by Duncan's Multiple Range Test (DMRT) to test for the significant difference at $p< 0.05$ [11].

2.2.4 Analysis of the quality of water
Water samples were filtered through a 5 µm glass fiber filter and analyzed for both physical and chemical characteristics including – temperature, pH, Electrical Conductivity (EC), Total Suspended Solids (TSS), Turbidity, Dissolved Oxygen (DO), Nitrate-Nitrogen (NO_3-N), Ammonia-Nitrogen (NH_4-N), Phosphate-Phosphorous (PO_4-P) and Total Alkalinity as $CaCO_3$ using standard method [12]. A transparent 30 cm plastic ruler was used to measure water depth. Odor, color, and temperature were measured using standard method [12] at the time of sampling. The temperature was measured using a thermometer. Distilled water was used to rinse the electrode between successive measurements. pH was determined using a pH meter (Toshniwal Instr. Pvt. Ltd No. 54) previously calibrated with a buffer solution with pH 7.0. Electrical Conductivity (EC) was determined using Systronics Conductivity Meter – 304 and recorded in micro Siemens per cm (µs/cm). Total Suspended Solids (TSS) was determined by filtering a known volume of sample through a thoroughly dried filter paper and the residue weighed in mg/l. The Total alkalinity was determined by the titration method and expressed as mg $CaCO_3$/l. Dissolved Oxygen (DO) was determined by Dissolved Oxygen meter, while Cadmium reduction method was used in the determination of Nitrate-nitrogen (NO_3-N). Ammonia-nitrogen (NH_4-N) was determined by Phenolnitroprusade method and Phosphate-phosphorous (PO_4-P) was determined by Ascorbic acid method.

3 RESULTS
The results obtained from the analysis are presented in Table 1 and detailed separately in the Appendices I and II of the supplemental information enclosed. The mean values of the physicochemical quality of water at the locations along different seasons are presented in Table 2 and Table 3 respectively.

Table 1: The physicochemical characteristics along the locations and the seasons.

		Physicochemical characteristics									
Location	Season	Temp °C	pH unit	EC µs/cm	TSS mg/l	Turbidity FAU	DO mg/l	NO_3-N mg/l	NH_4-N mg/l	PO_4-P mg/l	$CaCO_3$ mg/l
Cultivated wetlands	Dry	27.4	7.8	66	45	350	98	< 0.2	< 0.1	< 0.04	28
	Wet	23.0	7.52	94	30	30	6.49	0.000001	0.238	0.000009	32
Ihemi stream	Dry	28.5	7.8	72	17	500	95	< 0.2	< 0.1	< 0.04	30
	Wet	23.0	6.72	52	12	10	7.35	0.000001	0.200	0.000009	7
Ndembera down stream	Dry	28.5	7.3	75	20	550	55	< 0.2	< 0.1	< 0.04	33
	Wet	23.0	7.22	74	11	12	6.08	0.000001	0.2284	0.000005	43
Flood plain wetlands	Dry	29.0	8.3	82	17	45	50	< 0.2	0.2	0.15	36
	Wet	24.0	7.11	92	8	13	6.45	0.0000238	0.22111	0.000005	36
Msugulika stream	Dry	29.1	7.6	86	30	< 5	50	< 0.2	0.3	0.1	36
	Wet	25.0	7.50	82	13	0	5.94	0.000683	0.2276	0.000014	26
Ndembera upstream	Dry	29.2	6.6	135	0	55	5	< 0.2	0.3	0.06	55
	Wet	25.0	6.80	44	5	8	6.60	0.001394	0.2287	0.000014	13
Idete stream	Dry	28.8	7.1	250	7	350	5	< 0.2	< 0.1	0.08	225
	Wet	25.0	7.05	78	3	9	6.06	0.001512	0.2493	0.000024	40.40

Table 2: Mean values of the physicochemical quality of water at each location.

	Physicochemical characteristics								
Location	pH unit	EC µs/cm	TSS mg/l	Turbidity FAU	DO mg/l	NO_3-N mg/l	NH_4-N mg/l	PO_4-P mg/l	$CaCO_3$ mg/l
Cultivated wetlands	7.650	80.000	37.500	190.000	52.250	0.050	0.100	0.000	30.000
Ihemi stream	7.250	62.000	14.500	255.000	51.200	0.050	0.100	0.000	18.500
Ndembera downstream	7.250	74.500	15.500	281.000	30.550	0.050	0.100	0.000	38.000
Flood plain wetlands	7.000	87.000	12.500	29.000	28.250	0.050	0.200	0.100	36.000
Msugulika stream	7.550	84.000	21.500	2.000	27.950	0.050	0.250	0.050	31.000
Ndembera upstream	6.700	89.500	2.500	31.500	5.800	0.050	0.250	0.050	34.000
Idete stream	7.050	164.000	5.000	179.500	5.550	0.050	0.200	0.050	132.700

Table 3: Mean values of the quality of water along dry and wet seasons.

	Physicochemical characteristics								
Season	pH unit	EC µs/cm	TSS mg/l	Turbidity FAU	DO mg/l	NO_3-N mg/l	NH_4-N mg/l	PO_4-P mg/l	$CaCO_3$ mg/l
Dry	7.500	109.429	19.429	264.857	51.143	0.100	0.129	0.071	63.286
Wet	7.114	73.714	11.714	11.714	6.443	0.000	0.214	0.000	28.200

The mean dry season values of pH (7.500), EC (109.429 mg/l), TSS (19.429 mg/l), turbidity (264.857 FAU), DO (51.143 mg/l), NO_3-N (0.100 mg/l), PO_4-P (0.071 mg/l) and total alkalinity as $CaCO_3$ (63.286 mg/l) were higher than those of the wet season Table 3.

Results from ANOVA show that there was a significant variation of the physicochemical characteristics of the TSS in all locations (Table 4) and the seasons. Also Turbidity, DO and $P0_4$-P showed a significant difference in all the seasons with a p-value of 0.0246, 0.0190 and 0.0465 respectively (Table 5).

Table 4: Separated mean values of the TSS at sampling locations.

	Sampling locations						
	Cultivated wetlands	Ihemi stream	Ndembera down stream	Flood plain wetlands	Msugulika stream	Ndembera up stream	Idete stream
Mean value	35.5^{a}	14.5^{b}	15.5^{b}	12.5^{b}	21.5^{c}	2.5^{d}	5.0^{d}

Note: Mean values superscripted by different lower-case letter in the same row are significantly different following a separation by Duncan's Multiple Range Test (DMRT) at P value < 0.05.

Table 5: Separated mean values of the TSS, Turbidity, DO and $P0_4$-P across the dry and wet seasons.

	Physicochemical characteristics			
Season	TSS mg/l	Turbidity (FAU) mg/l	DO (% of saturation) mg/l	PO_4-P mg/l
Dry	19.429^{a}	264.857^{a}	51.143^{a}	0.071^{a}
Wet	11.714^{b}	11.714^{b}	6.443^{b}	0.000^{b}

Note: Mean values superscripted by different lower-case letter in the same column are significantly different following a separation by DMRT at P < 0.05.

4 DISCUSSION

Some marked variations of the quality water were observed along locations and the seasons. The water temperature had a range of 23°C to 29.2°C. The low water temperature (23°C) of the sub-catchment during the wet season could be a result of seasonal changes in air temperatures associated with the cold season experienced in the Southern Highlands of Tanzania during the wet season [13]. This temperature is within the range of 10°C–50°C for rivers in the tropical waters [12].

The higher mean values obtained at the dry season for pH, EC, TSS, turbidity, DO, NO_3-N, PO_4-P and total alkalinity could be caused by the reduced volume of water from major streams in the area. A similar trend was observed for Katogora wetlands in Nigeria [9]. EC of water varied slightly among and within the locations. This shows that water in the study area contained similar dissolved nutrients that are responsible for carrying electric current. The highest value recorded 164.000 µs/cm at Idete stream may be attributed to wetlands being bisected by road and closer to settlement areas thus vulnerable to pollution. Gongden and Lohdip [14] show that surface water is very vulnerable to pollution due to its ease of accessibility to human influence while the SMUWC [13] reported EC of waters in other sub catchment of the Southern Highlands Tanzania have a high capacity for electric currents that do not vary significantly.

Nitrate – Nitrogen concentrations are mostly low (0.1mg/l) beyond the detection limit for the analysis. Ammonia – Nitrogen results show a similar pattern. Samples collected at

Msugulika, Ndembera upstream and in the cultivated wetlands show higher levels of Nitrogen.

The low mean values for PH (7.250 units), EC (74.500 µs/cm), DO (30.550 mg/l), NO_3-N (0.050 m/l), $P0_4$ (0.000 mg/l) and total alkalinity (38.000 mg/l) obtained after the intervention could be one of the positive effects of the strategy. The SMUWC [13] observed higher mean values for the similar parameters in the catchment. However, higher mean values for TSS (15.500 mg/l), Turbidity (281.000 FAU) and NH_4-N (0.100mg/l) have been recorded at Ndembera downstream after the intervention. This could be caused by the effect of use of agrochemicals – including fertilizer in the wetland's cultivation, thus fluctuations of these parameters in the area.

5 CONCLUSION

The results showed that most of the physicochemical properties of water in the study area remained broadly similar despite the intervention. This shows that the strategy alone had not greatly changed the quality of water in the area and that human-related factors such as changing land uses, use of fertilizer, runoff from farmlands, and animal grazing are among contributing factors in the poor quality of water.

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APPENDIX I
RESULTS OF THE ANALYSIS OF WATER SAMPLES

```
Function: ANOVA - 2
Data case 1 to 14
Two-way Analysis of Variance over
Variable 1 (Sampling point/location) with values from 1 to 7 and over
Variable 2 (Season) with values from 1 to 2.
```

Variable 3: pH - A N A L Y S I S   O F   V A R I A N C E   T A B L E

Source	Degrees of Freedom	Sum of Squares	Mean Square	F-value	Prob
Location	6	1.54	0.257	1.75	0.2575
Season	1	0.52	0.521	3.53	0.1092
Error	6	0.88	0.147		
Total	13	2.95			

Grand Mean= 7.307 Grand Sum= 102.300 Total Count= 14. Coefficient of Variation = 5.25%. Means for variable 3 (pH) for each level of variable 1 (Sampling point):

Var 1 value	1	2	3	4	5	6	7
Var 3 Mean	7.65	7.25	7.25	7.70	7.55	6.70	7.05

Means for variable 3 (pH) for each level of variable 2 (Season):

Var 2 Value	1	2
Var 3 Mean	7.50	7.114

lsd at 0.05 alpha level = 0.502

Variable 4: EC - A N A L Y S I S   O F   V A R I A N C E   T A B L E

Degrees of   Sum of

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Source	Freedom	Squares	Mean Square	F-value	Prob
Location	6	13256.43	2209.405	0.88	0.5614
Season	1	4464.29	4464.286	1.77	0.2315
Error	6	15118.71	2519.786		
Non-additivity	1	10862.91	10862.913	12.76	0.0160
Residual	5	4255.80	851.160		
Total	13	32839.43			

Grand Mean= 91.571 Grand Sum= 1282.000 Total Count= 14. Coefficient of Variation= 54.82%. Means for variable 4 (EC) for each level of variable 1 (Sampling point):---

Var 1 values	1	2	3	4	5	6	7
Var 4 Mean	80.0	62.0	74.5	87.0	84.0	89.5	164.0

Means for variable 4 (EC) for each level of variable 2 (Season):

Var 2 Value	1	2
Var 4 Mean	109.429	73.714

lsd at 0.05 alpha level = 65.655

Variable 5: TSS - A N A L Y S I S O F V A R I A N C E T A B L E

Source	Degrees of Freedom	Sum of Squares	Mean Square	F-value	Prob
Location	6	1618.43	269.738	9.95	0.0066
Season	1	208.29	208.286	7.68	0.0324
Error	6	162.71	27.119		
Total	13	1989.43			

Grand Mean= 15.571 Grand Sum= 218.000 Total Count= 14. Coefficient of Variation= 33.44%. Means for variable 5 (TSS)for each level of variable 1 (Sampling point):---

Var 1 value	1	2	3	4	5	6	7
Var 5 Mean	37.5	14.5	15.5	12.5	21.5	2.5	5.0

Means for variable 5 (TSS)for each level of variable 2 (Season):

Var 2 Value	1	2
Var 5 Mean	19.429	11.714

lsd at 0.05 alpha level = 6.811

Variable 6: TURBIDITY - A N A L Y S I S O F V A R I A N C E T A B L E

Source	Degrees of Freedom	Sum of Squares	Mean Square	F-value	Prob
Location	6	160565.86	26760.976	1.06	0.4726
Season	1	224284.57	224284.571	8.89	0.0246
Error	6	151452.43	25242.071		
Total	13	536302.86			

Grand Mean= 138.286 Grand Sum = 1936.000 Total Count= 14. Coefficient of Variation = 114.89%. Means for variable 6 (TURBIDITY) for each level of variable 1 (Sampling point):---

Var 1 value	1	2	3	4	5	6	7
Var 6 Mean	190.0	255.0	281.0	29.0	2.0	31.5	179.5

Means for variable 6 (TURBIDITY)for each level of variable 2 (Season):

Var 2 Value	1	2
Var 6 Mean	264.857	11.714

lsd at 0.05 alpha level = 207.801

Variable 7: DO - A N A L Y S I S O F V A R I A N C E T A B L E

Source	Degrees of Freedom	Sum of Squares	Mean Square	F-value	Prob
Location	6	4250.62	708.437	1.03	0.4883
Season	1	6993.32	6993.315	10.12	0.0190

Error	6	4145.71	690.952		
Total	13	15389.65			

Grand Mean= 28.793 Grand Sum= 403.100. Total Count= 14. Coefficient of Variation= 91.29%. Means for variable 7 (DO) for each level of variable 1 (Sampling point):---

Var 1 value	1	2	3	4	5	6	7
Var 7 Mean	52.25	51.2	30.55	28.25	27.95	5.8	5.55

Means for variable 7 (DO) for each level of variable 2 (Season):

Var 2	Value	1	2
Var 7	Mean	51.143	6.443

lsd at 0.05 alpha level = 34.380

Variable 8: NO_3-N - A N A L Y S I S O F V A R I A N C E T A B L E

Source	Degrees of Freedom	Sum of Squares	Mean Square	F-value	Prob
Location	6	0.00	0.000		
Season	1	0.04	0.035		
Error	6	0.00	0.000		
Total	13	0.04			

Grand Mean= 0.050 Grand Sum = 0.700 Total Count= 14. Coefficient of Variation = 0.00%. Means for variable 8 (NO3-N) for each level of variable 1 (Sampling point):---

Var 1 value	1	2	3	4	5	6	7
Var Mean	0.05	0.05	0.05	0.05	0.05	0.05	0.05

Means for variable 8 (NO3-N) for each level of variable 2 (Season):

Var 2	Value	1	2
Var 8	Mean	0.100	0.000

lsd at 0.05 alpha level = 0.000

Variable 9: NH_4-N - A N A L Y S I S O F V A R I A N C E T A B L E

Source	Degrees of Freedom	Sum of Squares	Mean Square	F-value	Prob
Location	6	0.06	0.010	0.91	0.5435
Season	1	0.03	0.026	2.40	0.1723
Error	6	0.06	0.011		
Total	13	0.15			

Grand Mean= 0.171 Grand Sum= 2.400 Total Count= 14. Coefficient of Variation = 60.38%. Means for variable 9 (NH4N for each level of variable 1 (Sampling point):---

Var 1 value	1	2	3	4	5	6	7
Var 9 Mean	0.1	0.1	0.1	0.2	0.25	0.25	0.2

Means for variable 9 (NH4N) for each level of variable 2 (Season):

Var 2	Value	1	2
Var 9	Mean	0.129	0.214

lsd at 0.05 alpha level = 0.135

Variable 10: PO_4 - A N A L Y S I S O F V A R I A N C E T A B L E

Source	Degrees of Freedom	Sum of Squares	Mean Square	F-value	Prob
Location	6	0.02	0.003	1.00	0.5000
Season	1	0.02	0.018	6.25	0.0465
Error	6	0.02	0.003		
Total	13	0.05			

Grand Mean= 0.036 Grand Sum= 0.500 Total Count= 14. Coefficient of Variation = 149.67%. Means for variable 10 (PO4) for each level of variable 1 (Sampling point):---

Var 1 value	1	2	3	4	5	6	7
Var 10 Mean	0.00	0.0	0.0	0.1	0.05	0.05	0.05

Means for variable 10 (PO4) for each level of variable 2 (Season):

Var 2	Value	1	2
Var 10	Mean	0.071	0.000

lsd at 0.05 alpha level = 0.070

Variable 11: $CaCO_3$ - A N A L Y S I S O F V A R I A N C E T A B L E

Source	Degrees of Freedom	Sum of Squares	Mean Square	F-value	Prob
Location	6	18123.35	3020.559	1.30	0.3805
Season	1	4308.53	4308.526	1.85	0.2228
Error	6	13984.55	2330.759		
Non-additivity	1	12291.86	12291.862	36.31	0.0018
Residual	5	1692.69	338.538		
Total	13	36416.43			

Grand Mean = 45.743 Grand Sum = 640.400 Total Count = 14. Coefficient of Variation= 105.54%. Means for variable 11 (CaCO3) for each level of variable 1 (Sampling point):

Var 1 value	1	2	3	4	5	6	7
Var 11 Mean	30.00	18.50	38.0	36.0	31.0	34.0	132.7

Means for variable 11 (CaCO3) for each level of variable 2 (Season):

Var 2	Value	1	2
Var 11	Mean	63.286	28.200

lsd at 0.05 alpha level = 63.144

APPENDIX II
SEPARATED MEAN VALUES BY DUNCAN'S MULTIPLE RANGE TEST AT ALPHA < 0.050

Variable 5: TSS/TDS

```
Means for variable 5 (TSS) for each level of variable 1 (Sampling point):
  ---------------------------------------------------------------------
  Var 1, values        1       2      3      4      5      6      7
  Var 5, Mean     37.5A       14.5B  15.5B  12.5B  21.5C  2.5D   5.0D
  ---------------------------------------------------------------------

Means for variable 5 (TSS/TDS) for each level of variable 2 (Season):
      Var 2     Var 5
      Value     Mean
        1       19.429  A
        2       11.714  B
  ---------------------------------------------------------------------
```

Variable 6: Turbidity

```
Means for variable 6 (TURBIDITY) for each level of variable 2 (Season):
      Var 2     Var 6
      Value     Mean
        1      264.857  A
        2       11.714  B
  ---------------------------------------------------------------------
```

Variable 7: DO

```
Means for variable 7 (DO) for each level of variable 2 (Season):
Duncan's Multiple Range Test at alpha 0.050
      Var 2     Var 7
      Value     Mean
        1       51.143  A
        2        6.443  B
  ---------------------------------------------------------------------
```

Variable 10: PO_4

```
Means for variable 10 (PO4) for each level of variable 2 (Season):
      Var 2     Var 10
      Value     Mean
        1        0.071 A
        2        0.000 B
  ---------------------------------------------------------------------
```

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PLS-PM FOR ECOLOGICAL INTEGRITY MAPPING: CASE STUDY OF THE AVE RIVER BASIN, PORTUGAL

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ABSTRACT

The bonds between pollution sources, contaminant concentrations and ecological damage are quite complex to access, but the proper management of river basins requires the full understanding of those interactions. In the present study, four SEM-PLS models were used to set up environmental cause–effect relationships in a heavily polluted urban catchment: the Ave River Basin. Data were collected within this watershed relative to point source discharges, diffuse emissions, diffuse indicators (e.g. land use), contaminant concentrations and a Portuguese index of macroinvertebrates diversity (IPtIN). The same dataset was used in the four SEM-PLS models, but each run was based on a different combination of latent variables. In all cases, it was possible to recognize that nitrogen discharges from livestock production, industrial and urban treatment plants are the dominant threats to water quality. The model results were robust, characterized by high, adjusted R Squared values – from 0.744 to 0.931. The models were also used to draw water quality maps. Now, the purpose was to test their prediction capability. Since more than 80% of the water courses were correctly classified for IPtIN, the predictions were considered feasible.

Keywords: SEM-PLS, water quality, ArcGIS, Ave River basin.

1 INTRODUCTION

Growing population, intense economic development and following demographic expansion place not only heavy demands but also pollution sources in hydric resources. To respond to such threats is crucial to apply conservative management policies, guided by supportive studies with an environmental scope.

In water quality studies is crucial to use models, which can be process-based (mechanistic) or data-based (statistical) [1]. For the first case, it is necessary to have a deep scientific awareness, since these models are based in physical, chemical and biologic processes [2]. Streeter-Phelps equation [3], is a clear example of a mechanistic model, where dissolved oxygen and oxygen demands can be calculated along with time and distances. Many process-based models can be used for surface water quality studies, since they reveal to be powerful tools that can be used to predict transport of contaminants in water bodies, such as SWAT (Soil and Water Assessment Tool) [4], WASP (Water Quality Analysis Simulation Program) [5], MIKE 11 [6], HSPF (Hydrological Simulation Program-FORTRAN) [7], ELCOM-CAEDYM (Estuary and Lake Computer Model Computational Aquatic Ecosystem Dynamics Model [8]. Data-based models appeal to statistical methods and can be used for prediction or to establish cause-effect relationships. The advantage is that for experimental datasets the interactions between variables are revealed, what does not happen in process-based models, where all the interactions between pollution sources and contaminants are already defined.

SEM (Structural Equation Modelling), is an advanced statistical tool that has been widely used mostly to reveal complex cause-effect relationships. Generically there are two types of SEM [9], CB-SEM (Covariance-based SEM) and PLS-SEM (Partial Least Squares SEM)

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also called as PLS-PM (PLS Path Modelling). In the first case, the estimation procedure is based on a maximum likelihood estimation, while PLS-SEM is based in ordinary least squares regression [10]. The benefits of each type of SEM differs from study, purpose and dataset, but the opinion of the most appropriate method is still divergent [9], [10]. SEM first steps were given in social studies, nowadays non-social sciences are adopting this modelling technique, including environmental sciences. Already in 1994 SEM was applied to study surface water quality [11], years later other studies used SEM, for purposes such as an evaluation of groundwater quality [12], comparison of pollution sources in surface waters [13] and even population awareness about water quality [14], [15]. In a recent study [16] SEM-PLS was used to compare the relationship between point source pressures, diffuse pressures and diffuse indicators with contaminants and ecological integrity, while [17] used simplified SEM-PLS models.

In this study, SEM-PLS was applied to an Ave River basin environmental dataset. This area (Fig. 1) was chosen due to the vast water pollution background. In the second half of the 20th Century, it was classified as one of the most polluted river basins in Europe, due to the high effluent discharge without treatment. At the end of the century, the Portuguese Government was committed with a Plan to remediate the Ave River. Since then water quality has improved, but some problems persist, which has caught the attention of several experts and researchers that conducted studies to evaluate the pollution status and changes in this river basin. In 1992 a study [18] evidenced that several industries were the cause of heavy metal pollution. In 2009 when comparing data from previous studies [19] it was noticed that heavy metal pollution was decreasing [20], on the other hand, other threats have arisen in this river basin. The eutrophication effects were accessed in a study [21], accusing not only nutrients from discharges but even from agricultural practices, though other authors [22], [23] defend that livestock production is another threat for the water quality of this river basin. Therefore to approach such immensity of variables SEM-PLS was the chosen statistical method.

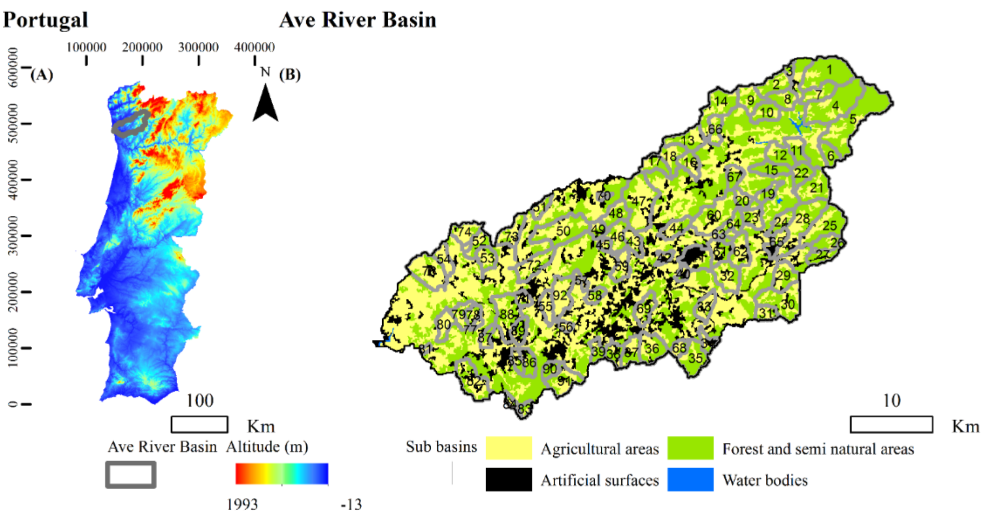

Figure 1: Portugal Map with altitude, Ave River basin land uses.

2 METHODOLOGY

The objective of this study was to use pollution data in four structural equation models, transpose the results into water quality maps for Ave River basin. The applied six-step methodology is represented in Fig. 2.

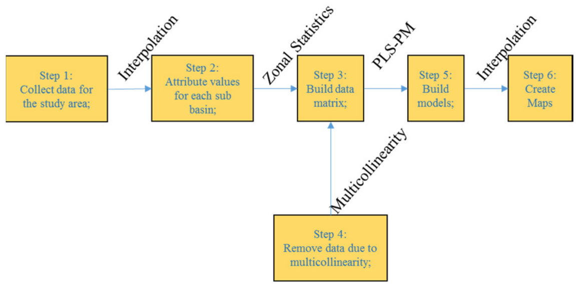

Figure 2: Schematic methodology.

As a first step, it was gathered all the necessary data for structural equation models. Data were grouped into three categories, pollution sources, contaminants concentration, and water quality.

For pressures, it was gathered a vast number of variables such as industrial and urban annual discharges in surface waters of phosphorous, nitrogen, oxygen demands (CBO_5 and COD) (kg.year^{-2}), percentage of area covered with different land uses and land use conflicts [24], population density, soil loss (t.ha^{-1}.year^{-1}), wildfire risk, nitrogen and phosphorous discharges from agriculture and forest (in the same variable) and livestock production (kg.km^{-2}.year^{-1}). For contamination, the gathered variables were the annual averages of concentrations of metals As, Cr, Cu, Fe, Pb, Zn (µg/l); nutrients NO_3 and PO_4 (mg/l); total suspended solids (mg/l) and oxygen demands COD and BOD_5 (mg/l). For Water Quality, was used as a single variable, North Invertebrate Portuguese Index ($IPtI_N$). This index was calculated through the count and diversity of benthic macroinvertebrates in river sites, variating the index score from 0 to 1 (dimensionless). A high score represents high macroinvertebrates biodiversity while a low score conveys that there is a lack of biodiversity. One advantage of the usage of this bioindicator is that macroinvertebrates are sensitive to practically all forms of pollution, so by calculating the $IPtI_N$ pollution effects are accessed, for a detailed explanation, please see [25]. All the data sources are demonstrated in Table 1.

For step 2, it was necessary to interpolate $IPtI_N$, surface water parameters, urban and industrial discharge, using Topo to Raster tool in ArcMap [26], to create a raster file for each variable. For other variables, it was not necessary to interpolate since the information was provided in the form of shapefiles and rasters covering the river basin. Since this study is hydrological and statistic, it was chosen to use sub-basins as statistical samples, delineated through ArcHydro [27]. In step 3 it was attributed a value of each variable for each sub-basin, using Zonal Statistic as Table tool, creating a data matrix for each river basin. In step 4 it was removed some variables due to multicollinearity, the used criteria were that the VIF (variance inflation factor) of each variable among a group (contamination, pressures) would not be higher than 5, which is a recommended limit value for SEM-PLS models [28]. For Water Quality this VIF analysis was not applied since this latent variable is composed of a single measured variable, $IPtI_N$. In Fig. 3 is demonstrated an example of an SEM-PLS formative model, composed of three latent variables (A, B and C) and nine measured variables (1 to 9).

Table 1: SEM-PLS data Source for models.

Variable	Used In Model	Units	Data Source
$IPtI_N$	x	Dimentionless	https://www.sciencedirect.com/science/article/pii/S014765131630207X
BOD_5	x	mg/l	http://snirh.pt/
COD	x	mg/l	
NO_3	x	µg/l	
PO_4	x	µg/l	
As		µg/l	
Cr	x	µg/l	
Cu		µg/l	
Fe	x	µg/l	
Pb		µg/l	
Zn		µg/l	
TSS		mg/l	
Wildfire Risk	x	dimensionless	http://www.icnf.pt
Population Density	x	inhabitant/km^2	http://censos.ine.pt
Agricultural Areas	x	%(km^2/km^2)	http://www.dgterritorio.pt/
Conflicts	x	%(km^2/km^2)	http://www.sciencedirect.com/science/article/pii/S0048969715313139
Agriculture and Forest N		kg/yr/ km^2	http://www.apambiente.pt
Agriculture and Forest P	x	kg/yr/km^2	
Livestock N	x	kg/yr/ km^2	
Livestock P		kg/yr/ km^2	
Industry BOD_5		kg/yr	
Industry COD	x	kg/yr	
Industry N	x	kg/yr	
Industry P		kg/yr	
Urban BOD_5		kg/yr	
Urban COD		kg/yr	
Urban N	x	kg/yr	
Urban P		kg/yr	

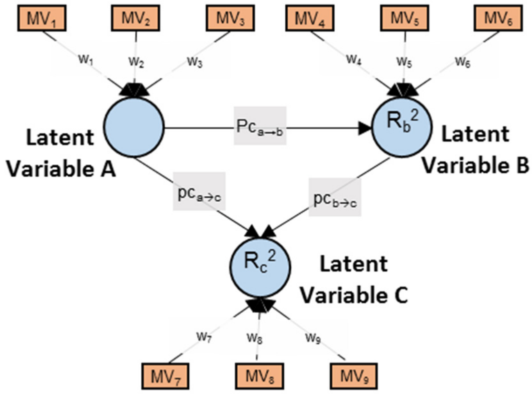

Figure 3: Formative structural equation model example.

As a fifth step, SEM-PLS models were created. In an SEM-PLS model, the user creates latent variables (LV), establishes the connections between them and chooses which measured variables (MV) compose each LV. The algorithm attributes weights (w) for each measured variable and path coefficients (pc) for each connection between LVs to maximize the R squared. For each LV is assigned to a measured and predicted score eqns (1) and (2)

$$\text{Measured Score: } LV_i = \textstyle\sum_{i=1}^{n} (MV_i \times w_i), \quad (1)$$

$$\text{Predicted score: } LV_j = \textstyle\sum_{i=1}^{n} (LV_{i\to j} \times pc_{i\to j}). \quad (2)$$

The measured score is based in the sum of the product of each MV with the attributed weight, while the predicted score is based in the sum product of the antecedent latent variables with the respective path coefficient. In the example, latent variable A is the only that does not have a predicted score because it does not have any antecedent latent variables. After determining the predicted score of $IPtI_N$ (for each sub-basin), it was created a raster file through the interpolation of the values in each sub-basin centroid. The created raster was used to attribute an average value of $IPtI_N$ for each watercourse, which is step 6.

3 RESULTS AND DISCUSSION

Four SEM-PLS models were applied for the same dataset. Model 1, Fig. 4, was depicted with only 3 latent variables, “pollution sources”, “contamination” and “water quality”, similar to one of the models presented in a previous study [17]. In Model 2 “water contamination” was divided into three types of contamination, by “oxygen demands”, “nutrients” and “metals”. Model 3 “pollution sources” were divided according to their type of source, “point source pressures”, “diffuse emissions” and “diffuse indicators”. Model 4, Fig. 5 it is the most complex model, where all the water contamination forms, and pollution sources are differentiated.

At first sight, all the models seem to be highly explicative, since the adjusted R squared values are high for “water quality”, where the values for models 1 to 4 are 0.931, 0.816, 0.928 and 0.828, respectively. It is also stated that, for the same dataset, when more latent variables are used in a model, the algorithm loses the capacity to reach higher R-squared values for endogenous latent variables (with incoming arrows), because are shown the adjusted r-squared values in models.

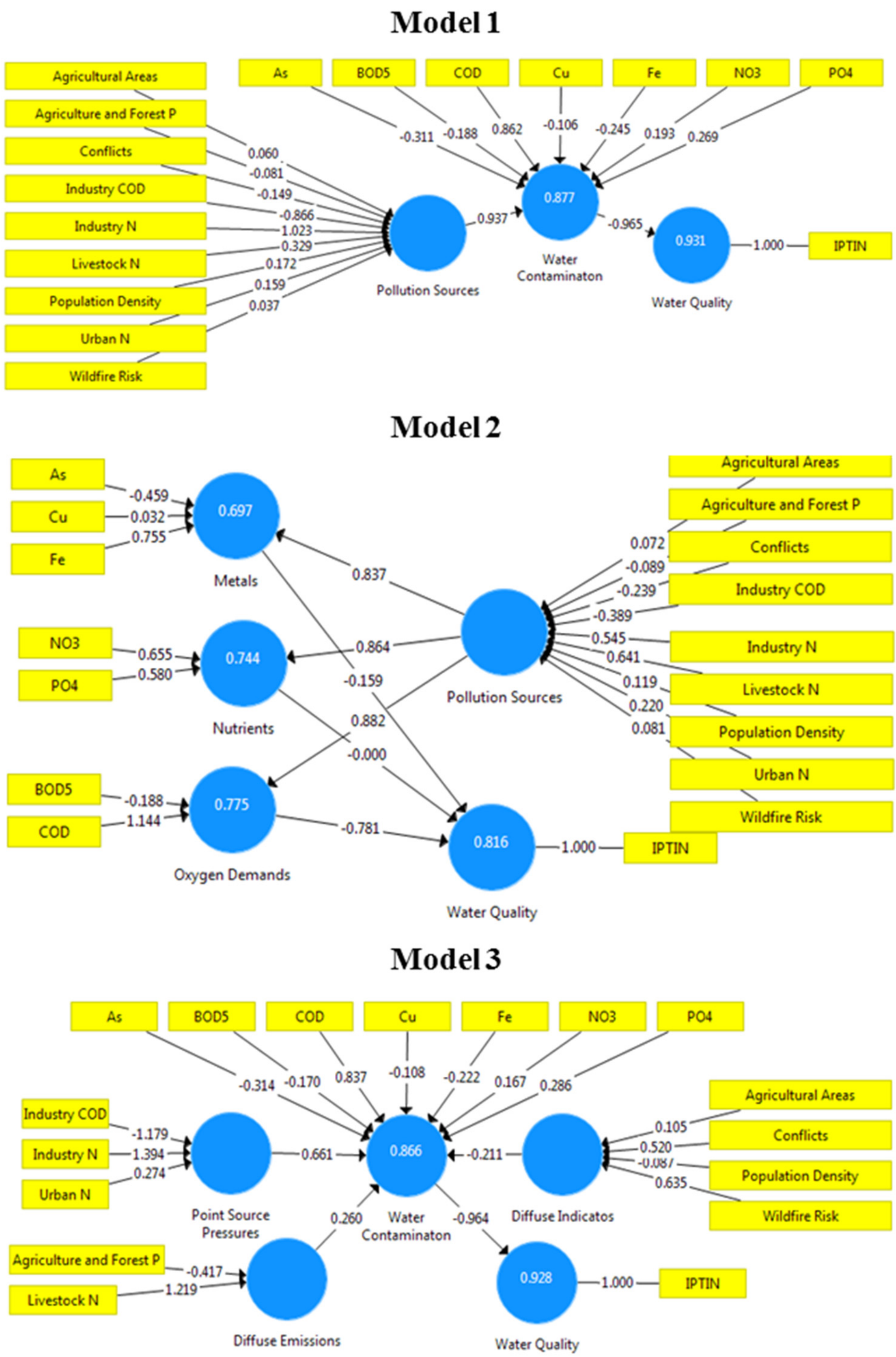

Figure 4: Structural equation models 1, 2 and 3.

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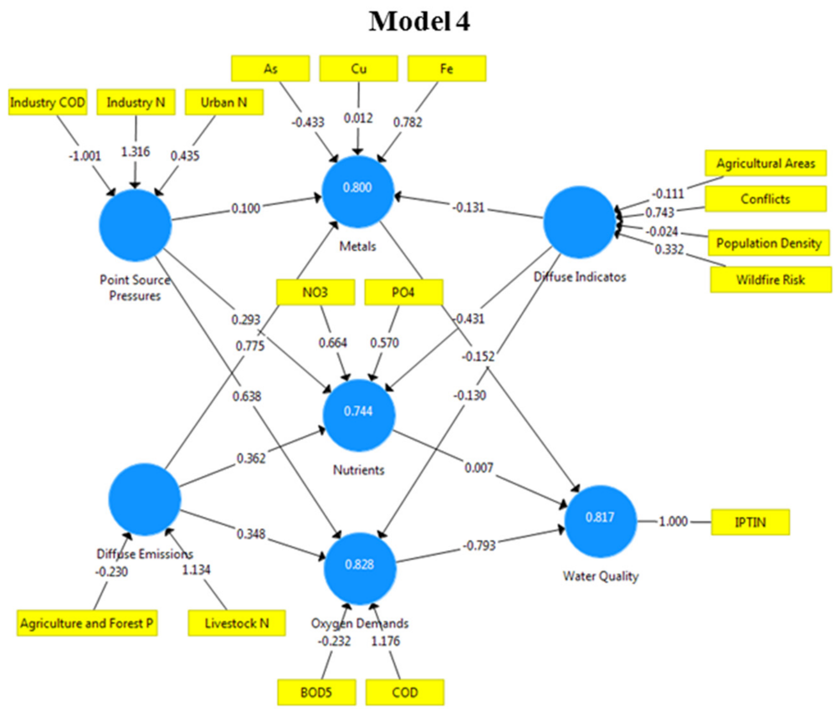

Figure 5: Model 4.

Most of the path coefficients from all the models seem to have a correct sign. For example in model 1 “pollution sources” increase “water contamination” (pc = 0.937) while “water contamination” decreases “water quality” (pc = -0.965). But in other models, there are some path coefficients that do not have an expected value. In model 2 “nutrients” have a null effect in “water quality” this can be possible if the other pollution sources have a stronger impact in the loss of ecological integrity, so the effect of “nutrients” is absorbed by other variables. In model 3 “point source pressures” and “diffuse emissions” increase “water contamination”, but “diffuse indicators” decrease it (pc = -0.211). Possibly this happens because the other LVs have a direct impact in “water contamination”, while “diffuse indicators” are not so directly associated to “water contamination” and is attributed a negative sign because the measured variables that composed it are positively correlated with “water contamination”. For model 4 is clearly verified the same, besides both “point source pressures” and “diffuse emissions” have a positive pc in “nutrients”, “oxygen demands” and “metals”, but “diffuse indicators” path coefficients are negative. In model 4 is still noticed that nutrients have an almost null effect in “water quality” just like in model 2.

To compare the effect of each latent variable and measured variable among the four models it was calculated the product between the total effect of each LV in “Water Quality” with the weight of each measured variable that composes it (Table 2). For instance, in model 1 the direct effect (or path coefficient) of “pollution sources” in “water quality” is 0 because these variables are not connected, but since “pollution sources” composes “water contamination” (pc = 0.937) that composes “water quality” (pc = -0.965), the indirect effect of “pollution sources” in “water quality” is the product of (-0.965 × 0.937) which is -0.904.

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The total effect is the sum of the direct and indirect effects, which is still -0.904 in this case. In model 1 the product of the total effect with the weight of nitrogen from urban discharges (Urban N weight = 0.159) is -0.144. This procedure was applied to all variables in all models, as is shown in Table 2.

Table 2: Product of total effect on water quality and the weight for each measured variable.

	Model 1	Model 2	Model 3	Model 4
BOD_5	0.181	0.164	0.164	0.184
COD	-0.832	-0.996	-0.807	-0.933
NO_3	-0.186	0.000	-0.161	0.005
PO_4	-0.260	0.000	-0.276	0.004
As	0.300	0.073	0.303	0.066
Cu	0.102	-0.005	0.104	-0.002
Fe	0.236	-0.120	0.214	-0.119
Agricultural Areas	-0.054	-0.067	0.021	-0.013
Agriculture and Forest P	0.073	0.082	0.105	0.090
Conflicts	0.135	0.221	0.106	0.089
Industry COD	0.783	0.356	0.751	0.520
Industry N	-0.925	-0.504	-0.888	-0.683
Livestock N	-0.297	-0.592	-0.306	-0.444
Population Density	-0.156	-0.110	-0.018	-0.003
Urban N	-0.144	-0.203	-0.175	-0.226
Wildfire Risk	-0.033	-0.075	0.129	0.040

By analysing the reported results in Table 2, it can be assured that chemical oxygen demand (COD) is the surface water parameter that has the most substantial effect in the decrease of "water quality", while biological oxygen demand (BOD_5) do not. This difference might be due to the fact that COD in surface water is high when many industrial effluents are discharged due to the low concentration of organic matter. In the other hand, BOD high values are typical from rivers with urban effluents due to the high organic loads. Probably the model attributed a stronger and negative effect to COD, and weaker and positive to BOD since industrial effluent discharge has a higher impact in the river basin, rather than urban effluents. Arsenic (As) concentration is another parameter that has a similar effect in all models, and it does not low "water quality". This cannot be viewed that As increases water quality, because the nefarious effects of arsenic in the environment are well-known, but according to the applied modulation technique this variable is not restraining water quality in Ave river basin, probably because pollution sources that release arsenic few, which is concordant to the decreasing tendency of heavy metal pollution [20].

According to the models, the contribution of NO3, PO4, Fe and Cu in $IPtI_N$ is inconclusive. Since is seen that in models 1 and 3 nutrients decrease water quality, while in models 2 and four, nutrients do not increase water quality, but Cu and Fe decrease. The main difference from models 1 and 3 to models 2 and 4 is that the latent variable "contamination" is substituted by three other latent variables, where the type of contamination becomes differentiated into "metals", "nutrients" and "oxygen demands". In models 2 and 4 is possible to trace the individual effects of "metals", "nutrients" and "oxygen demands". Maybe the effects of nutrients occur when these variables are gathered with other surface water parameters, which can be called as a combined effect. While for Fe and Cu, the effect might occur isolated. Anyhow for both of these variables, their contribution might be underestimated in different models due to the fact that COD has high influence in water quality and might absorb their effect. As it can be seen in supplementary material, COD is the variable with the strongest correlation with $IPtI_N$ ($r_{Pearson} = -0.888$), and so is the surface water parameter with strongest decrease effect with $IPtI_N$ along with the four models.

For agricultural areas, the product is positive for models 1, 2 and 4 but near to zero for all, so this variable does not seem to restrain water quality. For wildfire risk in models 1,2 and 4 the product is near to zero, only in model 3 the product is positive and considerable, so in an overall perspective, the effect of this variable is unknown for Ave river basin water quality. The releases of phosphorous from forest and agriculture, land use conflicts and released COD from industry are pressures that do not restrain water quality. Discharges of nitrogen from industry, livestock, and urban discharges are the pressures that considerably decrease water quality in the river basin, while for population density it is verified that besides the sign of the product is negative for all models, the results are near to zero, so it is assumed as a minor pressure.

The SEM-PLS prediction of $IPtI_N$ for each sub-basin were interpolated into raster files, for each watercourse. It was calculated the average value and then classified as very poor, poor, moderate, good and excellent according to the $IPtI_N$ Portuguese classification [25], Fig. 6.

Since adjusted R squared values of "water quality" are considerably high, the prediction maps of are quite similar measured $IPtI_N$. The classification of water courses majorly matches for all models, the unmatched watercourses are presented in Fig. 6 (F). For a clear distinction of the prediction results, the percentage of Ave River basin watercourses length is shown in Table 3, comparing the measured classification with the predicted.

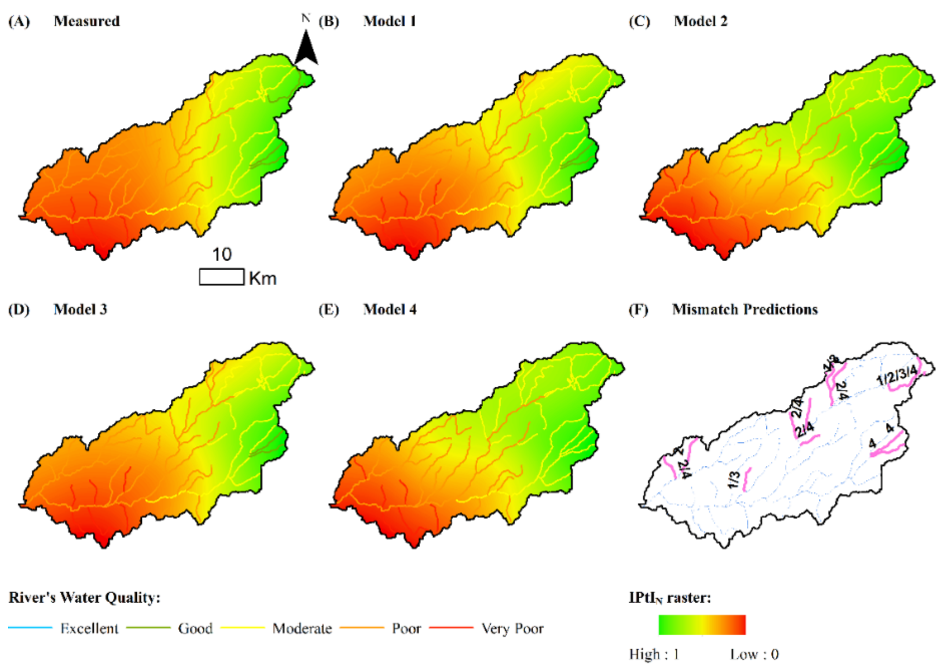

Figure 6: $IPtI_N$ comparison: (a) Measured; (b) Model 1 prediction; (c) Model 2 prediction; (d) Model 3 prediction; (e) Model 4 prediction; and (f) Mismatch predictions.

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Table 3: Comparison of measured $IPtI_N$ with prediction for each watercourse.

Measured → Model	Model 1	Model 2	Model 3	Model 4
Very Poor → Very Poor	7.9%	7.9%	7.9%	7.9%
Poor → Very Poor	1.3%	3.1%	1.3%	1.3%
Poor → Poor	53.2%	44.9%	53.2%	46.8%
Poor → Moderate	0.0%	6.4%	0.0%	6.4%
Moderate → Poor	1.6%	0.0%	1.6%	0.0%
Moderate → Moderate	29.3%	30.9%	29.3%	30.9%
Good → Moderate	3.0%	3.0%	3.0%	6.8%
Good → Good	3.7%	3.7%	3.7%	0.0%

For models 1 and 3, 94.1% of the prediction matches, while for models 2 and 4, 81.6% and 81.7% respectively. Models 1 and 3 have exactly the same prediction classification and the highest percentage of classification matches. These models have in common that the surface water parameters are all gathered in the same LV, which resulted in higher predictions, while in models 2 and 4 lower matching percentages were obtained. The used algorithm in SEM-PLS models tends to maximize all the R-Squared Values for all latent variables, so as more latent variables are placed in the model the R squared value of crucial variable “water quality” decreases, so since models 1 and 3 have only 2 latent variables that have a calculated R-squared, they can explain more variation of $IPtI_N$, which make them more adequate for prediction purposes rather than models 2 and 4.

According to the Portuguese legislation (Decree-law no. 236/98), the maximum allowed concentration for drinking purposes are 250 mg/l (NO_3), 50 μg/l (As), 100 μg/l (Cu), and 50 μg/l (Fe). In any the locations of Ave River basin, these thresholds were not overlapped. For COD, BOD and PO_4 the limit values are established for captured water for the production of human consumption water, respectively 3 mg/l, 30 mg/l and 400 μg/l. For the 92 analysed river basins it was founded that the concentration of BOD and PO_4 exceeded the limit values in 1 and 12 sub-basins, respectively. Besides the number of exceedances is not high, it is essential to refer that even when the concentrations are below legal limits there is still possible to track damages in ecosystems [29]. So when water quality is studied is crucial to use bioindicators, because not only chemical status determines water quality, but also ecological integrity.

SEM-PLS was the chosen prediction technique, due to the fact that the presented models are simple to analyse. The cause-effect relationships were clearly demonstrated in four models and the mismatch predictions were low. When modelling techniques are used, is important to have not only a robust and explicative model but also, when possible, simple to analyse, by readers and or users, because models are communications tools [30].

4 CONCLUSIONS

Four SEM-PLS data models were created with the same dataset, this study can lead to conclude that each model has its purpose. Model 1 is the simplest model, as an advantage is the most accessible model to interpret for practically any reader and like model 3, they are the most suitable for prediction purposes. Models 2 and 3 differentiate types of contamination and pollution sources separately, which makes them quite useful when these subjects are studied disjointedly. Model 4 contains more information than all the other models, due to the higher number of latent variables it can lead to a better understanding of the relationship between different pollution sources and released contaminants.

In further studies is intended to use these models to predict $IPtI_N$ for Ave River basin, by using new pressure values in sub-basins, in order to verify the validity of these models for future data. As it was demonstrated in another study [17] that the application of SEM-PLS in unpolluted basins can result in lower R-Squared values what would lead to an incorrect classification of $IPtI_N$. Anyhow this methodology should be compared and tested with another river basins, but it is warned that not the same variables can be always used because the dismissed variables through multicollinearity might not be the same.

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SOCIAL PARADIGM SHIFT REQUIRED TO COUNTER THE EUTROPHICATION OF THE HARTBEESPOORT DAM IN SOUTH AFRICA

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ABSTRACT

Sewage discharges are poisoning major rivers and dams in South Africa, including the Hartbeespoort Dam. High nutrient concentrations promote algae growth, leading to eutrophication. The dam has been in a hypertrophic state since the early 1970s. Mismanagement of waste water treatment works (WWTWs) within the catchment area are largely to blame, with over 280 tons of phosphate and nitrate deposits. Point source pollution in the form of malfunctioning WWTWs and diffuse sources from informal settlements present along streams and rivers within the catchment area, are responsible for the high nutrient levels. Many of these settlements use water directly from the river/stream. The first step to address the problem of eutrophication is by reducing the nutrient source. A conservative mass transport model was developed to predict phosphate levels and was used to assess the impact on the dam. The average phosphate levels entering the dam is 0.72 mg/L and the target to reduce algae growth is 0.15 mg/L. Various treatment options were investigated to solve the problem, but these efforts were mainly focused on treating the symptoms rather than the cause and treatment options were very costly. Legislation regarding water pollution this is in place, but is not enforced by government. The model predictions indicate that even if all WWTWs reach a zero discharge of phosphates, the required target will still not be met. It is concluded that the only feasible option would be a paradigm shift in the social behaviour of people living in informal settlements and this paradigm shift requires education. More often than not, scientists and engineers only consider technical solutions. The result of this study underlines the importance of a transdisciplinary approach, involving scientists and the rural communities to reach an effective solution.

Keywords: sewage discharges, social injustice, informal settlements, phosphate, transdisciplinary approach.

1 INTRODUCTION

South Africa is viewed as a water-stressed country with an average annual rainfall of 500 mm. Available water resources are already being intensively used and controlled. Seven of South Africa's nine provinces rely on inter-basin transfers which provide more than half of their water requirements [1].

1.1 The Hartbeespoort Dam

The Hartbeespoort Dam is an arch type dam situated in the North West Province of South Africa. It lies in a valley to the south of the Magaliesberg mountain range and north of the Witwatersrand mountain range, about 35 km north west of Johannesburg and 20 km west of Pretoria.

The Hartbeespoort Dam was designed for irrigation purposes, which is currently its primary use, as well as for domestic and industrial use. The catchment landcover and the associated WWTWs is shown in Fig. 1. It is clear that the majority of land use consists of agricultural irrigation and urban areas, with some scattered informal settlements.

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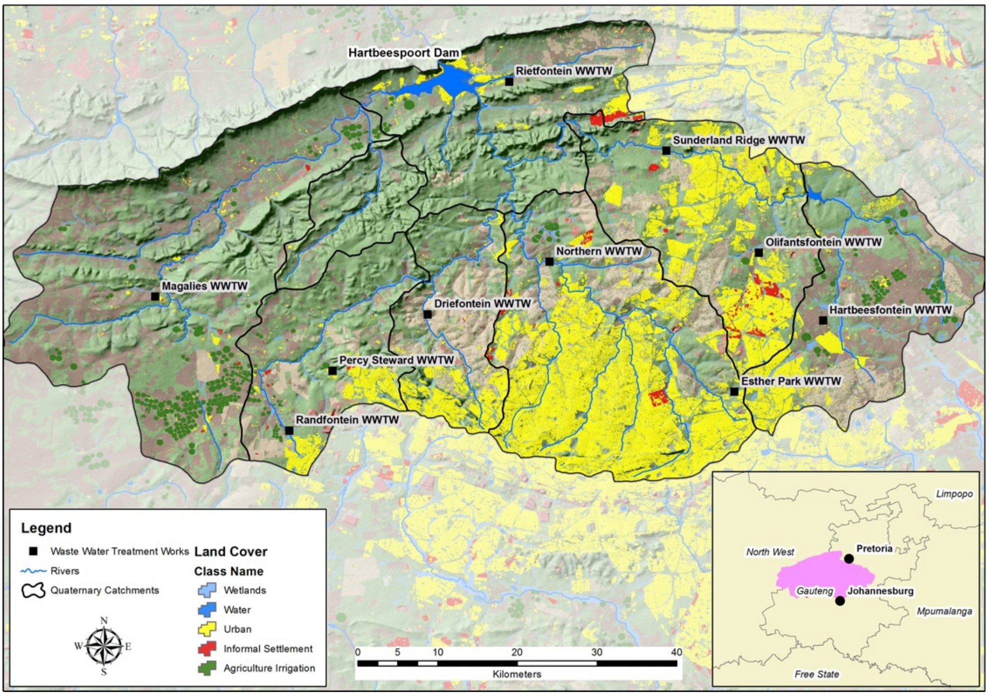

Figure 1: Hartbeespoort Dam catchment and WWTWs [20].

The dam has suffered from a hypertrophic state (excessive levels of nutrients) since the early 1970s. Mismanagement of waste water treatment from urban areas within the Hartbeespoort Dam catchment is largely to blame, having distorted the food web with over 280 tons of phosphate and nitrate deposits [2]. A total of ten WWTWs exist within the catchment of which some are known to be problematic [3].

Various scientific reports determined that phosphates and nitrates originating from sewage treatment plants in the catchment are the main source of nutrients involved in eutrophication [4]. Estimated phosphate concentrations from effluent together with the operating capacity (OC) for the various WWTWs are documented in Table 1. The extreme level of eutrophication is evident in excessive growth of microscopic algae, cyanobacteria, and water hyacinth as shown in Fig. 2.

Table 1: WWTW phosphate concentrations and operating capacities.

Waste water treatment works	OC (ML/d)	PO_4 (mg/L)	Waste water treatment works	OC (ML/d)	PO_4 (mg/L)
Driefontein	30	0.17	Magalies	0.38	5.98
Northern	390	0.30	Olifantsfontein	79	1.41
Sunderland Ridge	57	1.86	Hartbeesfontein	58	0.33
Randfontein	13	2.38	Esther Park	0.71	0.96
Percy Steward	17	1.85	Rietfontein	2.5	1.26

Figure 2: Aerial photo of the Hartbeespoort Dam [21].

1.2 Rehabilitation efforts

The Department of Water and Sanitation (DWS) implemented the Hartbeespoort Dam Integrated Biological Remediation Programme, Harties *Metsi-a-me* (translated: my water), in 2005 [2]. The aim of this programme was to address the imbalances and unhealthy biological conditions in the dam. The implementation was rolled out in two phases; Phase 1 focussed on establishing biological processes and mechanical harvesting of biomass (algae and hyacinths) as shown in Fig. 3 and Phase 2 focused on the treatment and bulk removal of phosphates. The program had various degrees of success, but in the long run it was not successful, due to poor project management. The failure to address mismanagement of WWTWs upstream of the dam before mitigation activities commenced, is one of the main reasons for this failure [5].

Figure 3: Algae harvesting barge [22].

1.3 Social justice

With the appointment of Nelson Mandela as President in 1994, a new era in the history of South Africa commenced. One of the first changes made by the new Minster of Water Affairs and Forestry, was to revolutionise the Water Act based on the rationale that water belongs to all South Africans, with sustainability, equity and efficiency being the guiding principles, or more simplistically "Some for all forever" [6].

Even though claims have been made that the South African National Water Act is one of the best in the world, the enforcement thereof remains a challenge. According to legislation, it mandatory that effluent discharge from WWTWs be treated to acceptable standards and returned to the water course from where it originated [4]. Clearly this is not the case in the Hartbeespoort catchment as is evident in media reports [5], [7]. The declining state of wastewater and sewage treatment infrastructure is contributing to the numerous pollution problems, including health problems in poorer communities [8].

Approximately 52% of poor underprivileged South Africans live in informal settlements [9]. These settlements tend to be unplanned and poorly serviced as in the case of settlements in the vicinity of the Hartbeespoort Dam. An example of one, is an informal settlements along the Jukskei River, which is a tributary of the Crocodile River reporting to the Hartbeesport Dam (Fig. 4).

Over the last 30 years, South Africa experienced rebellion of the poor [10]. The majority of these protests relate to poor service delivery (for example the lack of clean drinking water and poor sanitation).

Figure 4: Informal settlement along the Jukskei River [23].

In most informal settlements the inhabitants get water from a surface water body close by or groundwater. In the case of a surface water body, it is also the place where they bath and wash their clothes. In many instances pit latrines (Fig. 5) are also in close proximity to water sources, which pose a pollution risk. In the case of shallow groundwater systems, polluted groundwater can seep into downstream surface water bodies.

Figure 5: Example of a pit latrine [24].

2 PROBLEM

2.1 Problem statement

Recent programmes [2] and various research efforts [11], [12] focussed on treatment options for the Hartbeespoort Dam. It has been determined that the phosphate load entering the dam (average 0.73 mg/L) should be reduced to 0.15 mg/L to actively reduce the growth of algae. Being able to model the phosphate load entering the dam, allows for the investigation into individual pollution sources that are impacting the downstream system.

2.2 Aims and objectives

The aim of this study is to develop a water quality model to determine the impacts of point source pollution on the Hartbeespoort Dam. The specific focus is the levels of phosphates and how they relate to dysfunctional WWTWs. The objectives of this study are outlined as follows:

- Develop a water quality model to simulate the phosphate levels in the Hartbeespoort catchment.
- Estimate phosphate loads in the system where no data is available.
- Calibrate the model making use of existing monitoring data.
- Determine the impacts of various phosphate sources using the model.

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3 METHODOLOGY

3.1 Flow network data

To successfully model the phosphate loads in the Hartbeespoort catchment, observation data is required for model calibration. The DWS maintains an online hydrological database with all surface water flow gauging sites in South Africa [13]. In addition to the flow gauging information, water quality measurements are available from the resource quality database [14]. The water resource quality database contains many inconsistencies in chemical analysis results, which the user needs to take into consideration before using the data [15].

In 2011 a snapshot of the water quality database was taken and has been extensively modified, which included the removal of incomplete analyses and the addition of extra chemical variables calculated from concentrations of the major ions [15]. This augmented water quality dataset was chosen for the analysis. The best continuous set of monitoring data across all flow gauges in the Hartbeespoort catchment is October 2007 to July 2011. The associated flow network with gauging sites is shown in Fig. 6.

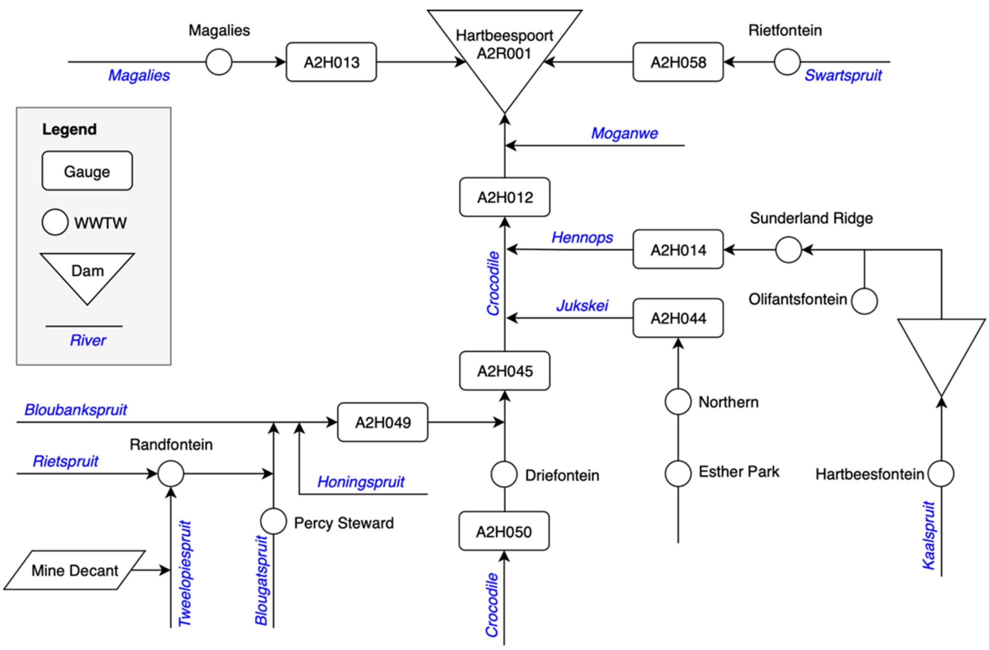

Figure 6: Flow gauging network.

In general, the effluent water qualities and volumes are not readily available for WWTWs. Personnel working at these facilities are reluctant to allow access to the premises for sampling. The only way to get an estimate of discharge qualities is to monitor up- and downstream of the WWTW. Operating capacities and estimated effluent qualities are documented in Table 1.

3.2 Model selection

The available data dictates the model to be used. The flow data is available both in daily and monthly time steps from the DWS hydrological database. Since water quality data is measured in monthly time steps, the selected model will also use monthly time steps for simulation purposes.

Various reactive mass transport model codes are available, but because only major ion analysis data is available, a conservative mass transport model is considered. Since the study requires the modelling of phosphates, the assumption of phosphates being conservative in the system of question should be investigated.

Binding of orthophosphate ($FePO_4$) in solution can take place in inflowing waters. However the uptake of $FePO_4$ by algae is more important than the physicochemical processes particularly in the pH range of 6.0–8.0. The greater the change of the pH from this range, the more likely $FePO_4$ will combine with iron, aluminium and manganese (at pH < 6) or calcium (at pH > 8) as shown in Fig. 7 [16].

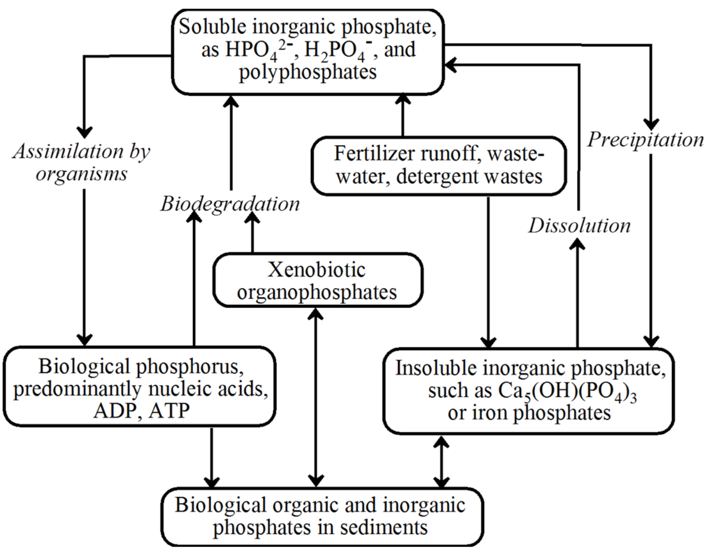

Figure 7: The phosphorous cycle [16].

As the mass transport model will be applied to the water courses and not the reservoir itself, the uptake from algae is not considered. The average pH across all monitoring points is alkaline and the general pH range is between 7.5 and 8.5 with a few selected events going as high as 9.1. Chemical binding of phosphates is therefore not completely ruled out, but considered negligible for the purpose of this study.

3.3 Water quality model

An alternative method to the traditional method of water quality modelling, is the backtracking approach [17]. This approach differs from the traditional one in that, instead of following the water in a volume element downstream, the system tracks back upstream to find the source concentrations of the pollutants. This scheme is depicted in Fig. 8, where:

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t = Time step;
i = Number of segments;
j = Number of concentrations;
C = Concentration;
V = Volume;
k = Decay rate constant;
T = Water temperature;
θ =Temperature correction coefficient.

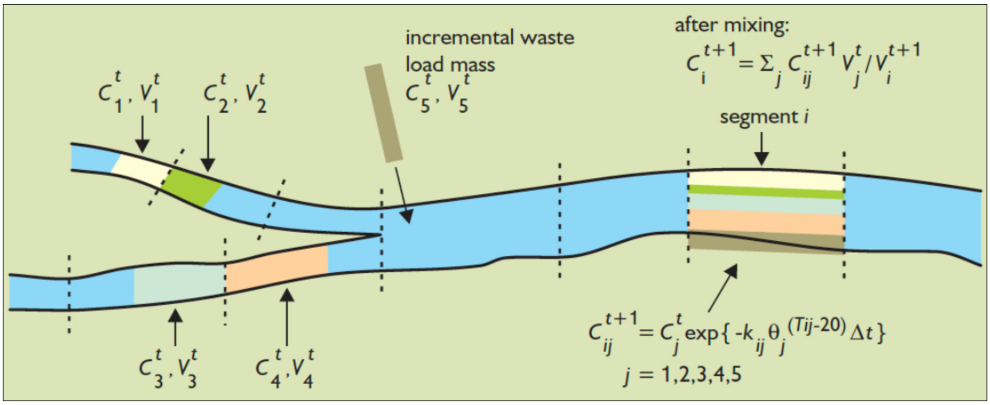

Figure 8: Backtracking approach for computing water quality [17].

Temperature measurements do not form part of the DWS monitoring data. The temperature term T_{ij} is chosen to be 20°C to effectively eliminate the θ term. Furthermore, since it was assumed that the phosphate behaves in a conservative manner, no decay will occur and the decay rate constant k, is chosen as zero.

3.4 Model calibration through genetic algorithm

Model calibration is carried out by assuming that constant phosphate loads are associated with WWTWs and applying a genetic algorithm (GA) to determine calibration parameters.

Genetic algorithms are randomized general-purpose search techniques used for finding the best values for parameters of existing models [17]. Unlike conventional optimization search approaches based on gradients, GAs work on a population of possible solutions, attempting to find a solution set that either maximizes or minimizes the value of a function of those solution values [18].

The parameter estimation, carried out by the GA, considers each parameter in question as a binary string where the length of the string *n* determines the maximum integer value that can be represented through 2^n. This binary parameter is then typically scaled between a minimum and maximum value. Karr et al. [18] notes that an additional bit can added to the binary string to represent the sign of the number. Finally, the individual parameter strings are concatenated to represent a single solution to the problem.

Initially the GA generates a random population of these solution strings, where each represents a potential solution to the problem. The problem in this instance is optimising the fit between simulated and observed values in the water quality model. The GA mimics the biological evolutionary process, where the binary solution string is considered a chromosome and each bit represents a gene. Once a chromosome (solution string) is generated, the individual parameters can be extracted from it and applied to the model to produce a result which is evaluated in terms of its fitness as a solution to the problem.

Reproduction is carried out by selecting only the chromosomes that provided the best fit to the problem. Various selection methods exist e.g. Elitist, Random, Roulette, Stochastic tournament and Tournament to name a few. New chromosomes are then constructed via a process called cross-over, where a random number of genes are swopped from two of the selected chromosomes to construct a new chromosome as shown in Fig. 9. This process allows random variation of the strongest chromosomes to be generated.

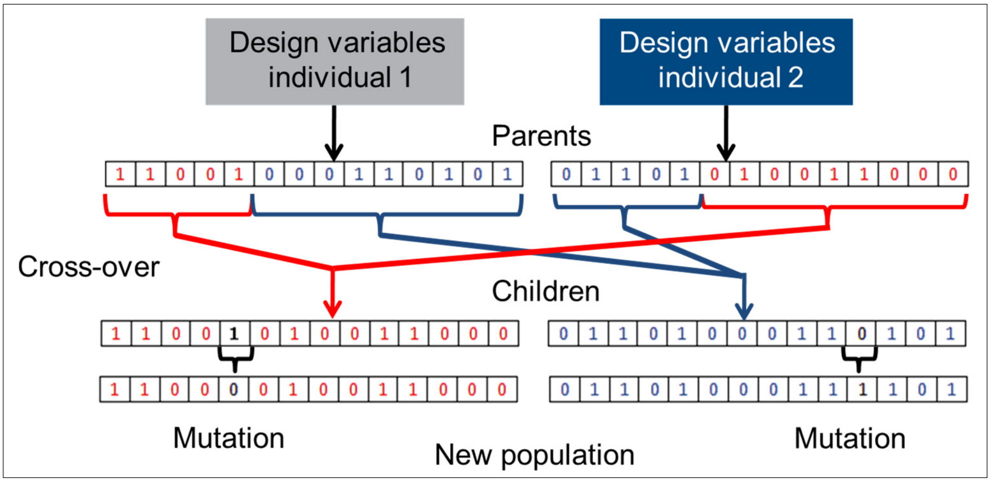

Figure 9: Crossover between two genotypes [25].

The last process of the GA, before it repeats itself, is mutation where a random bit in the newly created chromosome is toggled from its current value. This process is only applied to a small part of the total population to ensure an optimal solution is reached. Consider the case where none of the chromosomes had a specific gene in the same position, reproduction and crossover will never result in the presence of this specific gene, therefore the need for mutation.

The GA process is repeated until an acceptable goodness of fit is reached for the problem. Two statistical equations are used to quantify the goodness of fit between simulated and observed values, namely the Root Mean Square Error (RSME) and the Nash–Sutcliffe Coefficient (NSC). The RMSE is a frequently used error index, where it is generally accepted that the lower RSME value represents a better model fit than a higher RMSE value and is expressed in eqn (1)

$$\text{RMSE} = \sqrt{\frac{\sum(P_i - O_i)^2}{n}}, \tag{1}$$

where:
i = Total number of observation points;
P_i = Predicted value at point i;

O_i = Observed value at point i;
n = Number of reference points.

The NSC is a widely used statistical method to compare the predictive capability of a hydrologic model, it shows how well a hydrologic model performs. The NSC compares both the volume and the shape of the runoff and is expressed in eqn (2)

$$NSC = 1 - \frac{\sum_{i=n}^{n}(Oi - Pi)^2}{\sum_{i=n}^{n}(Oi - \bar{O})^2}, \quad (2)$$

where:
i = Total number of observation points;
P_i = Predicted value;
O_i = The observed values for the n observations;
$\bar{O}$ = The mean of the observed values.

The NSC ranges between $-\infty$ and 1 and values ranging between $0.75 < NSC \leq 1.00$ are classified as very good, values between $0.65 < NSC \leq 0.75$ classified as good, values between $0.50 < NSC \leq 0.65$ classified as satisfactory and values of $NSC \leq 0.50$ as unsatisfactory.

4 RESULTS AND DISCUSSION

4.1 Calibration results

Both RMSE and Nash–Sutcliffe methods were considered as goodness-of-fit criteria for use in the GA together with the use of the five selection methods mentioned previously. The best results were obtained my making use of the RMSE as minimization criteria together with the Elitist selection algorithm.

The network calibration results are shown in Fig. 10. Good calibration is achieved throughout the network with respect to flow. The model only over predicts the final average flow at A2R001 (Hartbeespoort Dam) with 4.6%.

The phosphate calibration results are satisfactory for most of the gauge positions with the exception of A2H013 and A2H049. The differences between the observed and measured phosphate concentrations at A2H013 and A2H049 can be attributed to the fact that phosphate loads at the WWTWs are modelled as a constant, as no actual time series discharge volumes and water quality data is available. This is also the case for the mine decant taking place upstream of A2H049. The phosphate concentrations at A2H013 is the lowest of all the gauges considered and represents only 0.02% of the phosphate load at A2R001. The model over predicts the average phosphate concentration at A2R001 with 5.2% and the average phosphate load with 10.1%.

To improve the overall calibration, actual WWTW discharge volumes and water qualities will be required. The calibration result is deemed satisfactory considering data restrictions and the assumption that the phosphates behave conservatively.

Modelled phosphate loads for the segments between gauges in the network, forms part of the calibration set and these calibrated loads are representative of the diffuse phosphate sources. These diffuse sources relate to wash off and shallow groundwater seepage into the streams and rivers. Phosphate contributions from informal settlements (Fig. 4) are then by implication also contained within this term.

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Figure 10: Network calibration results.

4.2 Modelled scenarios

It has been shown earlier that the WWTWs are considered as the main culprit in the eutrophication state of the Hartbeespoort Dam. When considering the extreme case where all WWTWs are simulated with a zero-phosphate concentration, the total phosphate load at the inflow of the dam is reduced by nearly 40%. The average resultant phosphate concentration is then 0.39 mg/L which still does not reach the 0.15 mg/L target required to inhibit algae growth.

Mine decant took place at Tweelopiespruit (upstream of gauge A2H049) during the calibration period. The phosphate concentrations of the decant water are very low (~0.01 mg/L), and do not make a significant contribution to the final phosphate load. Currently the mine decant has ceased due to pumping of the mine water. The decant volume was roughly 3% of the total inflow to the dam and the loss of this flow volume has an insignificant effect on the total phosphate load.

A detailed study of each informal settlement would be required to quantify the phosphate load emanating from each of them. However, a first estimate can be obtained by using some of the catchments within the study area as reference. For this scenario, the phosphate concentrations for all the WWTWs was set to zero. To obtain an estimate for background phosphate concentrations, gauge A2H050 was used as the land cover comprise of mainly of small holdings and urban areas. The average phosphate concentration is 0.151 mg/L which coincidentally compares with the 0.15 mg/L target concentration required at the dam inflow. The Magalies River catchment was chosen to get an indication of the contribution of agricultural activities to the phosphate load, since the land cover of this catchment is predominately natural with agricultural activities (see Fig. 1). The average phosphate concentration was calculated as 0.297 mg/L and it is assumed this concentration includes the estimated background phosphate concentration of 0.151 mg/L. Since 93% of the flow to the dam originate upstream from gauge A2H012, the average phosphate concentrations at this point was calculated as 0.432 mg/L, bearing in mind all WWTWs were set to have zero phosphate concentrations. This results in an average net contribution of 0.135 mg/L phosphates that are assumed to be contributed from the informal settlements. By also removing this contribution, in addition to the phosphate load from the WWTWs, the phosphate load entering the dam is reduced by 60.6% which translates to a phosphate concentration of 0.284 mg/L at the dam inflow.

5 CONCLUSIONS AND RECOMMENDATIONS

A water quality model, used to simulate the phosphate concentrations within the Hartbeespoort catchment, was successfully setup and a good calibration was achieved, considering the assumption that phosphates behave conservatively in water courses.

Existing monitoring data was used for calibration purposes. Data from October 2007 to July 2011 were used, mainly because the flow gauges have good continuous data over this period and data verification and corrections to the dataset was performed during a previous project. Calibration was performed by making use of a GA, which minimises the RMSE between simulated and observed values at every monitoring point and uses the Elitist selection algorithm. Unknown phosphate loads within the system were treated as calibration parameters and are therefore only presented as constant values within the network.

An extreme scenario was considered where the phosphate concentrations of all the WWTWs were reduced to zero to determine the impact of the phosphate load entering the dam. This resulted in a 40% reduction in the phosphate concentration to 0.39 mg/L which still does not meet the target of 0.15 mg/L. The impact of the mine water decant was also investigated, but was deemed negligible.

Informal settlements along streams also contribute a to the total nutrient load entering the dam. In a first estimate of possible phosphate contributions from informal settlements, it was estimated that they contribute roughly 20% of the phosphate load to the dam. It is however stressed that a detail assessment of these settlements is required to give more accurate predictions regarding possible impacts. These settlements are a result of social circumstances and to relocate the inhabitants is not always practical solution. A social paradigm shift is required in the form of social upliftment. It is recommended that practices that have emerged as powerful upliftment tools [19] should be implemented. Examples of these upliftment tools include education of the local women, as they are responsible for feeding the household and ensuring there is water; and partnerships between government, international organisations and academics to assist in improving housing, facilities and education.

Finally, it is concluded that to reach the 0.15 mg/L target for phosphate concentrations entering the dam, the phosphate contributions from both the WWTWs and diffuse sources in the catchment needs to be addressed.

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TURBIDITY PATTERNS IN THE ALBUFERA LAKE, SPAIN, AND THEIR RELATION TO IRRIGATION CYCLES

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ABSTRACT

The Albufera Natural Park (Valencia, Spain) is one of the most representative coastal wetlands in the Mediterranean basin. It holds several protection designations at national and international level, such as Spanish Natural Park, Special Protection Areas (SPAs) for birds, Sites of Community Importance (SCIs) and Ramsar Site. Both the park and its main lake, Albufera's lake, face several environmental problems. One of them is reduced transparency and lake clogging. The lake is highly dependent on the rice cycle and on irrigation returns, mainly from the Acequia Real. In this study, we analyse the monthly transparency and turbidity patterns during year 2018, and we relate them to irrigation cycles. We used Sentinel 2A satellite images from the European Space Agency, which have an atmospheric correction. Remote sensing results were compared with in situ data from the monitoring program of the Environment General Subdivision of the regional government. This monitoring program samples five points on a monthly basis, and analyses Secchi disk depth, suspended solids and chlorophyll a. Our results show the temporal and spatial pattern of turbidity in the Albufera lake which offers relevant information for water resources management.

Keywords: sentinel, satellite, turbidity, Secchi disk.

1 INTRODUCTION

Wetlands are of vital importance because they provide a great variety of ecosystem services [1]. Among others, they are an important freshwater reserve and a source for groundwater recharge, and in coastal areas they provide defence against marine intrusion. However, they are among the most endangered ecosystems, especially in coastal areas due to several anthropogenic threats, e.g. treated or untreated wastewater discharges or reduced water inputs due to agricultural uptake. These threats cause changes in water quality parameters such as reduced transparency and increased phytoplankton biomass [2]. In recent years there is a growing interest in developing indicators to monitor environmental change in these areas [3]. Many scientific studies have addressed the issue of mapping and monitoring natural habitats through remote sensing and obtaining indicators of their conservation status [3].

Remote sensing is a valuable tool for monitoring several parameters. Some studies have analysed the distribution of sediment in suspension allowing the construction of a synoptic description of turbidity patterns [4]. MODIS images have been used to determine the spatio-temporal variability of turbidity from their reflectance; this variability has been related to the Secchi disk depth in ocean and coastal waters [5]–[8] and to a lesser extent in rivers [9]. Also, Landsat reflectance images have been used (in a turbid estuary [10]), and their signal penetration at different depths [11], [12]. Studies on wetland water bodies are more scarce due to a higher complexity caused by their typical shallowness and turbidity.

The determination of turbidity in shallow waters requires the use of spectral bands that are sensitive to turbidity and have a limited depth penetration to avoid substantial interference from the bottom [13]. Water absorption increases rapidly from red (645–700 nm) to red edge NIR (700–780 nm) [14]. This absorption limits the light received from the bottom, while it returns light scattered by suspended materials. This offers a good balance between turbidity

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detection and bottom detection [15]. Several studies have already indicated that these spectral bands are appropriate for the monitoring of turbidity or suspended solids in optically complex regions [13], [15], [16]. According to [13], the 704 nm wavelength gives the greatest return of light to the sensor at depths between one and two meters. However, at longer wavelengths, sensitivity to suspended material in shallow and highly turbid waters is lost [13].

In addition to remote sensors, a simple and low-cost way of observing changes in suspended matter is the Secchi disk depth. It is a measure of water transparency, measured by lowering a white (in marine waters) or black-and-white (in continental waters) disk with a diameter of about 30 cm in the water until it is no longer visible to an observer on the surface [8], [17].

The objective of this research was to analyse the monthly transparency and turbidity pattern during year 2018 in the Albufera lake, a shallow and turbid lake from the wetland Albufera Natural Park (Valencia, Spain). This objective was achieved using Sentinel 2A images and in situ data from the monitoring program of the Environment General Subdivision of the regional government.

2 MATERIALS AND METHODS

2.1 Study area

The Albufera Natural Park is one of the most representative coastal wetlands in the Mediterranean basin. It is a shallow and hypertrophic coastal lagoon and is located on the Mediterranean coast, 10 km south of the city of Valencia (Fig. 1) [18], [19].

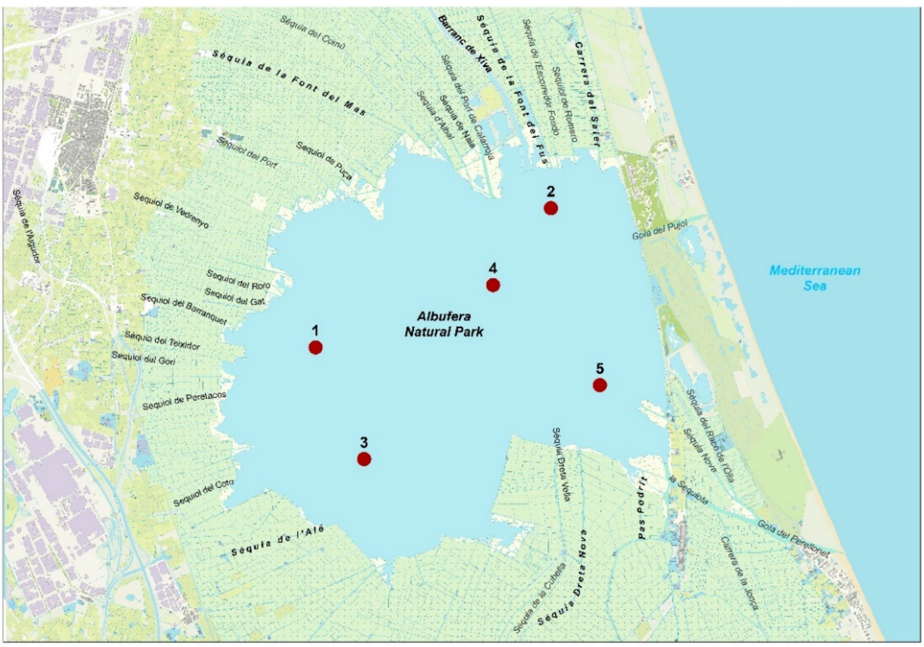

Figure 1: Study area, the Albufera lake and surroundings. Numbered red points are sampling stations from the monitoring program of the Environment General Subdivision of the Valencian government.

It holds several protection designations at national and international level, such as Spanish Natural Park, Special Protection Areas (SPAs) for birds, Sites of Community Importance (SCIs) and Ramsar Site. However, the park faces several environmental problems. This research focus on its main lake, Albufera's lake. The lake is highly dependent on the rice cycle, which is the main crop in the watershed, and on irrigation returns, mainly from the Acequia Real. The lake is connected to the Mediterranean Sea through three floodgates, "Golas" in Spanish, from North to South, Gola de Pujol, Gola del Perelló and Gola del Perellonet. These floodgates are operated to satisfy rice crop needs. The floodgates are open from January to March to allow the water level of the lake to increase mainly during this period for irrigation. During the rice growing season (April–September) the floodgates remain closed to allow fields flooding and with an insignificant flow to the lake. The doors open in September to allow the rice fields drying for the rice harvest. Finally, the doors are closed again in November to allow the flooding of the harvested rice fields, which favours the mineralization of nutrients [20]. It also receives some treated wastewater from nearby urban and industrial areas [21]. The lake exhibits reduced transparency and it is threatened with clogging, hence the importance of studying turbidity patterns.

2.2 Secchi disk and suspended matter

Secchi disk depth (cm) and suspended matter (mg/L) were measured monthly by the monitoring program of the Environment General Subdivision of the Valencian government in the five red points depicted in Fig. 1 from 1995 to 2018. These data can be accessed at the website www.agroambient.gva.es/es/web/espacios-naturales-protegidos/programa-de-seguimiento-de-zonas-humedas.

Secchi disk depth was measured with a 30 cm diameter black-and-white disk, which was submerged in the water until it was no longer visible to an observer on the surface [8], [17]. Secchi disk depth is inversely proportional to the amount of dissolved and/or particulate matter present in the water column; thus, is a turbidity indicator. Suspended matter (total suspended solids, TSS) was determined following the Standard Methods (2005) procedure, 2540D, for surface waters. Secchi disk depth and suspended matter data were standardized using the following equation:

$$Z = \frac{x_i - \bar{x}}{SD}, \tag{1}$$

where x_i is the month datum of year i, $\bar{x}$ is the month average from 1995 to 2018, and SD is the monthly standard deviation from 1995 to 2018.

The standardized values were classified as follows: (1) values in the interval (−1, 1) indicate average values; (2) values in the interval (1, 2) are above average conditions, and (3) values (> 2) are highly anomalous. The limit of the anomalous conditions was based on an Inverse Cumulative Distribution Function (ICDF), in a normal distribution, which defines 2 standard deviations as the limit of values without noise with 90% confidence [22].

Then, the month average of the standardized values from 1995 to 2018 was calculated to characterize each month.

2.3 Satellite data

Sentinel 2A and 2B images were obtained from the Sentinel Scientific Data Hub (https://scihub.copernicus.eu/). For each month the better image available was selected, that is, the image with less cloud coverage. Images were processed at Level-2A, that is, an orthoimage Bottom-Of-Atmosphere (BOA) corrected the reflectance product. The band 5 (705 nm) used in this work has a spatial resolution of 20 meters (ESA).

The reflectance values of band 5 (705 nm) were spatially standardized following eqn (1). Spatial standardization means that we analyse the spatial distribution of reflectance values. So, in this case eqn (1) variables are the following: x_i is the month datum of sampling station i pixel, $\bar{x}$ is the month average of all Albufera lake pixels, and SD is the monthly standard deviation of all Albufera lake pixels.

3 RESULTS AND DISCUSSION

Suspended matter concentration shows a temporal pattern in the Albufera lake. Suspended matter is higher from March to October in all sampling stations (except sampling station 1 from March to August), and thus the Secchi disk depth is lower in March–October (Fig. 2).

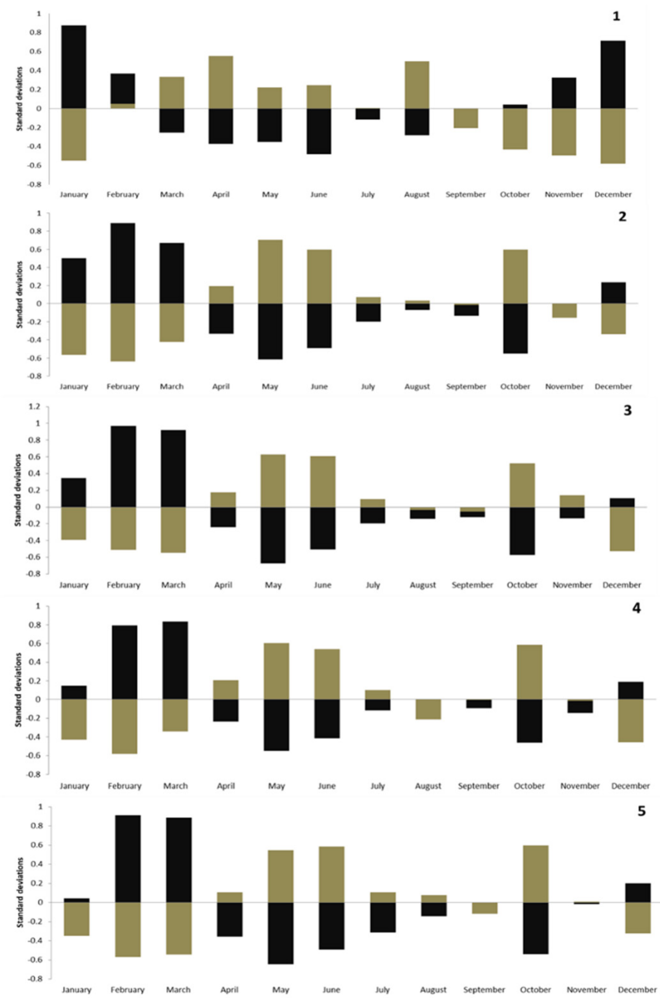

Figure 2: Standardized monthly averages of Secchi disk depth (black bars) and suspended matter (green bars) for the period from 1995 to 2018, in the five sampling stations of Albufera lake.

During the study period from 1995 to 2018, the lowest water transparency is in May–June and October in sampling stations 2 to 5. Sampling station 1 exhibits a little different behaviour, that is, lower water transparency is maintained from March to September, and transparency only shows a recovery during November to January.

To better analyse the spatial pattern, the monthly standardized reflectances, band 5 (705 nm) from Sentinel 2A, for year 2018 can be examined in Fig. 3. This reflectance represents turbidity as follows: values in the interval (−1, 1) indicate average values (blue colour); values in the interval (1, 2) are above average conditions (yellow colour), and values (> 2) are highly anomalous (red colour).

The spatial distribution of turbidity observed in Fig. 3 is related to meteorological events. From October to December 2018, several heavy rain events carried more sediments to the lake through surface runoff. Rain events were linked to turbidity values above the average

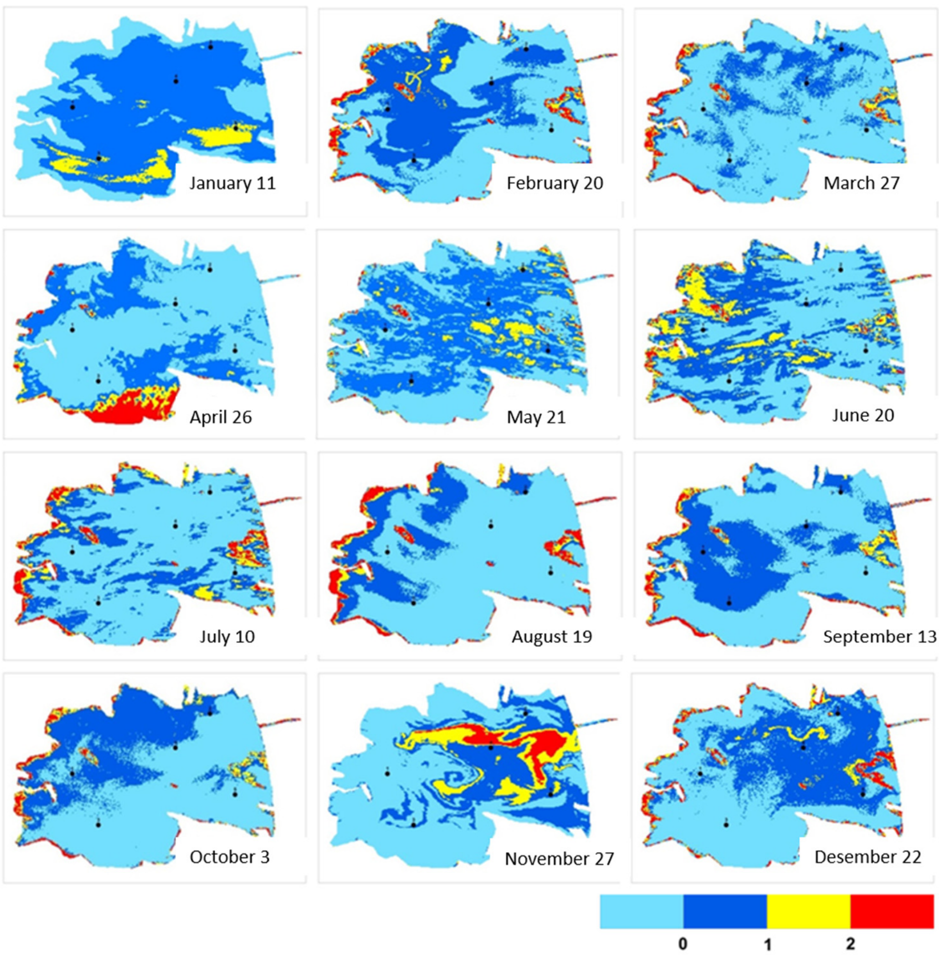

Figure 3: Monthly standardized reflectances band 5 (705 nm) from Sentinel 2A, year 2018, in the Albufera lake. Turbidity is represented as follows: values in the interval (−1, 1) indicate average values; values in the interval (1, 2) are above average conditions, and values (> 2) are highly anomalous.

ones (yellow colour) and even highly anomalous ones (red colour). During this period the floodgates were opened and allowed a discharge to the sea through the "Golas". From July to September, during the rice growing season, when freshwater inputs to the lake are much more reduced, the most important variable is east wind. The wind dominant direction from sea to land causes the accumulation of suspended material in the west area of the lake. In April a false anomaly is observed, which was due to cloud presence. The study images were selected taking into account the lowest cloud coverage to avoid these interferences, but no better image was available in April 2018.

A statistical analysis was done to check the correlation between remote sensing and in situ information. The monthly standardized data of Secchi disk was correlated with standardized reflectance of Sentinel band 5 (Table 1). According to p-value, the correlation was statistically significant ($p\text{-value} < 0.05$) for all sampling stations except sampling station 1.

Table 1: Correlation between the monthly standardized data of Secchi disk and band 5 (705 nm) of Sentinel 2.

Sampling stations	Pearson correlation	P-value
1	0.574	0.051
2	0.579	0.048
3	0.592	0.042
4	0.623	0.031
5	0.637	0.026

According to the morphometric analysis carried out in 2005, the average depth of the Albufera lake was 0.9 m [23]. The results of the statistical analysis corroborate that the reflectance of band 5 (705 nm) is suitable for the analysis of shallow lakes, such as the Albufera lake, even in eutrophic conditions. Sampling station 1 showed a temporal and spatial behaviour that differed from the others. This station is located at the shallower area of the Albufera lake (<0.9 m).

The analysis of turbidity gives information about organic and inorganic suspended materials, that is, about phytoplankton and inorganic particles. Previous remote sensing research [24], [25] focuses mainly on chlorophyll *a* study, which is an indicator of phytoplankton biomass. Our study of turbidity patterns provides an important supplementary information to those previous studies. Soria [23] demonstrated that flushing pulses are key to improve water quality and to remediate eutrophication. In our study, we demonstrated that during important rain events, the turbidity pattern shows higher values towards the floodgates "Golas". Then, it is important that during rain events the connection between the lake and the sea remains open to allow sediment discharge and avoid lake clogging. Increasing flushing pulses frequency would be a good management measure that could help in alleviating not only eutrophication problems but also lake clogging.

4 CONCLUSION

Turbidity dynamics in the Albufera lake are variable along the year. The main variables affecting turbidity patterns are precipitation, wind and management of floodgates. Having taken into account the temporal and spatial pattern of suspended matter, it is important to develop a conscious management of irrigation practices. Closing the floodgates during important rain events prevents the discharge of solids to the sea. This can have several negative effects both for the lake and for the receiving coastal waters and ecosystem. The lake has a clogging trend that can be worsened due to the accumulation of non-discharged solids. The beaches next to the receiving coastal waters do not receive an important load of solids to nourish them.

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THEORETICAL INVESTIGATION OF A NOVEL SOLAR STILL CONFIGURATION FOR ENHANCED HIGH-QUALITY DRINKING WATER PRODUCTION

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ABSTRACT

Lack of safe and reliable drinking water constitutes a major problem due to a rising worldwide population, global socio-economic development, increasing environmental pressure and climate change. Hence, solar distillation technology for drinking water production presents a conceivable solution for reducing the global water stress. The method requires low capital investment, low maintenance and no energy cost. However, the yield is generally limited. This paper proposes a new solar still configuration using an alternative mode of condensation and thermodynamics. The new solar still was designed to increase the productivity and to improve the efficiency of the conventional solar still. A theoretical study is developed based on a mathematical modelling approach and aims to investigate the performance of the new concept. The obtained results using Matlab software were compared to the conventional solar still system. It has been found that the daily productivity enhancement of the proposed system is around 68% compared to the simple device. An optimization procedure of the proposed solar still was performed in this study based on the design of experiment technique (DoE) using Taguchi approach.

Keywords: solar still, solar energy, design, modelling, simulation, productivity, microcontroller, design of experiment, Taguchi method.

1 INTRODUCTION

Nowadays millions people do not have access to a secure source of fresh water. Though the availability of global water reserves is about 1.4 billon km^3, where the seawater constitutes about 97% and only 3% is fresh water [1]. Therefore, seawater desalination processes prove to be a suitable alternative for the drinking water crisis. The use of renewable energies in desalination processes exhibits an interesting chance to supply the local population with fresh water. The solar still is a viable process, economical and simple device used for water purification, especially in remote and rural areas. In order to improve its productivity and efficiency, some researchers introduced modified geometries of solar stills, such as, tubular stills [2], vertical stills [3], hemi-spherical stills [4], solar stills with internal and external reflectors [5], with additional condenser [6], multiple-stage stills [7], and wick type stills [8], etc.

The present study aims to describe a new configuration of solar still device and highlight the improvements made in design and in thermodynamic process. Combining the two ideas of enhancing the productivity of the solar still and maintaining the simplicity and the low cost is expected to yield an economically viable design for a solar still. A theoretical study based on mathematical modelling has been developed using a meteorological data of a typical summer day in Northern Africa. In order to validate the analysis results, an experimental investigation of the new system will be involved afterwards. As a preparatory step for the experimental approach, a design of experiments method (DoE) based on Taguchi

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methodology is applied with the aim of effectively creating an experimentation strategy that will help in investigating the influence of multiple variables simultaneously on the solar still's performance with a reduced number of experiments.

2 DESCRIPTION OF THE NEW SOLAR STILL CONFIGURATION

Recently, the higher productivity of solar stills is the focus of intensive research [9]. Many studies have found that the best yield is achieved based on increasing the evaporating and condensation processes and on reducing the heat losses to the ambient [9]. In this study, an interesting new enhancement on the solar still's design and materials is introduced for testing, with the aim of overcoming the limited productivity problem. The new configuration of the solar still consists of a tray with black porous wick, which is continuously soaked with saline water. Through this wick, the feed water slowly flows and then, it is heated and evaporated once receiving the solar radiation. The main improvement in this new setup is the implementation of a modified condensation process, which reduce the heat loss from the solar still to the atmosphere and raise the evaporation rate for high water vapour production. The condensation heat loss is reduced by moving the produced water vapor from the outer skin of the still to the inside and transferring the condensation heat to the raw-water. Hence, the solar still will be divided into two parts by the tray where the feed water is flowed as shown in Fig. 1. The water vapor transfer is achieved through forced convection by using a simple fan and it is condensed against the under-side of the tray. The recovered heat underneath the tray increases the temperature of the brine water and it is available to support the evaporation process. Besides, the key to greater productivity of this new solar still system is the identification of the optimal working point, which should be automatically maintained. This working point is characterised by a feed-rate of the brine and the circulation rate of the vapor. Hence, a microcontroller is installed and programmed in order to automatically operate the pump for the brine water flow and control the fan speed installed under the tray. Furthermore, a system of sensors (temperature, humidity, salinity, solar intensity) is defined to continuously monitor the internal and external conditions of the still. Based on the information collected by this system, the set-point of the still will be shifted to keep it constantly at the optimum.

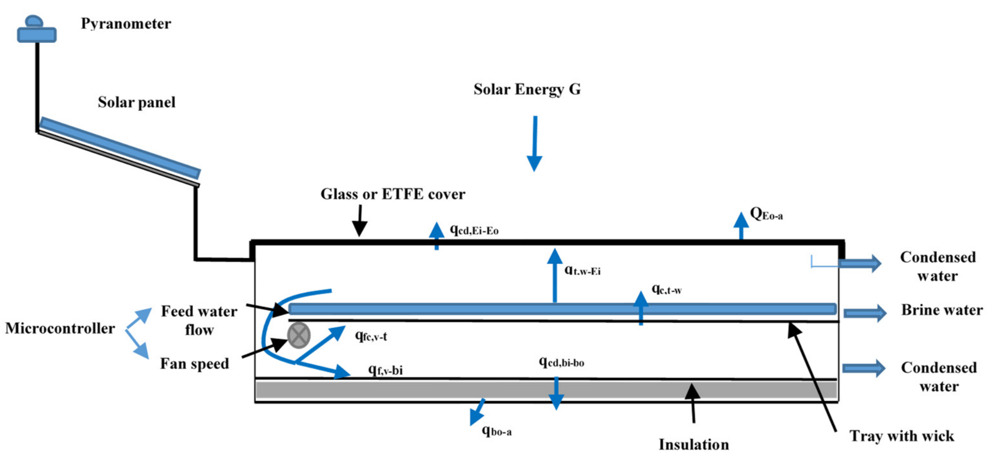

Figure 1: Schematic diagram of the new proposed solar still.

The enhancement of the solar still productivity can also be performed by an optimum selection of the top transparent cover characteristics, such as, type of material and thickness. Glass has been the traditional transparent cover material used by most of solar distillation units over the world. The main advantage of glass is that it is cheap and widely available, however, it is also heavy and has a high potential for breakage, making it unsuitable and unsafe for some installation. Fluoropolymer material, such as, ETFE (Ethylene Tetra-Fluoro-Ethylene) foil represents a promoting alternative for a lightweight top cover, which is available to replace glass in the new setup. The ETFE foil is a co-polymer of Ethylene and Teflon, which was widely used in the construction industry as roofing material [10]. This great material transmits between 94 and 97% of visible light [11]. However, a 6 mm glazing can only transmit 89% of visible light [11]. Furthermore, a typical ETFE film has a weight of approximately 175 g/m^2 for a film thickness of 100 microns [12]; hence, it can be applied as a double layer for increased thermal efficiency without a major increase in the still's weight. The new improved solar still described above is proposed for testing in order to ensure more efficiency, the high productivity and good quality of the produced drinking water.

3 THEORETICAL ANALYSIS OF THE NEW SOLAR STILL

Numerous researches introduced a series of thermal analysis and mathematical modelling as well as thermodynamic balances with the purpose of investigating the productivity of the solar still [13]. The first thorough research of solar still modelling was published by Dunkle in 1961. Dunkle provided a theoretical overview of roof type solar stills by highlighting the heat and mass transfer relationships [14]. Based on the Dunkle's relations, many investigations on solar still with different designs and modifications have been carried out by researchers over years. In this section, a theoretical investigation of the new improved concept is presented based on a mathematical modelling approach. The internal and external heat transfer phenomena are evaluated. The energetic analysis is developed in order to compare the performance of the conventional solar still with the new system. The energy balance equations are written for various parts of the solar still, such as ETFE cover, water mass, tray and basin liner.

3.1 Energy balance of the outer ETFE cover

The outer surface of ETFE cover receives the energy from the incident solar radiation and from the inner surface by conduction. The heat is lost from the outer skin of ETFE cover to the atmosphere by convection and radiation

$$\alpha'_E\, G(t) + q_{cd,Ei\text{-}Eo} = q_{c,Eo\text{-}a} + q_{r,Eo\text{-}a}, \tag{1}$$

$$\alpha'_E\, G(t) + \frac{k_E}{e_E}(T_{Ei} - T_{Eo}) = h'_{Ea}(T_{Eo} - T_a), \tag{2}$$

$$T_{Eo} = \frac{\alpha'_E G(t) + \frac{k_E}{e_E} T_{Ei} + h'_{Ea} T_a}{\frac{k_E}{e_E} + h'_{Ea}}. \tag{3}$$

The fraction of solar radiation absorbed by the ETFE is given by [15],

$$\alpha'_E = (1 - R_E)\,\alpha_E. \tag{4}$$

The global heat exchange coefficient from ETFE to ambient, h'_{Ea}, is given by [16],

$$h'_{Ea} = h_{c,Ea} + h_{r,Ea}. \tag{5}$$

The coefficient of heat convective transfer between ETFE and sky, $h_{c,Ea}$, is given by [17],

$$h_{c,Ea} = 2.8 + 3\,V. \tag{6}$$

The radiative heat transfer coefficient between ETFE and sky, $h_{r,Ea}$, is given by [17],

$$h_{r,Ea} = \frac{\varepsilon\,\sigma\,((T_{Eo} + 273)^4 - ((Ts + 273)^4\,)}{(T_{Eo} - Ts)}. \tag{7}$$

The effective sky temperature, Ts, is given by [13],

$$Ts = Ta - 6. \tag{8}$$

3.2 Energy balance of the inner ETFE cover

The inner surface of the ETFE cover receives the energy from the water surface by convection, evaporation and radiation. A part of heat is stored in the ETFE cover due to its specific heat and the remaining heat is passed by conduction to the outer surface.

$$q_{t,w\text{-}Ei} = (\,e_E\,\rho_E\,Cp_E\,\frac{dT_{Ei}}{dt}) + q_{cd,Ei\text{-}Eo}, \tag{9}$$

$$\frac{dT_{Ei}}{dt} = \frac{1}{e_E\,\rho_E\,Cp_E}\,(h'_{wE}\,(T_w - T_{Ei}) - \frac{k_E}{e_E}(T_{Ei} - T_{Eo})). \tag{10}$$

The global heat exchange coefficient from water to ETFE cover, h'_{wE}, is defined as following,

$$h'_{wE} = h_{c,wE} + h_{e,wE} + h_{r,We}. \tag{11}$$

The convective heat transfer coefficient, $h_{c,wE}$, is given by [16],

$$h_{c,wE} = 0.884\,((T_w - T_{Ei}) + \frac{(P_w - P_{Ei})(T_w + 273.15)}{268.9\times10^3 - P_w})^{1/3}. \tag{12}$$

The evaporative heat transfer coefficient, $h_{e,wE}$, is given by [16],

$$h_{e,wE} = 16.276\times 10^{-3} h_{c,wE}(\frac{P_w - P_{Ei}}{T_w - T_{Ei}}). \tag{13}$$

The radiative heat transfer coefficient, $h_{r,wE}$, is given by [16],

$$h_{r,wE} = \varepsilon\,\sigma\,((T_w + 273)^2 + (T_{Ei} + 273)^2)\,(T_w + T_{Ei} + 546). \tag{14}$$

The partial saturated vapor pressure at different temperatures, P_i, is given by [16],

$$P_i = \exp\,(25.317 - \frac{5144}{T_i + 273)}). \tag{15}$$

3.3 Energy balance of the water mass

Heat energy is absorbed by the water due to the fraction of transmitted solar radiation striking on it and due to the transferred heat from the tray by convection. The received energy is consumed in two ways, a part of the heat is stored in water due to its specific heat, and the other part is transferred from water to the inner ETFE cover by convection, radiation and evaporation

$$\alpha'_w\,G(t) + q_{c,t\text{-}w} = (\,e_w\,\rho_w\,Cp_w\,\frac{dT_w}{dt}\,) + q_{t,w\text{-}Ei}, \tag{16}$$

$$\frac{dT_w}{dt} = \frac{1}{e_w\,\rho_w\,Cp_w}\,(\alpha'_w\,G(t) + h_{c,tw}(T_t - T_w) - h'_{wE}\,(T_w - T_{Ei})). \tag{17}$$

The fraction of solar radiation absorbed by water is given by [15],

$$\alpha'_w = (1-\alpha_E)\,(1-R_E)\,(1-R_w)\,\alpha_w. \quad (18)$$

The convective heat transfer coefficient between tray and water, $h_{c,tw}$, is given by [16],

$$h_{c,tw} = \frac{Nu.k}{L}. \quad (19)$$

For the natural convection, Nusselt number Nu is given by [18],

$$Nu = 0.54\, Ra^{1/4} \qquad \text{For, } 10^5 < Ra < 2\times10^7, \quad (20)$$

$$Nu = 0.15\, Ra^{1/3} \qquad \text{For, } 2\times10^7 < Ra < 3\times10^{10}. \quad (21)$$

3.4 Energy balance of the tray

The tray received the heat energy from the absorbed solar radiation and from the transmitted water vapor by forced convection using the fan. A part of the absorbed heat is stored in the tray and the remaining heat is transferred by convection to the water mass

$$\alpha'_t\, G\,(t) + q_{fc,v\text{-}t} = \left(e_t\, \rho_t\, Cp_t \frac{dT_t}{dt}\right) + q_{c,t\text{-}w}, \quad (22)$$

$$\frac{dT_t}{dt} = \frac{1}{e_t\, \rho_t\, Cp_t}\left(\alpha'_t\, G\,(t) + h_{fc,vt}\,(T_v - T_t) - h_{c,tw}\,(T_t - T_w)\right). \quad (23)$$

The fraction of solar radiation absorbed by the tray is given by [15],

$$\alpha'_t = (1-\alpha_E)\,(1-R_E)\,(1-\alpha_w)\,(1-R_w)\,\alpha_t. \quad (24)$$

Air–water vapor mixture temperature, T_v (°C), is assumed to be the arithmetic mean value of water and inner ETFE cover temperatures [17]

$$T_v = \frac{T_w + T_{Ei}}{2}. \quad (25)$$

The heat transfer coefficient by forced convection between water vapor and tray, $h_{fc,vt}$, is given by [19],

$$h_{fc,vt} = \frac{Nu.k}{L}. \quad (26)$$

For flow over flat plate and for forced convection, Nusselt number Nu is given by [19],

$$Nu = 0.023\, Re^{0.8}\, Pr^{\,0.4}. \quad (27)$$

3.5 Energy balance of inner basin liner

The inner surface of the basin receives the heat energy from the transmitted water vapor by forced convection and evaporation. The absorbed heat energy is stored into the basin and the remaining heat is passed to the outer skin by conduction

$$q_{f,v\text{-}bi} = \left(e_b\, \rho_b\, Cp_b \frac{dT_{bi}}{dt}\right) + q_{cd,bi\text{-}bo}, \quad (28)$$

$$\frac{dT_{bi}}{dt} = \frac{1}{e_b\, \rho_b\, Cp_b}\left(h_{f,vbi}(T_v - T_{bi}) - \frac{k_i}{e_i}(T_{bi} - T_{bo})\right). \quad (29)$$

The global heat exchange coefficient from water vapor and the inner basin liner, $h_{f,v\text{-}bi}$, is the sum of the forced convective heat transfer coefficient, $h_{fc,vbi}$, and the evaporation heat transfer coefficient, $h_{fe,vbi}$

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$$h_{f,v\text{-}bi} = h_{fc,vbi} + h_{fe,vb}, \tag{30}$$

where, the forced convective heat transfer coefficient, $h_{fc,vbi}$, is calculated the same way as $h_{fc,vt}$. Furthermore, the evaporation heat transfer coefficient between water vapor and tray, $h_{fe,vt}$, is given by [16],

$$h_{fe,vbi} = 16.276\times 10^{-3} h_{hfc,vbi} \left(\frac{P_v - P_{bi}}{T_v - T_{bi}}\right). \tag{31}$$

3.6 Energy balance of outer basin liner

The heat energy passed by conduction from the inner basin liner is lost to the ambient by conduction

$$q_{cd,bi\text{-}bo} = q_{bo\text{-}a}, \tag{32}$$

$$\frac{k_i}{e_i}(T_{bi} - T_{bo}) = U_{ba}(T_{bo} - T_a), \tag{33}$$

$$T_{bo} = \frac{\frac{k_i}{e_i} T_{bi} + U_{ba} T_a}{\frac{k_i}{e_i} + U_{ba}}. \tag{34}$$

The overall external heat loss coefficient from bottom to the atmosphere is given by [15],

$$U_{ba} = \frac{1}{\frac{kb}{eb} + \frac{1}{h_{ba}}}. \tag{35}$$

The total heat transfer coefficient from basin liner to ambient, h_{ba}, is given by [16],

$$h_{ba} = h_{c,ba} + h_{r,ba}, \tag{36}$$

$$h_{ba} = (2.8 + 3\,V) + \left(\frac{\varepsilon g\,\sigma((T_{bo}+273)^4 - ((T_s+273)^4)}{(T_{bo} - T_s)}\right). \tag{37}$$

3.7 Distillate water production and hourly efficiency

The mass of distillate water per unit area per unit of time could be defined as the ratio of the evaporation rate, and the latent heat of water vaporization [13]. Owing to the recycled water vapor under the tray in the new system, a second condensation process is taking place on the bottom of the solar still. Therefore, the mass of distillate water is calculated as following

$$\dot{m}_{ew} = \frac{h_{e,wE}(T_w - T_{Ei}) + h_{fe,vbi}(T_v - T_{bi})}{L_{ev}}. \tag{38}$$

The hourly efficiency of the solar still is determined by the following expression [13],

$$\eta = \frac{\dot{m}ew\, L_{ev}}{G(t)\times 3600}. \tag{39}$$

4 RESULTS OF THE THERMAL MODELLING AND DISCUSSION

The aforementioned nonlinear ordinary differential equations are resolved based on a computer simulation program with the assistance of Matlab software. The diverse temperatures are evaluated and the hourly yield variation is computed relying on the meteorological data of a typical summer day in Northern Africa (Tunisia) between 6:00 am and 7:00 pm. Fig. 2 illustrates the hourly variation in the temperatures of water, tray, inner and outer ETFE cover, inner and outer basin liner. All the temperature curves show the same

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shape depending on the solar intensity variation during the day. All the temperatures increase during the morning until they reach the maximum between 12:00 am and 3:00 pm, than they decrease gradually. The theoretical results indicate that the hourly variation of the water and tray temperatures almost coincide each other. It is due to the fact that the water flows slowly through the wick, thus, the depth of the water is very low. Furthermore, it is clearly observed that, there is a high temperature difference between the inner and the outer ETFE cover. These results could be explained by the good thermal properties of the ETFE material used as a transparent cover.

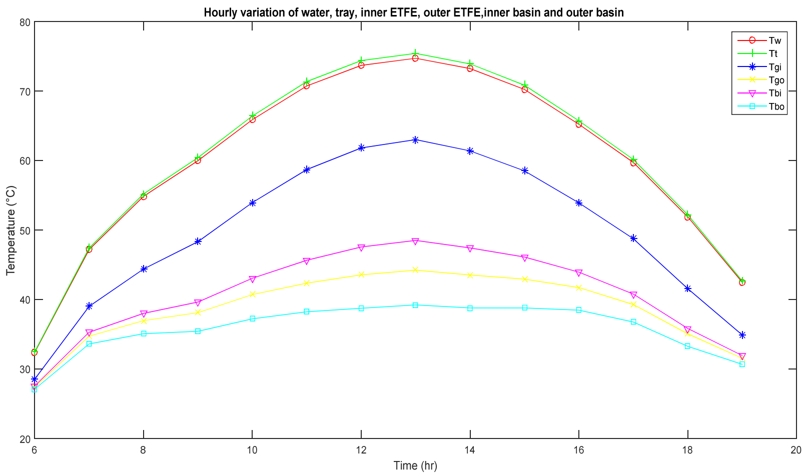

Figure 2: Hourly temperature variation of water (T_w), tray (T_t), inner cover (T_{gi}), outer cover (T_{go}), inner basin (T_{bi}) and outer basin liner (T_{bo}).

Similar results are also obtained for the inner and the outer surfaces of the basin liner. The temperature difference between the two surfaces is the result of using a thermal insulation with thickness of e_i = 5 cm between the two skins that reduces the heat loss from the bottom of the still to the ambient. The efficiency of the proposed concept has the capacity to reach about 70% for days with high solar irradiation. The best efficiency correspond to the highest global heat transfer coefficient and especially to the maximal evaporation rate. Thus, it can be concluded that all improvement made on the solar still's configuration that lead to accelerate the evaporation process has a greatest effect on the enhancement of efficiency. The obtained theoretical results for the improved solar still are compared to the study of Sarray et al. [17], which has been carried out to investigate the heat and mass transfer for a simple solar still device in Tunisia. A remarkable increase in the water temperature is obtained due to the transferred heat energy by convection from the tray to the water film ($q_{c,t-w}$). The tray receives the heat energy from the absorbed solar radiation ($\alpha'_t \times G$ (t)) and from the transmitted water vapor by forced convection using the fan ($q_{fc,v-t}$). Therefore, the rise of the tray temperature especially between 11:00 am and 3:00 pm, leads to an increase in the temperature of water, which flows with very low depth. The new condensation process has a significant effect on minimizing the condensation heat loss from the cover to the ambient. Likewise, the major part of the condensation energy is reserved and reintroduced into the process with the aim of enhancing the productivity of the system as it may be clearly concluded from Fig. 3. The daily outputs are; 5 L/m^2.d for the conventional solar still and 8.4 L/m^2.d for the new configuration. Thus, the daily productivity enhancement of the proposed solar still is around 68%. The second condensation process achieved under the tray is the result of the high temperature difference between the transferred water vapor and the inner surface of the basin liner($T_v - T_{bi}$). Furthermore, the condensation energy is passed forward by convection to the tray, than to the brine water, thereby an accelerated evaporation process is achieved.

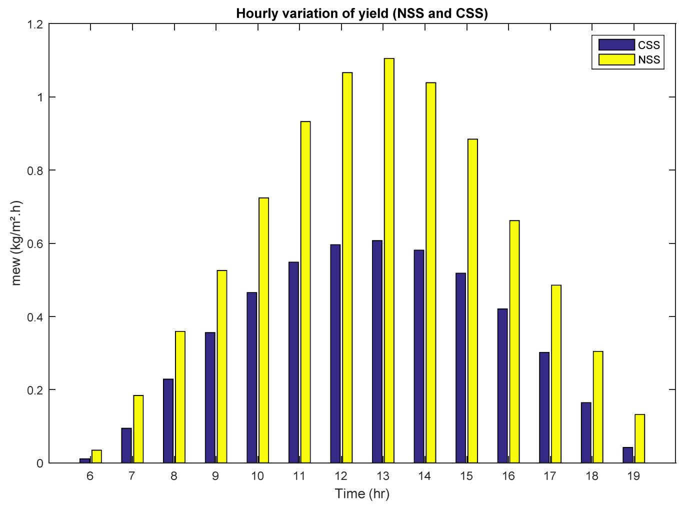

Figure 3: Hourly variation of yield of the conventional solar still (CSS) and the new solar still (NSS).

5 DESIGN OF EXPERIMENTS FOR THE NEW SOLAR STILL OPTIMISATION

DoE can be defined as an experimental optimization approach used to study multiple variables simultaneously and identify their influence on the output in an efficient way and with a reduced number of performed experiments [20]. Some of the most used DoE methods are: Full Factorial Design, Fractional Factorial Design, Analysis of Variance (ANOVA), Taguchi method and Response Surface Modelling (RSM) [21]. In order to improve its productivity and efficiency, many researchers have focused on investigating the influence of various parameters on the solar still's performance using several design of experiments methods. In the present study, the selected design of experiment method is the Taguchi method. The choice of the Taguchi method is based on the simplicity and the efficiency of this method in building a robust experimental plan. Furthermore, the Taguchi approach gives the opportunity to develop designs for studying variation caused by noise factors, which are usually ignored in the others DoE approaches [22]. This research is interested in applying the proposed Taguchi design method to optimize six control factors with three levels each. These parameters are; type of the transparent cover (A), distance between the evaporation and condensation surfaces (B), water salinity (C), angle of inclination (D), inlet water flow (E) and fan velocity (F). In order to investigate the effect of noise sources on the productivity of the system, it will be needed to conduct each run of experiment once, for each combination of noise factors. The noise factors are; the wind velocity (G), the ambient temperature (H) and the solar intensity (I). Taguchi orthogonal array can include two matrices. The design matrix (or inner array) is the matrix reserved to the control factors setting and, the noise matrix (or outer array) is the matrix of the uncontrollable factors [23]. Table 1 illustrates the completed orthogonal array using L27 inner array and L4 outer array. After the experimental runs and data collection, the analysis of the results is the final step of Taguchi method. The data analysis aims to determine the optimal levels for all the control factors and to identify the most effective factors in reaching the high productivity of the system.

Table 1: Taguchi's orthogonal array.

Noise factors (L4 Outer array)			
Replication	**G**	**H**	**I**
1	Low	Low	High
2	Low	High	Low
3	High	Low	Low
4	High	High	High

Design factors (L27 Inner array)						
Experiment	**A**	**B**	**C**	**D**	**E**	**F**
1	GLASS	0.1	5	20	2	80
2	GLASS	0.1	5	20	4	120
3	GLASS	0.1	5	20	6	200
4	GLASS	0.2	20	25	2	80
5	GLASS	0.2	20	25	4	120
6	GLASS	0.2	20	25	6	200
7	GLASS	0.3	40	30	2	80
8	GLASS	0.3	40	30	4	120
9	GLASS	0.3	40	30	6	200
10	E300	0.1	20	30	2	120
11	E300	0.1	20	30	4	200
12	E300	0.1	20	30	6	80
13	E300	0.2	40	20	2	120
14	E300	0.2	40	20	4	200
15	E300	0.2	40	20	6	80
16	E300	0.3	5	25	2	120
17	E300	0.3	5	25	4	200
18	E300	0.3	5	25	6	80
19	E300/100	0.1	40	25	2	200
20	E300/100	0.1	40	25	4	80
21	E300/100	0.1	40	25	6	120
22	E300/100	0.2	5	30	2	200
23	E300/100	0.2	5	30	4	80
24	E300/100	0.2	5	30	6	120
25	E300/100	0.3	20	20	2	200
26	E300/100	0.3	20	20	4	80
27	E300/100	0.3	20	20	6	120

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6 CONCLUSION AND FUTURE WORK

This study presents a new solar still configuration based on using an alternative cover material, a modified condensation process and thermodynamics. The proposed solar still is an economical and eco-friendly device enabling to produce a good quality of drinking water and to overcome the limited yield of the conventional solar still with maintaining a simple technology and low cost. A theoretical thermal model was performed in this study, based on developing an energy balance equations system for the different parts of the proposed solar still. The obtained results showed a great enhancement in the productivity of the proposed solar still compared to the simple device. Likewise, a design of experiment model was developed, using the Taguchi approach. This technique aims to build an efficient plan of experimentation. As a future scope of work, an experimental investigation will be carried out, as well as, an extensive validation of the theoretical model will be fulfilled by comparing the simulation results against experimental data. The validated model will offer the possibility to estimate the productivity of the enhanced device in any place in the world based on the meteorological data. On the other hand, the experiments will be conducted according to the trial conditions specified in Taguchi's orthogonal array. The analysis of the results will be performed in order to identify the most effective factors in reaching the highest yield.

NOMENCLATURE

Cp:	specific heat (J/kg.K)
CSS:	Conventional Solar Still
e:	thickness (m)
g:	acceleration due to gravity (m/s^2)
G(t):	intensity of solar radiation (W/m^2)
Gr:	Grashof number
h:	heat transfer coefficient ($W/m^2.K$)
i:	iteration
k:	thermal conductivity (W/m.K)
L:	representative dimension (m)
L_v:	latent heat of water vaporization (kJ/kg)
$\dot{m}_{ew}$:	mass of distillate water ($kg/m^2.s$)
NSS:	New Solar Still
Nu:	Nusselt number
P:	partial pressure of saturated vapour at the glass temperature (Pa)
Pr:	Prandtl number
q:	heat transfer rate (W/m^2)
R:	reflectivity
Ra:	Rayleigh number
Re:	Reynolds number
T:	temperature (°C)
t:	time (h or s)
U_{ba}:	overall bottom heat loss coefficient ($W/m^2.K$)
V:	wind velocity (m/s)

Greek letters

α:	absorptivity
α':	fraction of absorbed solar radiation
β:	coefficient of volumetric expansion coefficient (K^{-1})
ρ:	density (kg/m^3)

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μ: viscosity ($N.s/m^2$)
ε: emissivity
η: hourly efficiency of the solar still (%)
σ: Stefan Boltzman constant (5.67×10^{-8} $W/m^2.K^4$)

Subscripts
a: ambient
b: basin liner
c: convection
cd: conduction
e: evaporation
E: ETFE
f: forced convection
i: insulating material
r: radiation
s: sky
t: tray
v: vapor
w: water

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MICROBIOLOGICAL TESTING OF DRINKING WATER IN THE WESTERN TRANSDANUBIAN REGION OF HUNGARY USING API TESTS

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ABSTRACT

Using standard and routine methods for drinking water microbiological quality control may lead to uncertainty. In some cases, biochemical tests for confirmation of presumptive colonies have negative results. It can also happen that the target bacteria cannot be found, but the high concentration of the background biota contaminates water sampling points or even the entire water supply system. The aim of the study was to investigate and identify bacterial colonies retrieved from water samples of drinking water supply systems using a relatively cheap, fast and easy-to-use method as well as to acquire information on the presence of pathogens in the background biota. To achieve our goals, water samples from 18 western Hungarian settlements were collected during a two month period. A total of 66 morphologically different bacterial colonies growing on four media were tested for taxonomic identification by three different API (Analytical Profile Index) tests which are suitable for the identification of bacteria at species level. Out of the 66 bacterial colonies involved in the study, 58 could be identified by API tests. During the identification, the presence of 27 different taxa were proved in the water samples. As a result of our research, species (*Aeromonas hydrophila*, *Pseudomonas fluorescens*, *Burkholderia cepacia*) that can cause confusion in the evaluation of water samples by forming morphologically typical colonies on the medium or presenting in high number of colony form units as background contaminants were identified. The presence of species (*Pseudomonas aeruginosa*, *Aerococcus viridans*, *Aeromonas hydrophila*, *Gemella morbillorum*, *Streptococcus constellatus*) which originated from the background biota on different agar plates and can cause human diseases, were also confirmed. Even if the organisms which indicate water quality degradation are not present in the water sample, the background biota may contain human pathogenic bacteria that might lead to health problems when enriched in the drinking water supply system.
Keywords: microbiology, drinking water, API test, background biota, cultivation on agar medium.

1 INTRODUCTION

In Hungary, the quality requirements for drinking water are laid down in Government Decree 201/2001 (X.25.) [1]. The legislation defines the chemical and microbiological parameters to be investigated and the standard methods to be used. Bacteriological water quality characteristics (total colony count, total coliforms, *Escherichia coli* count, *Enterococci* count, *Pseudomonas aeruginosa* count, *Clostridium perfringens* count) have to be identified by growing on nutrient or selective media. However, the microbiological quality control may lead to uncertainty, as in some cases biochemical tests have negative results or the target bacteria cannot be found, but the high concentration of the background biota contaminates water sampling points or even the entire water supply system.

The major objective of this study was to investigate and identify bacterial colonies retrieved from water samples of drinking water supply system using a relatively cheap, fast and easy-to-use method as well as to acquire information on the presence of pathogens in the background biota.

Several national and international research have examined the microbiological quality of water in the drinking water supply system. Lejtovicz [2] investigated the effect of

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chlorination on the microbial community of the Budapest (Hungary) water supply network. They found that the microbial community in the water supply system is characterized by a number of typical aquatic, heterotrophic bacteria, e.g. *Mycobacterium, Sphingomonas, Sphingopyxis, Sphingobium, Flavobacterium* and *Micrococcus* genus. However, as a result of chlorination, both bacterial germ count and diversity were reduced and representatives of the *Mycobacterium* genus prevailed as being the most resistant to chlorination.

Felföldi et al. [3] investigated the occurrence and chlorine resistance of human pathogenic *Pseudomonas aeruginosa* and *Legionella* species at several sample points in a water supply system for three months using molecular techniques. Their results demonstrated the disinfectant effect of chlorination on the water supply system. However, it was highlighted that the chlorination process in the network was only effective near to the chlorination point, because these taxa reappeared places further away from chlorination.

Kovács et al. [4] investigated the seasonal and spatial changes of microbiological water quality characteristics of water supply system in Győr (Hungary) and its surroundings by cultivation methods. They reported that in warmer periods the presence of faecal indicator bacteria *Escherichia coli* and *Enterococcus faecalis* was more frequent than in cooler periods, while in the case of *Pseudomonas aeruginosa*, coliform and heterotrophic bacteria the seasonal dynamics could not be detected. In addition, the water quality parameters did not depend on the different geographical locations of the water networks.

Figueira et al. [5] compared *Enterobacteriaceae* bacterial communities in river, wastewater and drinking water in the vicinity of Porto (Portugal) by cultivation methods. Bacteria were isolated from coliform selective media and cultures were identified using DNA-based molecular methods and API 20E test based on enzymatic reactions. The measurements detected the members of the genus *Citrobacter, Enterobacter, Klebsiella* and *Raultella* of the *Enterobacteriaceae* group in the largest quantity. The proportion of *Klebsiella* in river water samples was extremely high (above 55%) compared to other samples. However, representatives of *Raoultella* were missing from the river samples. In addition, representatives of the genus *Serratia, Pantoea* and *Hafnia* were found to a lesser extent in all three water types but with similar rates (about 10%).

2 MATERIALS AND METHODS

To achieve our goals, water samples from 18 western Transdanubian Hungarian settlements (Győr and its surroundings) were collected during a two month period (from the beginning of February to the end of March 2019). The investigated drinking water samples originated from the Győr, Nyúl, Kapuvár and Csorna water supply system from public outflow and user sampling points. The water is derived from porous underground water and only iron and manganese removal treatments are necessary. In some water treatment plants chlorination also occurs but regular water disinfection is not required in the investigated water supply systems.

Thirty-four water samples collected during the two month period were involved in the research and analysed by API tests to identify typical and atypical microorganisms including the ones that are not investigated and cannot be identified using the standard methods required by the relevant legislation. Out of the 34 samples, 25 water samples complied, and nine water samples did not comply with the relevant legislation using the obligatory standard methods. The presence of coliforms was detected in seven water samples using the ISO 9308-1 standard method and the presence of *Pseudomonas aeruginosa* was detected in three water samples using ISO 16266 standard method. (In one sample both coliforms and *Pseudomonas aeruginosa* were detected.)

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Water samples were processed by plate incorporation and membrane filtration methods to cultivate bacterial colonies of different appearance, which were identified at the species level using API tests. Bacterial colonies were isolated by growing on five media:

- Chromogenic coliform selective agar (Biolab, ISO 9308-1) for testing members of Family *Enterobacteriaceae*, using membrane filtration method (MSZ EN ISO 9308-1:2015).
- Pseudomonas-CN selective agar (Merck, ISO 16266) for testing non-*Enterobacteriaceae* Gram-negative rod-shaped bacteria, using membrane filtration method (MSZ EN ISO 16266:2008).
- Yeast extract agar (Merck, ISO 6222) for testing total colony count, using inoculation in nutrient agar culture medium (MSZ EN ISO 6222:2000).
- Salt-blood agar (ÁNTSZ, Győr, MSZ ISO 13690-2) for testing heterotroph Gram-positive coccus bacteria, using membrane filtration method (MSZ ISO 13690-2:1989).
- Enterococcus selective agar (Biolab, ISO 7899-2) for testing Enterococci, using membrane filtration method (MSZ EN ISO 7899-2:2000).

The isolates were further cultured on non-selective Columbia agar and finally tested for taxonomic identification by three different API tests. API tests are suitable for the quick identification of clinically relevant bacteria at species level using test strips and online databases. Nowadays more than 20 API tests exist to identify species belonging to a particular bacterial group. In this study three different API tests were used:

- API 20 E kit (API 20 E 25 Strips, bioMérieux) is suitable to identify Gram-negative fermenting rod-shaped bacteria such as members of Family *Enterobacteriaceae*. The test can identify a total of about 100 bacterial species (e.g. *Enterobacter*, *Escherichia*, *Citrobacter*, *Klebsiella* species).
- API 20 NE kit (API 20 NE 25 Strips, bioMérieux) is suitable to identify Gram-negative non-fermenting rod-shaped bacteria. 60 species, e.g. *Aeromonas* and *Pseudomonas* species, as well as other oxidase positive bacteria can be identified.
- API 20 Strep Kit (API 20 Strep 25 Strips, bioMérieux) is suitable to identify about 50 species including *Streptococci*, *Enterococci* and closely related species.

API test strips comprise wells (microtubules) containing dehydrated substrates. The isolated bacterial suspensions were used to rehydrate each of the wells. After that the strips were incubated for the prescribed time period. In the wells different metabolic reactions of bacteria can be observed, such as enzymatic activity, fermentation of carbohydrate, catabolism of proteins or amino acids. Metabolism produces colour changes that are either spontaneous or revealed by the addition of reagents and positive and negative test results can be easily distinguished (Fig. 1).

Figure 1: Colour changes of a culture in the case of API 20 E strips.

At the end of the incubation time, a taxon-specific colour reaction sequence can be obtained. Taxonomic determination of cultures was performed using APIWEB™ software and an online database (Biomérieux [6]). The colour reaction line was recorded on the APIWEB™ online interface, which generates a seven digit biochemical profile number (Fig. 2). The biochemical profile number was then compared with profile numbers in a commercial codebook (online by the APIWEB™) to determine the identification of the bacterial species.

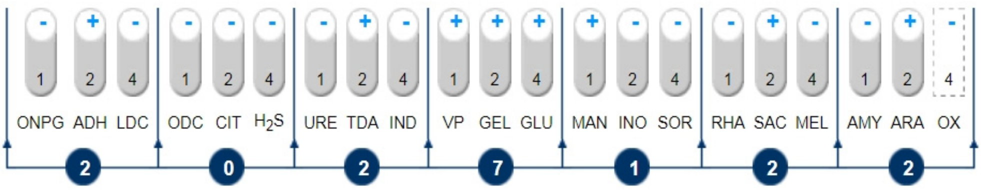


Figure 2: Biochemical profile determined by colour changes. *(Source: Biomérieux [6].)*

3 RESULTS AND DISCUSSION

During our research, 32 colonies were isolated growing on chromogenic coliform selective agar, 13 colonies on Pseudomonas-CN selective agar, seven colonies on yeast extract agar, and 14 colonies on salt-blood agar. Nevertheless, Enterococcus-positive sample did not occur during the examined period, so colonies growing on the Enterococcus selective agar could not be examined. Thus, a total of 66 morphologically different bacterial colonies growing on four media were tested for taxonomic identification by the 3 different API tests.

Fifty-eight of the 66 bacterial colonies growing on the four media could be identified by the API tests, and in eight cases the identification procedure was unsuccessful. During the identification, we could confirm the presence of 27 different taxa from the water samples by the three API tests (Table 1).

Table 1: Successfully identified bacterial colonies by the API tests (in brackets: number of samples).

API 20 E test	API 20 NE test	API 20 Strep test
Aeromonas hydrophila (6) *Serratia marcescens* (2) *Pseudomonas sp.* (2) *Pseudomonas aeruginosa* (2) *Aeromonas salmonicida* (1) *Citrobacter freundii* (1) *Escherichia hermannii* (1) *Escherichia coli* (1) *Enterobacter amnigenus* (1) *Pantoea sp.* (1) *Pseudomonas fluorescens* (1) *Serratia fonticola* (1) *Serratia odorifera* (1)	*Pseudomonas fluorescens* (16) *Achromobacter denitrificans* (1) *Burkholderia cepacia* (1) *Chromobacterium violaceum* (1) *Ochrobactrum anthropi* (1) *Pseudomonas putida* (1) *Rhizobium radiobacter* (1) *Sphingobacterium spiritivorum* (1)	*Aerococcus urinae* (5) *Aerococcus viridans* (3) *Enterococcus avium* (2) *Enterococcus faecalis* (1) *Gemella morbillorum* (1) *Lactococcus lactis* (1) *Streptococcus constellatus* (1)
21 samples, 13 taxa	23 samples, 8 taxa	14 samples, 7 taxa

Using API 20 E test, 23 morphologically different bacterial colonies growing on chromogenic coliform selective agar was evaluated, of which 21 were successfully identified at species or genus level. Altogether 13 different taxa were detected. (One of them is *Pseudomonas fluorescens*, which was also identified by API 20 NE test in the case of 16 samples.)

Using API 20 NE test, 24 colonies growing on three different media were investigated. All the 13 morphologically different bacterial colonies growing on Pseudomonas-CN selective agar were successfully identified. Three of the four rod-shaped bacterium colonies growing on yeast extract agar were successfully identified. All seven bacterial culture with atypical morphology growing on chromogenic coliform selective agar were successfully identified at species or genus level. Altogether eight different taxa were detected.

Using API 20 Strep test, 19 colonies growing on three different media were investigated. 11 of the 14 bacterial colonies growing on salt-blood agar were successfully identified. Two of the three coccus colonies growing on yeast extract agar were successfully identified. Furthermore, after microscopic cell examination, two atypical cocci growing on chromogenic coliform selective agar were investigated by API 20 Strep test, and one of them was successfully identified taxonomically. Altogether seven different taxa were detected.

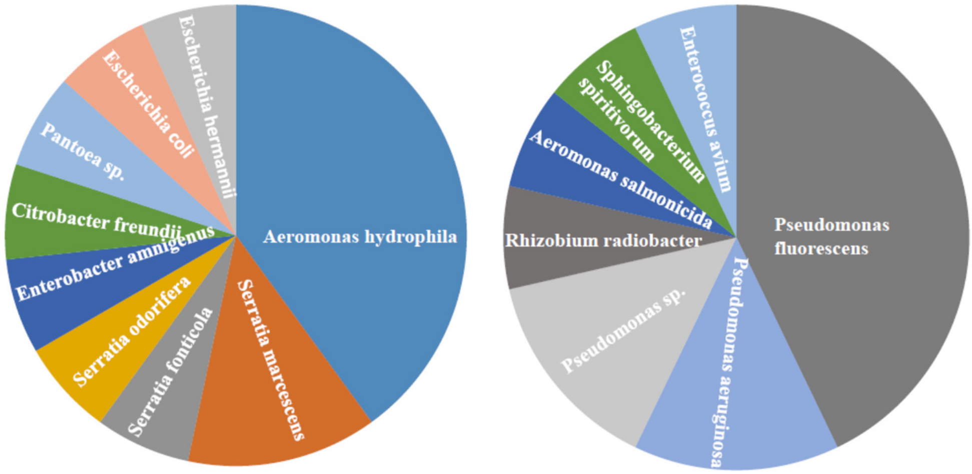
The API tests confirmed the presence of coliforms in six out of the seven cases, where the presence of coliforms was detected preliminary using the ISO 9308-1 standard method. However, in one case the result of the standard method and the API test was different. The colony believed to be coliforms according to the standard method was later identified as *Aeromonas hydrophila* using the API 20E test. The API tests did not confirm the presence of *Pseudomonas aeruginosa* in the three water samples, where their presence was detected preliminary using the ISO 16266 standard method. The typical colonies were identified in two samples as *Burkholderia cepacia* and in one sample as *Pseudomonas fluorescens* by the API 20 NE test.

3.1 Successfully identified colonies growing on chromogenic coliform selective agar

Thirty-two colonies were isolated growing on chromogenic coliform selective agar out of which 29 were successfully identified by using the API tests: API 20 E test: 21/23 (successfully identified/isolated), API 20 NE test: 7/7, API 20 Strep test: 1/2. The 29 isolated cultures belonged to 16 taxa.

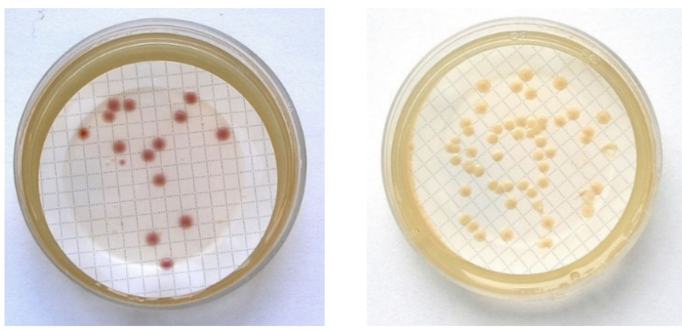
The typical colony forming species (15 isolated culture, nine taxa) can be seen in Fig. 3(a). These involve the suspected coliform culture coloured from pink to purple according to the standard as can be seen in Fig. 4(a). A significant proportion of them (six of the 15 isolated cultures) was *Aeromonas hydrophila* oxidase positive bacteria, which is not included in the target group of the standard microbiological quality control. *Aeromonas hydrophila* is a biofilm-forming pathogen in drinking water networks (Burke et al. [7]), which may cause inflammation of the gastro-intestinal tract as well as muscle inflection, septicaemia and skin diseases (Igbinosa et al. [8]). Among the typical colonies, various *Serratia* species and representatives of *Enterobacter, Pantoea, Citrobacter* and *Escherichia* genus were also identified. All of them belong to coliforms (Guentzel [9]).

The elements of the background biota (14 isolated culture, seven taxa), which are atypical colony forming species are shown in Fig. 3(b) and an example in Fig. 4(b). Six of the 14 isolates were identified as *Pseudomonas fluorescens*, which is an environmental soil bacterium but can cause bacteremia in humans, especially in hospital environments due to the transfusion of contaminated blood product or the use of contaminated equipment



(a) (b)

Figure 3: Successfully identified colonies growing on chromogenic coliform selective agar (29 isolated colonies, 16 taxa). (a) Typical colony forming species (15 isolated colonies, nine taxa); and (b) Atypical colony forming species (14 isolated colonies, seven taxa).



(a) (b)

Figure 4: (a) Typical coliform-suspicious pink colonies on chromogenic coliform agar; and (b) Atypical yellow-white colonies on chromogenic coliform agar.

associated with intravenous infusions and catheters (Scales et al. [10]). *Pseudomonas aeruginosa* is a ubiquitous environmental bacterium. It is the most common human pathogen of the *Pseudomonas*, and one of the leading causes of nosocomial infections (Moradali et al. [11]). *Rhizobium radiobacter* nitrogen fixing soil bacteria was also identified in the background biota. *Aeromonas salmonicida* was first isolated in cold-water environments and is considered as pathogen of aquatic vertebrates, but Tewari et al. [12] presented the first report of *Aeromonas salmonicida* isolated from human blood. *Sphingobacterium*, which is a ubiquitous environmental bacterium genus, was also identified. It is usually isolated from soil, water and plant material, and is rarely involved in human infections (Lambiase et al.

[13]). It is interesting that *Enterococcus avium*, a Gram-positive *Coccus* bacterium, could be identified by growing on chromogenic coliform selective agar. *Enterococcus avium* is a nosocomial pathogen which may cause infections of the abdominal and urinary region, but only a few reported cases are known (Patel et al. [14], Bipinchandra et al. [15]).

3.2 Successfully identified colonies growing on Pseudomonas-CN selective agar

Thirteen colonies were isolated growing on Pseudomonas-CN selective agar and all of them were successfully identified by using API 20 NE test. Fig. 5 shows the taxonomical distribution of colony form units isolated on Pseudomonas-CN selective agar.

The typical, bluish-green fluorescent colonies can be seen in Fig. 6, whose morphology corresponds to the standard description. The typical colony forming species (seven isolated culture, three taxa) were identified as *Pseudomonas fluorescens*, *Pseudomonas putida* (found in most soil and water habitats), and *Burkholderia cepacia* (Fig. 5(a)). *Burkholderia cepacia* is a human pathogenic bacterium (may cause pneumonia), that widely occurs in terrestrial habitats, and it has the ability to form biofilm (Coenye and Mahenthiralingam [16]).

Non-fluorescent white and greenish colonies as atypical colony forming species (six isolated culture, three taxa) were identified as *Pseudomonas fluorescens*, as well as two heterotrophic soil bacteria (*Ochrobactrum anthropi* and *Achromobacter denitrificans*) (Fig. 5(b)).

3.3 Successfully identified colonies growing on yeast extract agar

Seven colonies were isolated growing on yeast extract agar and five of them were successfully identified by using the API tests: API 20NE test: 3/4 (successfully identified/isolated) and API 20 Strep test: 2/3. The five isolated cultures belonged to four taxa: *Pseudomonas fluorescens*, *Chromobacterium violaceum*, *Gemella morbillorum* and

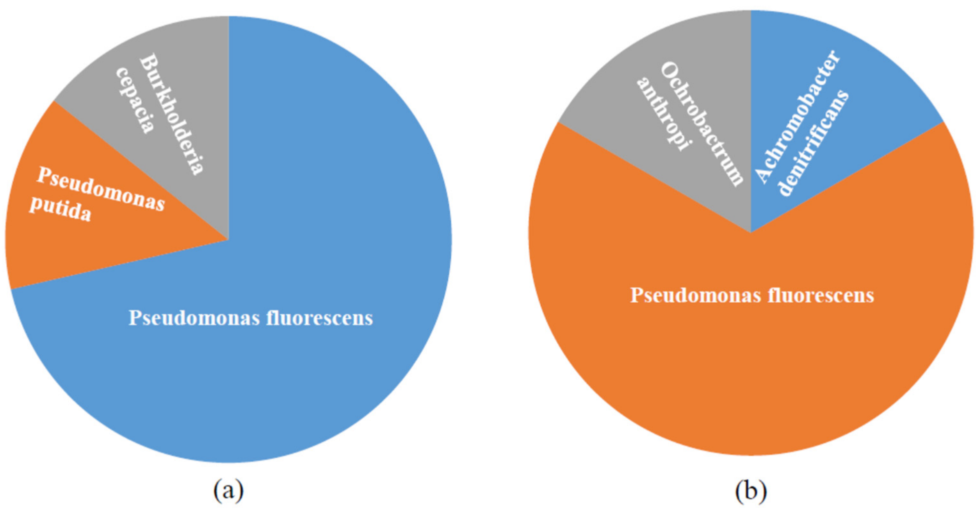


Figure 5: Successfully identified colonies growing on Pseudomonas-CN selective agar (13 isolated colonies, five taxa). (a) Typical colony forming species (seven isolated colonies, three taxa); and (b) Atypical colony forming species (six isolated colonies, three taxa).

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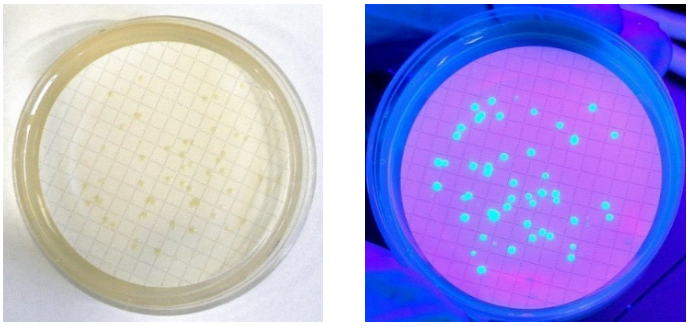

Figure 6: (a) Typical *Pseudomonas*-suspected colonies on Pseudomonas-selective medium under normal light; (b) Typical Pseudomonas-suspected colonies on Pseudomonas-selective medium under UV-A.

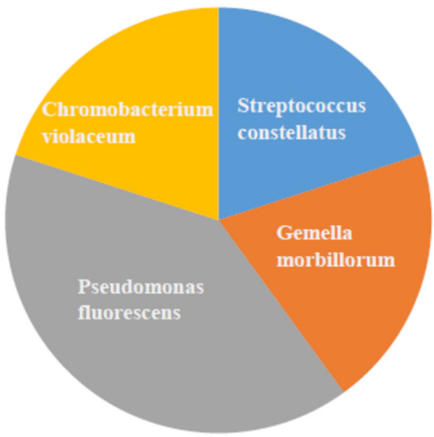

Figure 7: Successfully identified colonies growing on yeast extract agar (five isolated colonies, four taxa).

Streptococcus constellatus (Fig. 7). *Chromobacterium violaceum* is a facultative anaerobic environmental bacterium, common inhabitant of soil and water in tropical and subtropical regions (Ray et al. [17]). *Gemella morbillorum* is part of the normal microflora of the oral cavity (Vasishtha et al. [18]). *Streptococcus constellatus* is a member of the human intestinal and genitourinary flora (Whiley et al. [19]).

3.4 Successfully identified colonies growing on salt-blood agar

Fourteen colonies were isolated growing on salt-blood agar and 11 of them were successfully identified by using the API 20 Strep test: 11/14 (successfully identified/isolated). The 11 isolated cultures belonged to five taxa (Fig. 8). In the highest proportion members of the *Aerococcus* genus (*Aerococcus urinae* and *Aerococcus viridans*) were isolated on salt-blood agar. *Aerococcus* are Gram-positive cocci, which were first identified from contaminated air samples in the 1950s. *Aerococcus urinae* and *Aerococcus viridians* are widely distributed in hospital environments. They are considered to be predominantly nosocomial pathogens, causing urinary tract infections, bacteraemia and endocarditis, especially in weakened organisms (Parrey et al. [20], Mohan et al. [21]). However, their significance may be overlooked and easily misidentified as *Streptococci* or *Staphylococci* (Rasmussen [22]). The environmental bacterium *Lactococcus lactis* was also identified. It is used in dairy product fermentation as lactic acid bacteria and recognised as safe status with probiotic properties (Song et al. [23]). Although no *Enterococci* could be detected on the Enterococcus selective agar, we could isolate the human pathogen *Enterococcus faecalis* growing on salt-blood agar.

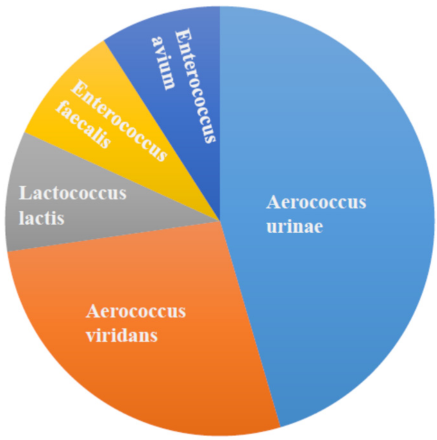

Figure 8: Successfully identified colonies growing on salt-blood agar (11 isolated colonies, five taxa).

4 SUMMARY

During our research, we were able to identify in drinking water samples 27 taxa at species or genus level by using API tests. Species as *Aeromonas hydrophila, Pseudomonas fluorescens, Burkholderia cepacia* that can cause confusion in the evaluation of water samples by forming morphologically typical colonies on the medium or presenting in high number of colony form units as background contaminants were identified. The presence of species which were originated from the background biota on different agar plates and can cause human diseases, were also confirmed: *Pseudomonas aeruginosa, Aerococcus viridans, Aeromonas hydrophila, Gemella morbillorum, Streptococcus constellatus*.

In the next phase of our research the connection between geographical location and microbiological composition of water samples are to be investigated using cluster analysis and principal component analysis. Although those results are not presented in this paper, the preliminary examination does not indicate connection between the water base of the sampling sites and their typical bacteriological composition, so it may be declared that the microbiological load originates from the water supply system and obviously not from the underground water base. Evaluation of samples concerning the morphology of identified taxa will also be the object of our future research.

As a conclusion, it is worth to check the drinking water supply systems using additional methods, e.g. API tests where the background biota is regularly detected in high amount by the conventional standard and routine methods. Even if the organisms which indicate water quality degradation are not present in the water sample, the background biota may contain human pathogenic bacteria that may lead to health problems when enriched in the drinking water supply system.

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WASH IMPLICATIONS OF UNPROTECTED LANDFILL ON GROUNDWATER QUALITY: A CASE STUDY OF UMUERIM, NEKEDE, IMO STATE, NIGERIA

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ABSTRACT
WASH related infections in Nigeria at large can be attributed partially to incessant and unlicensed disposal of hazardous waste in unprotected sanitary landfills. However, the contaminant plume of this potential point source of waste depletes the quality of groundwater sources, thus rendering it unsafe for consumptive purposes. Empirically, the WASH drive towards accessing quality water per capita has provided a push for the evaluation of water quality for boreholes located around a waste disposal site along Umuerim, Nekede, Owerri-West Local Government area of Imo state, Nigeria. The objective of this study is to monitor the physicochemical properties of boreholes over a period spanning five years, as well as developing the water quality index in the study area. In this collaborative work between The Federal Polytechnic Nekede, Owerri, Imo State Ministry of Environment and Umuerim Community, representative sample volumes of 225 cl of water were continuously collected from each of three different boreholes within the vicinity of the dump site. The water samples collected were tested for pH, phosphate, temperature, conductivity, nitrate, turbidity, E-coliform, DO, and BOD. From the test results obtained, the Water Quality Index (WQI) of an overall representative sample evaluated using National Sanitation Foundation Water Quality Index (NSFWQI) is 65.769, which represents water of medium quality. When the individual test results were rated with WHO and Federal Environmental Protection Agency (FEPA) standards for potable water, the values obtained indicate that the water was of a poor quality and can be attributed to leachate infiltration from the landfill. Thence, further treatment is recommended to ensure potability. Imo State Ministry of Environment and Federal Polytechnic Nekede, Owerri should collaborate and proffer an appropriate waste disposal method, a protected sanitary landfill for waste disposal. However, efforts at sensitizing the community on affordable water treatment options for the various households are already yielding results.
Keywords: aquiferous zone, borehole, dissolved oxygen, dump site, leachate, landfills, plumes, potability, quality index, WASH.

1 INTRODUCTION

Water is an integral aspect of life. It is only a satisfactory supply that must be made uncommittedly available to all. Man's daily activities revolve around water which include domestic, pharmaceutical, and diverse industrial and agricultural activities. As an outstanding priority, acceptable water quality must be met for consumptive purposes. Water quality encompasses its distinctive features such as chemical, radiological, physical and biological characteristics [1]. It is a measure of the conditions of water relative to the requirements of one or more biotic species. However, the paucity of good quality water in the globe remains a major contributing factor to high morbidity and mortality rates especially among children [2]. World Health Organization (WHO) recommends minimum daily water consumption of 2.7–3.7 l per capita per day. Current events have revealed that people manage water with far less than recommended standard [3].

Undoubtedly, this could be because of non-renewal of water sources, drought, desertification and contamination of water sources. Incessant and unlicensed disposal of solid waste in unauthorized sanitary landfill pose prompt pollution hazard to groundwater sources [4]. Several locations in Nigeria have experienced this challenge including Umuerim Nekede

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area of Imo State. The groundwater of this zone of interest is unduly exposed to this point pollution source. WASH related infections in this zone can be attributed partially to these unsafe practices. WASH is the acronym for water, sanitation and hygiene [5].

The contaminant plumes percolate into the aquifer through leachate infiltration and successfully disperse transversely within the aquiferous zone [6]. In line with World Health Organization (WHO), about 80% of all the world's diseases are caused by water. The use of befoul water and poor sanitary conditions result to increased vulnerability to water – borne diseases including diarrhoea, which leads to deaths of more than 70,000 citizens annually [7].

Assiduous research shows that 73% of this sickness along enteric disease burden is associated with WASH [6]. Interestingly, the contaminant alters the water quality and from experience, the aquifer is present at about 25 m beneath the earth surface. The landfill site is an abandoned borrow pit and extends to nearly 20 m depth. Several boreholes in this area are drawing from this threatened aquifer with resultant exposure to several water-borne challenges. Due to the growing concern that quality water has become scarce in the area taking cognizance of the future generation, it became imperative to evaluate water quality of this zone. The objective of this study is to monitor the physicochemical properties of boreholes by sampling over a period spanning five years (2014–2018). These selected physicochemical properties of the average values would then be transformed into water quality index using National Sanitation Foundation Water Quality Index Method.

2 METHODOLOGY

The methodology used to carry out this groundwater quality monitoring in the pollution prone zone is The National Sanitation Foundation Water Quality Index.

2.1 Study area

The study area covers the dump site located in Nekede along the Federal Polytechnic Nekede-Ihiagwa road, Imo State Nigeria with chainage(4+473), taking Naze junction as the starting point (0+000). It is bounded by longitude 60° 50'E and 70° 04'E and latitude 50° 23'N and 50° 30'N. The landfill site is an abandoned borrow pit and extends to nearly 20 m in depth. The dump site is shown in Fig. 1.

Figure 1: Dump site in Nekede along Ihiagwa road.

2.2 Sample collection

The water samples were collected from three different boreholes around the dumpsite. The first sample was collected 10 m away from the dumpsite, while, the second and third samples were collected 20 m and 30 m away from the dumpsite respectively. Water samples were collected with sterilized plastic containers. These samples were collected in the months of July and September during peak rains. This is the time that will yield more leachate in the landfill. Sampling data, place and time were recorded on the sample containers and were taken to the laboratory for analysis in accordance with the standard methods for examination of water and wastewater [10].

2.3 The National Sanitation Foundation Water Quality Index method

National Sanitation Foundation Water Quality Index method classified water quality into nine quality parameters according to the degree of purity by using the most commonly measured water quality variables [8]. The water quality data are recorded and transferred to a weighting curve chart where the numerical values of Qi are obtained. Mathematically, NSFWQI is expressed below:

$$\text{NSFWQI} = \sum_{i=1}^{n} W_i I_i \tag{1}$$

where NSFWQI is National Sanitation Foundation Water Quality Index, I_i is sub-index for i^{th} water quality parameters, W_i is the weight associated with i^{th} water quality parameters, n is the number of water quality parameters.

3 RESULTS AND DISCUSSION

3.1 Results

Table 1 below was used for water quality rating as per National Sanitation Foundation Water Quality Index method according to WHO and FEPA recommended standards for potability.

Table 1: Water quality rating as per National Sanitation Foundation Water Quality Index method. *(Source: Liou et al. [4].)*

WQI Value	Rating of water quality	Grading
91 – 100	Excellent water quality	A
71 – 90	Good water quality	B
51 – 70	Medium water quality	C
26 – 50	Bad water quality	D
0 – 25	Very bad water quality	E

3.2 Discussion

Water quality index of a water body is established from various important physicochemical parameters. From Table 2, the final index value after the analysis is 65.769 which falls within the index assessment range of 51–70 or Category C (Table 1).The various physicochemical parameters for calculation of water quality index are presented in column 2 of Table 2.

The result shows that the average temperature for borehole water is 27.1°C, which is above acceptable limits. Turbidity value was found to be 10 NTU quite above the limit set by WHO and FEPA standards, as can be seen in Table 3. The turbidity affects clarity of water and presents an unpleasant look of the water. It is also indicative of the presence of microorganisms. Total dissolved solids had average value of 350 mg/l. The TDS content of eater affects its palatability and is also related to hardness. It has been observed that TDS concentration below 1,000 mg/l is usually acceptable to consumers [7].

Table 2: Average test values and interpolated Q values of water quality parameters.

Test parameters	Average test result (5 years)	Interpolated q-values	Weighting factors	NSFWQI
DO	0.52 mg/l	98.60	0.17	16.762
Phosphate	0.15 mg/l	96	0.10	9.600
BOD	11.2 mg/l	29.60	0.11	3.256
E – Coliform	184 cfu/100 ml	38.28	0.16	6.125
TDS	350 mg/l	70	0.07	4.9
Nitrate	0.52 mg/l	95.92	0.10	9.592
pH	5.86	42.6	0.11	4.686
Temperature	27.1°C	12.48	0.19	1.248
Turbidity	10NTU	76	0.10	7.6
Total				65.769

Note: The weighting factors are predefined standard factors for each test parameters.

Table 3: Comparison of experimental results with WHO and FEPA Standards.

Parameters	Units	Average test result (5 years)	WHO STD	FEPA
DO	mg/l	0.52	100	NS
Phosphate	mg/l	0.15	NS	>50
BOD	mg/l	11.2	5	NS
E – Coliform	cfu/100 ml	184	MNBD	NS
TDS	mg/l	350	NS	NS
Nitrate	mg/l	0.52	10	10
pH		5.86	6.5–8.5	6.5–8.5
Temperature	°C	27.1	27	25
Turbidity	NTU	10	≤ 5	5

NS – not specified; ND – not detected; MNBD – must not be detected.

Average value was obtained by calculating the mean for the three (3) samples:

$$\text{NSFWQI} = \sum_{i=1}^{n} W_i I_i = 65.769.$$

The pH expresses the extent of acidity or alkalinity of a sample. It was found to have an average value of 5.86. This is an indication of weak acidity. The soil type may be such that it permits dissolution of materials which bring about slight acidity in the sample. The pH was found to be lower than the WHO and FEPA range of 6.5–8.5 for borehole waters. Nitrate was determined to be 0.52 mg/L. The presence of nitrates in a water sample could be due to inorganic fertilizers, plants, animal decomposition and hazardous wastes which may have percolated the soils over time [11].

The presence of phosphate in a water source could be attributed to discharges related to contaminant plumes [12]. The average value of dissolved Oxygen (DO) was 0.52 mg/L. This parameter is important for the sustenance of aquatic lives [12].

The results of parameters in borehole water after collection are presented in Table 2. For the parameters discussed, the average results show a rise in temperature (27.1°C), Turbidity (10 NTU), and total dissolved solids (350 mg/L). This may be attributed to the fact that the particles in the water had no opportunity for settlement. The average values of nitrate (0.52 mg/L) and Phosphate (0.15 mg/L) which expressed lower concentrations were within acceptable limits. The reason for this is also not clear but it could be that soluble particles that are chemical in nature could be well distributed in the body of water and possibly interact with the water molecules.

However, the BOD value obtained was way higher than the standard WHO values and this is further supported by the low DO value. This is an indication that biological activity is on-going within the aquiferous zone.

The implication therefore is that borehole water collected during the rainy season presented a better water quality monitoring for drinking. The overall water quality index obtained for the boreholes indicates a medium water quality, using NSFWQI rating [9]. This value is corroborated by the unacceptable values of the parameters obtained in the tests conducted.

4 CONCLUSION

Water quality index is a good means of predicting the condition of any water source at a particular time. The most definitive of contaminant distributions requires the installation of monitoring wells and the collection and analysis of water samples. Monitoring usually continues over a period of several years and requires several sampling rounds. A water analysis would typically include the major cations and anions (routine analysis) and packages of organic and metal analyses, depending on the type of contamination involved. The study was aimed at developing WQI to monitor the current water quality in the bid to continuously monitor that unprotected landfill. Most of the individual quality parameters fell below acceptable standards set by the WHO and FEPA. Assessment of WQI is necessary for control and treatment of contaminated water supplied to homes from boreholes within the affected area. From this study, it is therefore established that the borehole waters should be subjected to some level of treatment prior to use for drinking purpose.

RECOMMENDATIONS

Achieving Sustainable Development Goal in terms of safe drinking water in the zone before 2025 requires assiduous strategies. Considering the peculiarities of the location, there are no alternative water supply options since the nearby surface water source has not been adequately harnessed.

Development and implementation of an appropriate waste disposal system in the area will help to prevent leaching of contaminant plumes into the groundwater sources. Strengthening the capacity of National and Sub-national bodies to develop and implement WASH policies, strategies and guidelines will underpin the drive towards safeguarding family health. Sensitization of local dwellers on low cost sanitary systems is needed to eliminate open waste disposal of any nature. Sensitization of households on practical materials and guidance for water disinfection techniques will go a long way to reduce WASH related infections.

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SUSTAINABILITY OF WATER INVESTMENTS IN WEST AFRICA

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ABSTRACT
The objective of this case study was to assess the sustainability of the water investments made by the United States Agency for International Development through the West Africa Water, Sanitation and Hygiene Program (USAID WA-WASH) between 2011 and 2015 in Burkina Faso, Ghana, and Niger. During this period, the Program promoted low-cost water technologies with 376 drinking water points installed or rehabilitated; 8,192 household latrines constructed; 5,855 agricultural producers trained on short-term agricultural sector productivity or food security; 5,657 stakeholders increased their capacity to adapt to the impacts of climate change; 7,198 people trained on mainstreaming gender into their development activities. A tool was developed and used to assess the financial, institutional, environmental, technical, and social aspects of the sustainability of the Program investment included in WASH services. The results presented herein focus on the sustainability of the water investments in these three countries. The approach consisted of identifying the number of communities to be monitored; the number of water infrastructures within the community; meeting with local authorities; organizing focus group discussions; visiting all water points installed by the Program in each community; and collecting data on the functionality of the water points. The monitoring and evaluation team conducted four field visits between January 2016 and December 2017 to 72 communities in Burkina Faso, Ghana, and Niger. A different weight was given to each of the five sustainability areas. Data gathered during each of the visits was statistically analysed. The results showed that the water supply sustainability score was very good in Ghana (81%) but somewhat lower in Niger (63% – management committees not functional and no payment of user fees), and in Burkina Faso (55% – relocation of mechanics and a lack of maintenance). In most cases, the beneficiaries continue to use the information and skills acquired from the training, focus group discussions, and technical assistance provided by the USAID WA-WASH Program and the majority of the water points continue to be functional.
Keywords: West Africa, sustainability, water supply, investment, USAID, Florida International University.

1 INTRODUCTION

According to the 2017 United Nations Human Development Index (HDI), Burkina Faso and Niger were ranked 183 and 189, respectively, among the countries with the lowest HDI in the world. However, Ghana, ranked 139, is considered a medium HDI index country [1]. Although Ghana is ranked higher compared to Burkina Faso and Niger, all three countries are very similar when it comes to access to water supply, sanitation and hygiene services. In the urban areas of these countries, drinking water is provided by a central public or private agency, the National Water and Sanitation Agency (ONEA in French) in Burkina Faso, the Ghana Water Company Limited (GWCL). and the Niger Water Utility Company (SEEN in French). In rural areas, water provision is handled by small private companies or by the rural communities themselves with the support of international development agencies, non-governmental organizations, etc. Different types of water infrastructures are available to urban and rural dwellers in the three countries where this work was conducted (see Table 1).

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Table 1: Water supply in the study area in 2017. *(Source: JMP [2].)*

Country	Setting	Safely managed	At least basic	Limited service	Unimproved facilities	Surface water
		%				
Burkina Faso	Urban		79.9	15.1	4.5	0.5
	Rural		35.5	32.9	30.5	1.6
Ghana	Urban	56.5	36.2		2.2	0.3
	Rural	11.5	56.1	13.1	6.2	13.2
Niger	Urban		84.3	11.4	2.3	2.0
	Rural		43.6	15.6	36.7	4.1

As of 2017, Burkina Faso and Niger showed encouraging signs in the access to at least basic services in urban settings with an access rate of 79.9% and 84.3%, respectively. However, there remains great disparities between urban and rural areas in these two countries. Ghana urban dwellers have better access to safely managed services than rural populations. While more urban people in Ghana have access to at least basic services (92.7%) as compared to Burkina Faso (79.9%) and Niger (84.3%). Substantial efforts are still needed in all three countries to bring rural areas to at least a basic service level but more so in Burkina Faso where more than 60% of the rural population have limited access or worst services.

Sustainability is a concept that has been gaining prominence throughout the scientific and development communities for the past decades. Sustainability is defined by Abrams [3] as "whether or not something continues to work overtime". This definition applied to WASH suggests that the technologies installed in the provision of safe drinking water need to continue to be operational beyond the life of a project/program in order to achieve sustainability. This definition lacks a clear specification of the concept of "overtime" and that is where some controversy of the concept of sustainability in the WASH sector comes from. Overtime it can be the designed physical lifetime of the facilities, the lifetime of the project under which it was installed or even a fixed amount of time. Hodgkin [4] brings some clarification to the time concept of sustainability by specifying that sustainability is achieved when the WASH facilities maintain operation over a long period of time when all external investments form international development agencies such as the United States Agency for International Development (USAID), the World Bank (WB), the African Development Bank (AfDB) etc. are withdrawn. Hodgkin infers that a good starting point for the measurement of sustainability should be the end of funding of the WASH facilities; this begins mostly after the installation of the facility. Although the start of sustainability is identified, the end seems to be ideally infinite according to Schouten and Moriarty [5]. Acknowledging that the infinite time is practically impossible, they explain that communities using the facilities will never revert to a lower service level while allowing for system replacement or upgrade at the end of its natural lifespan.

The concept of sustainability is without any doubt a complex yet vital requirement in the WASH sector; therefore, it is imperative to find ways to quantify it. This will allow the sector actors to include it in the design, the implementation, and the monitoring of WASH services provision. Several studies to have strong correlation with sustainability [6]–[11], have identified multiple technical and non-technical factors to assess sustainability. These factors include operational community organizations, the ability of the community to function, maintain facilities and raise adequate user fees for spare parts, and a strong backup support from external parties at the local or district level to solve major breakdowns. Measuring these factors is a challenge but various tools have been developed for that purpose with the most relevant to our study: (1) the Dutch WASH Alliance-Sustainability Monitoring Framework (SMF); (2) the Governance into Functionality Tool (GiFT); and (3) the USAID-Rotary International-Sustainability Index Tool (SIT).

All three tools are similarly structured: (1) questions for each indicator category are developed, administered and graded following a specific scale to each question; (2) the grades are aggregated by category and all categories weighted according to their importance (defined by the tool developer); and (3) all scores are summed for a final grade. Boulenouar et al. [12], provide extensive details on each of these tools. USAID WA-WASH sustainability tool encompasses indicators drawn from the Gender Analysis Snapshot (GAS), GiFT, SMF, and SIT. Most of these indicators were reformulated to meet the Program specific needs. Accordingly, this study aims to assess the sustainability of WASH services provided in Burkina Faso, Ghana, and Niger using the USAID WA-WASH sustainability tool.

2 METHODOLOGY

2.1 Data collection method

Rural WASH services provision in developing countries, particularly in Burkina Faso, Ghana, and Niger is in major part financed by international agencies and implemented by international by various organizations. For the purpose of this study, the investigated WASH services were implemented in the three countries during Phase I (2011–2015) of the USAID WA-WASH Program. The Program aimed to:

- Support catalytic approaches to accelerate regional access to improved water supply/sanitation services and improved hygiene behaviors.
- Develop and implement improved models for sustainability of rural and sub-urban WASH service delivery that could be replicable throughout West Africa.
- Build synergies among WASH actions and critical USAID/West Africa regional priorities related to food security, climate change, and sustainable resource management.
- Strengthen the regional enabling environment and capacity for WASH to achieve WASH Millennium Development Goals in West Africa

The Program's Phase II (2016–2017) focused on three objectives one of which was essentially the monitoring and evaluation of Phase I activities. Under this objective, 72 communities (32 in Burkina Faso, 20 in Ghana and 20 in Niger) were selected. The Program setup a two-year (2015–2017) assignment to conduct periodic monitoring visits in the selected communities within the three countries. The number of communities visited and the total number of water facilities monitored varied from one country to the other because of the initial number of installed facilities (Table 2). The monitoring and evaluation plan was based on the communities' size and the sites' accessibility. Fifty percent of the total improved water points installed by the Program in the three countries were visited. However, all the water facilities in each of the selected communities were monitored/visited.

Table 2: Total number of water facilities installed and monitored under the Program.

	Burkina Faso	Ghana	Niger	Total
Water facilities installed	327	28	52	406
Water facilities monitored	128	28	47	203

2.2 Sustainability tool development

USAID WA-WASH sustainability tool encompasses indicators drawn from GAS, GiFT, SMF, and SIT. Other custom indicators were added by the Program to complement the tool and ensure the coverage of all USAID WA-WASH past water supply activities. The tool administration methodology was set up in sequential steps: (1) identify the number of communities for water supply activities; (2) identify the number of water points in each community; (3) meet with the local authorities to announce the field visit objectives and gather their feedback; (4) organize focus group discussions with community members including village development council members, water user associations, etc.; (5) visit all the water points installed by the Program in each community and collect data on each water point. In addition, the USAID WA-WASH team met with the pump manufacturers, driller teams, masons, etc., to document their sales or service provided after the Program field activities, report challenges encountered, and suggest ideas on how they can improve their performance. A one-day workshop per country was organized with these stakeholders after each of the field visits in order to propose and adopt improvement plans for the low-cost technologies promoted by the Program.

Based on the set of questions a scoring system was developed as follows: (1) determine the sustainability score of each water points (out of a possible 10 points) for the five sustainability areas; (2) compute an average score for each water point; (3) aggregate the scores for each sustainability area to obtain an overall score for that area in each community; (4) compute the sustainability score of each sustainability area for all communities (maximum score equals to the number of communities covered multiplied by 10 points); and (5) compute an average sustainability score for each of the countries. For instance, if the monitoring of the water supply past activities was implemented in 20 communities and the sum of the sustainability scores of all 20 communities is 170, the average sustainability score for water supply is 8.5 points (out of a possible of 10). Using this approach, the sustainability scores can be produced by country, province or community.

The tool comprised 28 specific questions grouped into five sustainability categories as follows:

- Technical Sustainability: The technology or hardware installed continues to function, is maintained, repaired and replaced by beneficiaries and it is not depleting the natural resources on which its functioning depends.
- Environmental Sustainability: The implementation of the approach is integrated with sustainable management of water and waste flows and resources.
- Financial Sustainability: A continuity in the delivery of products and services related to WASH; locally financed and do not depend on external (foreign) subsidies.
- Social Sustainability: The appropriate social conditions and prerequisites are realized and sustained.
- Institutional Sustainability: The WASH service users, authorities, and service providers at the local and the national level are clear on their roles, tasks, and responsibilities.

The scores from each of the questions were aggregated to constitute the category score and the categories scores are weighted following the SIT tool guidelines for weights and summed for the final sustainability score. Table 3 shows the repartition of sustainability questions per sustainability category as well as the weight used to compute the final score. It should be noted that the financial, social, and institutional sustainability categories account for 75% of the total water supply sustainability score, therefore they have the greatest impact on the overall sustainability score.

Table 3: Sustainability questions repartition and weight per category for the water infrastructures.

Water	Number of questions					
	Financial	Social	Institutional	Environmental	Technical	Total
Water supply	7	5	5	5	6	28
Weight (%)	35	20	20	15	10	100

2.3 Data analysis approach

- Data cleaning and transformation: The initial data collected form the interviews and the observations made in the field are of the "string" type (words and phrases). In this process, the string data are transformed to the corresponding numeric value. This is a tedious but required step in the data processing and analysis procedure.
- Data exploration and management: In this process descriptive statistics in the form of frequency tables are generated for each variable/question. The goal of this exercise is to compare the actual responses to the questions with respect to all possible choices offered. Missing responses and wrong types of responses were detected and removed from the data set.
- Data summary generation: Data set are used to generate statistical outputs of sustainability levels chronological observation per country. Comparisons are made between different sustainability categories and between countries to determine the underlying reasons for success or failures and the possible solutions to be implemented.
- Interpretation: The final interpretation of the data is a single score per facility on a scale of 1 to 10 where a score of: less than 5.9 = poor sustainability; between 6 and 6.9 = fair sustainability; between 7 and 8.4 = good sustainability; and between 8.5 and 10=very good sustainability.

Four visits where completed during the two-year period (2016–2017) meaning that each facility was visited four times during the monitoring and evaluation period. The sustainability of the water infrastructures was assessed using the sustainability tool developed by the Program as described previously.

3 RESULTS AND DISCUSSION

As stated above, the financial, institutional and social sustainability categories have considerable influence on the environmental and technical sustainability categories making them the core categories for the analysis of each of the three countries.

3.1 Burkina Faso

The water supply activities and facilities in Burkina Faso displayed a stable and fairly good sustainability over the period of the monitoring visits. Fig. 1 shows the evolution over time of the sustainability score. The average sustainability score was about 60%. A decline of a three percentage points in the sustainability score is observed from Visit 1 (August 2016) to Visit 2 (January 2016); while in Visit 3 (June 2017) that decline was recovered. However, the last visit showed a decline of nine percentage points in the score.

The observed pattern of the overall sustainability score followed the pattern of the financial sustainability which in this case has an impact on all the other categories except for the technical (Fig. 2). In June 2017, the overall sustainability score increased (64%) because of the increase of the financial sustainability score due to several factors (existence of funds for repairs, affordable spare parts, etc.). During the four visits the institutional sustainability, which measures the existence of management committees, caretakers, mechanics, etc., kept decreasing. This is explained by the mobility of people involved in the institutional activities as they may move to different areas for personal reasons or productive activities and by the fact that people did not take care of their water facility. Indeed, during the visits, the team noticed the presence of stagnant water around some of the water points. Even with a good technical sustainability score (8 out of 10), beneficiaries stated that they did not use preventive measures to prevent breakdowns of the rope pumps. Beneficiaries reported frequent pump failures due to breakage of the rope even though institutionally, mechanics where present (high institutional sustainability score). The ropes which does not cost much needs to be replaced from time to time because of usage.

For Burkina Faso, most sustainability scores are characterized by a general drop on Visit 2. However, these scores were higher during Visit 3 except for the institutional score. The financial sustainability remained low across all visits especially in Visit 2 (4 out of 10) due to a lack of funding for the replacement of the ropes, a necessary maintenance item for the continued operation of a good service delivery.

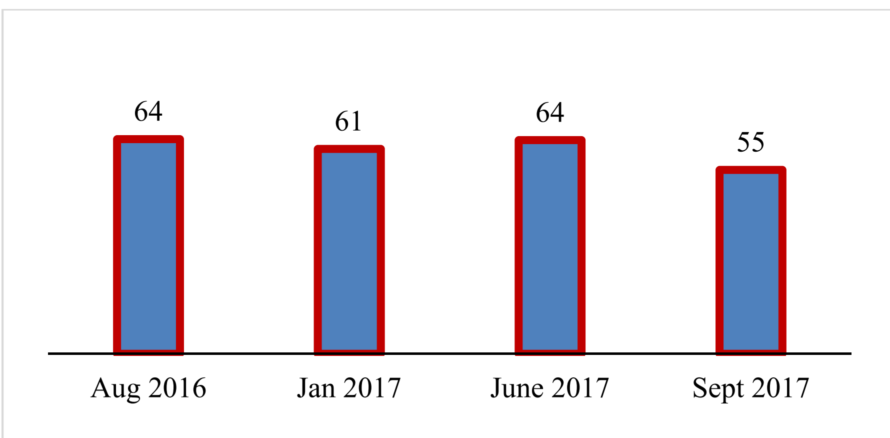

Figure 1: Burkina Faso water supply sustainability score (%) from August 2016 to September 2017.

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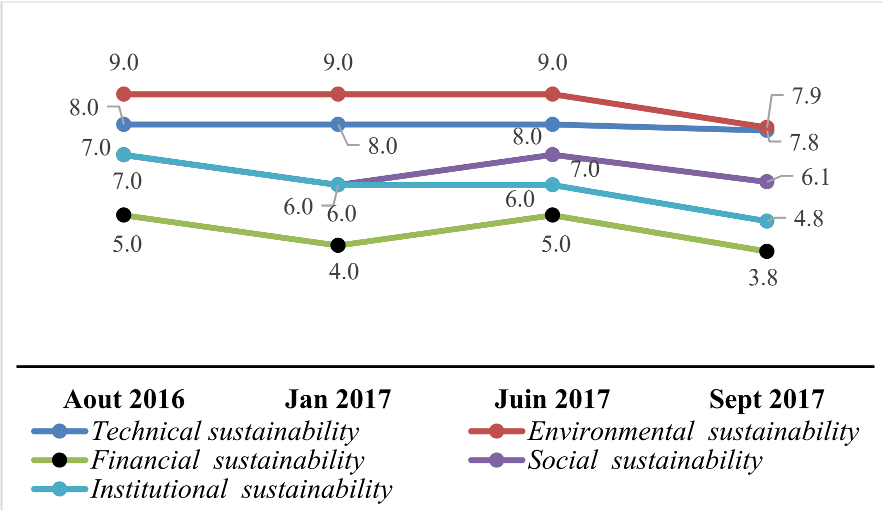

Figure 2: Sustainability category scores (scale 1 to 10) between August 2016 and September 2017 in Burkina Faso.

The highest financial sustainability scores are observed when the social and institutional sustainability factors have simultaneously very high scores. This is due to the fact that 70% of the sustainability points allocated to the social and institutional sustainability categories are directly related to the beneficiaries been able to have funds when needed for the necessary repairs since the pump is owned by the household. In Burkina Faso, in order to obtain a high financial sustainability score, it is critical that beneficiaries have the funds needed for repairs and do not necessarily rely on outside help for such expenditures.

3.2 Ghana

Through the first two field visits, the water supply sustainability score in Ghana remained constant and in the good sustainability range (a point away from the highest sustainability range). The score fell into the fair sustainability range on the third visit as shown in Fig. 3. However, in the fourth visit, Ghana showed the highest score among the three countries.

A slight increase was observed in all sustainability scores from Visit 1 (June 2016) to Visit 2 (November 2016) except for the technical sustainability that experienced a 1-point decrease. In Visit 3 (April 2017), all categories declined except the institutional sustainability which experienced a slight increase. The financial sustainability category experienced the highest decline due to a bad management of the financial records by the water management committee, an issue related to the sharp decline of the social sustainability category. The effect of the social sustainability decline was also felt in the technical sustainability category with a decline in preventive maintenance of the water points.

Overall, the institutional sustainability in Ghana was high and constant for the two year's monitoring period (Fig. 4) mainly because of the availability of caretakers and mechanics. This situation contributed to the good water supply sustainability score. Indeed, the involvement of the caretakers (institutional sustainability) helped in improving the role of women (social sustainability) and cleaning the surroundings of community pumps (environmental sustainability). The sustainability score went up after the third visit because more repairs were done, and more water points were functional mostly because beneficiaries had more funds for repairs and maintenance. Also, it should be noted that at the beginning of the rainy season the financial sustainability score was low because resources were allocated to farming operations. Indeed, the beneficiaries underlined the fact that during the rainy season, even though micro credit exists they invest more in agriculture than in the repair and maintenance of the water points. The social and environmental sustainability scores seem to follow the same trend as the financial sustainability score.

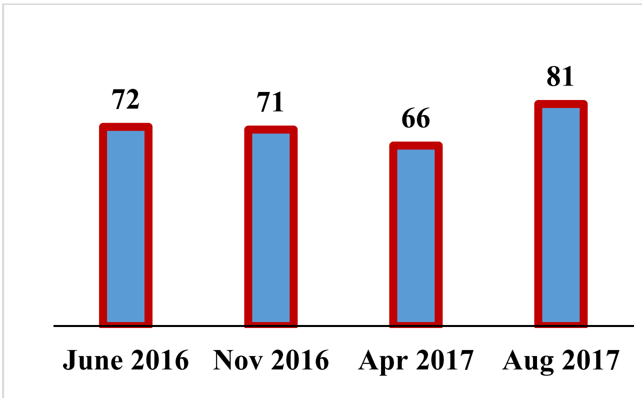

Figure 3: Ghana water supply sustainability score (%) from June 2016 to August 2017.

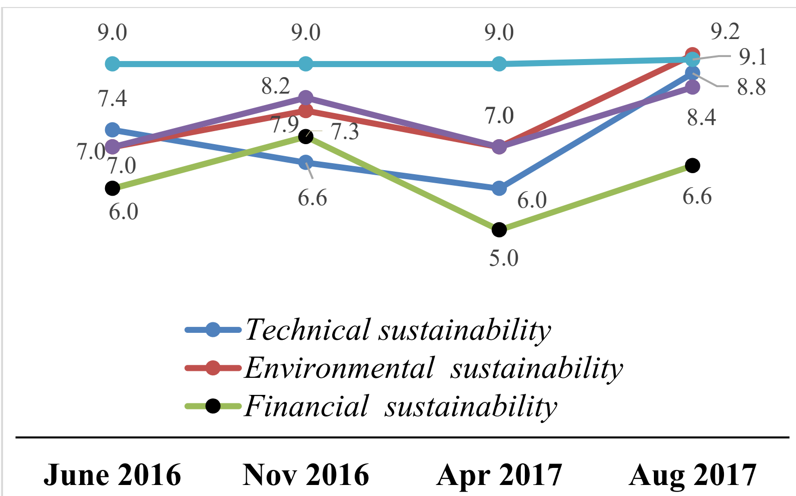

Figure 4: Sustainability scores (scale 1 to 10) between June 2016 to August 2017 in Ghana.

3.3 Niger

The overall sustainability score for water supply for Niger remained low across all visits and in the range of poor sustainability (Fig. 5). The sustainability score decreased from May 2016

(56%) to September 2016 (52%) because the management committees were no longer functional and therefore this situation contributed to the hindrance of the repairers' activities. However, the score increased from September 2016 (52%) to July 2017 (63%) due to the re-establishment of the management committees by the Program team allowing the resumption of the collection of fees for water usage and for the operation and maintenance of the water points. The interventions of the Program team resulted in a score increase for all sustainability areas (Fig. 6).

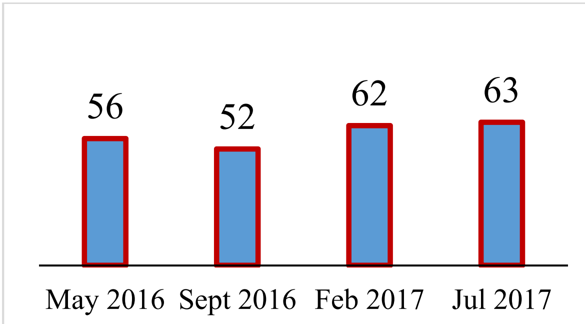

Figure 5: Niger water supply sustainability score (%) from May 2016 to July 2017.

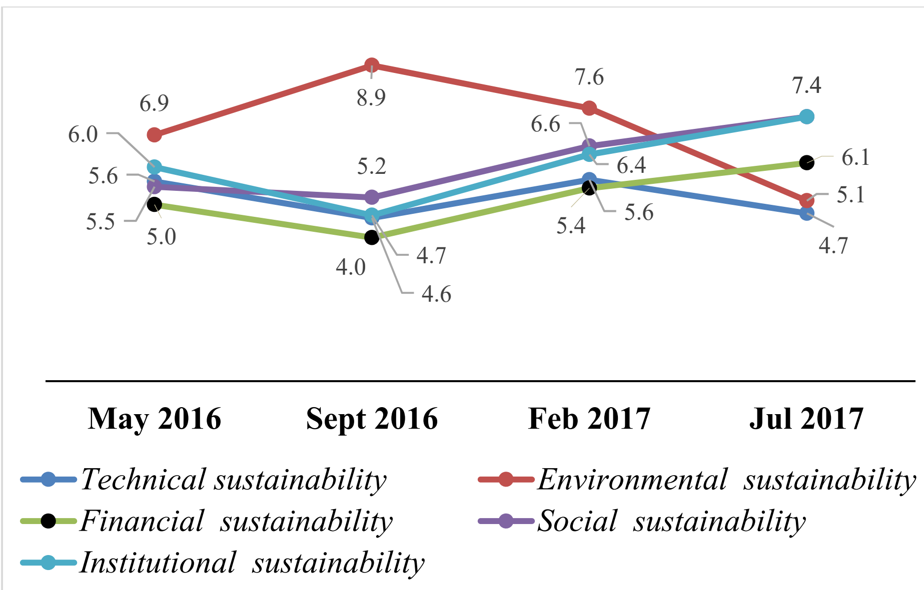

Figure 6: Sustainability scores (scale 1 to 10) between May 2016 to July 2017 in Niger.

The general trend observed in the analysis of the data from Burkina Faso and Ghana is also observed for Niger as well: a high score in social and institutional sustainability creates the conditions for a high financial sustainability score just as the opposite creates a low financial sustainability score (Fig. 6). The data also indicated that the low social sustainability score observed in Niger was due in part to the occurrence of conflicts around the water point. As to the questions related to the setup and functionality of a water management committee, the communities scored 0. This explains the drop in the financial sustainability because when the water management committees are not functional the financial sustainability is more likely to be low regardless of the institutional sustainability score.

Despite the support from the Program, no notable improvements were made between visits suggesting that the beneficiaries did not address the major recommendations made by the Program.

The financial and institutional sustainability areas experienced a decline between Visit 1 (May 2016) and Visit 2 (September 2016). In Visit 3 (February 2017) most of the factors experienced an increase due to more active water management committees and the involvement of women (social sustainability areas). The financial sustainability areas benefitted from the social improvement with a better collection of service delivery and operation and maintenance fees.

4 CONCLUSION AND RECOMMENDATIONS

The last sustainability scores observed in the three countries, Burkina Faso 55%, Ghana 81% and Niger 63%, indicate that the differences between the countries are substantial. In Burkina Faso, the lack of preventive maintenance contributed to the low overall sustainability score despite the presence of mechanics. In addition, the beneficiaries reported that the spare parts (rope) was not affordable. While the cost of the rope is very low, we believe that people expect financial assistance even for small things. The positive thing about Ghana is that the breakdowns lasted less than three days and the breakdown frequency was less than three breakdowns per quarter. Most of the communities had funds dedicated to the repairs. Also, the water points in Ghana were well maintained, very few water points had livestock around them and or the existence of solid waste – there was no presence of possible sources of contamination around the water points. However, some of the water points in Niger were characterized by a lack of preventive maintenance and the existence of solid waste and stagnant water around them. In addition, the water users' fees (the water points in Niger were community water points) were not always collected resulting in some cases in the shortage of funds for maintenance and repairs.

Our results show that there is correlation between the five sustainability categories as they impact each other either directly or indirectly. While being the most important sustainability categories with the highest weights, the financial, social, and institutional categories have an impact on the technical and environmental categories through a cause and effect relationship. In the domain of water supply it is safe to assert that the social sustainability category has a strong correlation with the financial sustainability category. This finding highlights the social component of water supply projects as the center piece in the overall sustainability of the project because it guides the financial aspect of sustainability which relates undoubtedly to all the other factors identified as crucial to the overall sustainability of the investments made by USAID WA-WASH in Burkina Faso, Ghana, and Niger. Overall, and despite the Program's similar interventions in the three countries, the communities in Ghana were better organized than those in Burkina Faso and Niger and took good care of their water points.

Millions of dollars have been and continue to be injected in developing countries in order to help issues related to basic needs such as the provision of a safe water supply. These funds will be vain unless they are designed and accompanied by a sustainability assurance component. This is necessary to guarantee that the services provided remain operational even after the ends of the funding from international development agencies and other institutions.

In this case study, the results showed that in general the water supply activities have a good sustainability score. While water supply proved to be highly influenced by the social aspect in/of the beneficiary communities. Taking this social component of the activities a step further, it is noted that privately managed and community managed water points were implemented. Our sustainability results were not conclusive in terms of the durability of the community managed water points versus the ones owned by the households. One would think that a privately-owned water point would be taken care of better than a community management water point. A better sense of ownership of the community water points could lead to a better organization and care of the water point. Conversely, a household owned water point because it is used less often should last longer and will be more sustainable. Thus, we cannot recommend that community managed water points should be prioritized over household managed ones. Therefore, the focus of the development efforts in the rural areas for all three countries should focus on water supply technologies especially low-cost technologies to bring more access to basic services with an emphasis on the sustainability of the built facilities/installations.

In conclusion, finally, we observed that after four years, most beneficiaries continue to use the information and skills they have acquired from the Program support through capacity building, focus group discussions, and technical assistance, and the majority of the water points in the three countries continue to be function and are serving the needs for which they were intended.

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BIOLOGICAL NUTRIENT REMOVAL EFFICIENCIES FOR HYDRAULICALLY OVERLOADED WASTEWATER WORKS

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ABSTRACT
In this current age the environmental laws have become more stringent towards health, economy and reduction of pollution at the point of sources. Results of a comprehensive study are reported for Darvill wastewater works (WWW) inflow in relation to biological nutrient removal process. The incoming and outgoing nutrient (ammonia and soluble reactive phosphorus (SRP)) concentrations were determined using standard testing methods. Calculations of biological nutrient removal (BNR) efficiencies were used to evaluate the effects of high inflow to the biological treatability of the activated sludge for the period 2016–2017. At inflows above design capacity the nutrient removal efficiency was found to be at an average of 40% and SRP removal efficiency being 64% for the period of the study. The nutrient removal efficiency had an inversely proportional relationship to the inflow into the plant with ammonia removal being mostly affected. When the plant is overloaded the BNR process is adversely affected.
Keywords: biological nutrient removal, hydraulically overloaded plants, nutrient removal efficiency.

1 INTRODUCTION

Wastewater treatment is a critical chain in the urban water cycle. Nature has its own means of attenuating waste however in larger volumes and concentrations the process becomes slower and more problematic. This has led to the design of wastewater works (WWW) which are intended to aid in the faster biodegradation and removal of pollutants found in waste water [1]. The purpose of a WWW can be elaborated as the treatment of municipal and industrial wastewater (WW) to acceptable effluent quality, devoid of excess organics chemical oxygen demand (COD), ammonia (NH_3), and nitrogen (N) and phosphorus (P) nutrients.

When these nutrients are released into a water resource they cause an unnatural stimulation of organisms such as algae and certain aquatic vegetation such as water hyacinths. This in turn can affect the suitability of water for farming, recreation or potable (drinking) use. It is for this reason that much attention has been given lately to biological nutrient removal (BNR)+ [2]. A new deal for wastewater engineers is now to stretch the performance of existing infrastructure, which represents one of the most significant challenges to the practice of wastewater engineering [3]. Traditionally, the complexity associated with implementing BNR in WWW has been primarily in terms of balancing competing requirements for nitrogen and phosphorus removal, particularly with respect to the use of influent COD as a carbon source for the microorganisms [4].

The nitrogen that enters the wastewater system is found as NH_3, ammonium ions (NH^{4+}), nitrites (NO^{2-}) and nitrates (NO^{3-}) in wastewater. Ammonia and ammonium ions are the most reduced forms of nitrogen and are often products of organic decomposition. Nitrite is, however, the intermediate, with nitrate being the end product of organic oxidation during nitrification [5]. Ammonia and Ammonium ions are both commonly referred to as “ammonia nitrogen”. This form of ammonia will be observed in this study. Nitrification is mediated by specific chemical autotrophic nitrifying bacteria (Fig. 1). Henze et al. [6] infer that these bacteria obtain their carbon requirement (anabolism) from dissolved carbon dioxide (CO_2)

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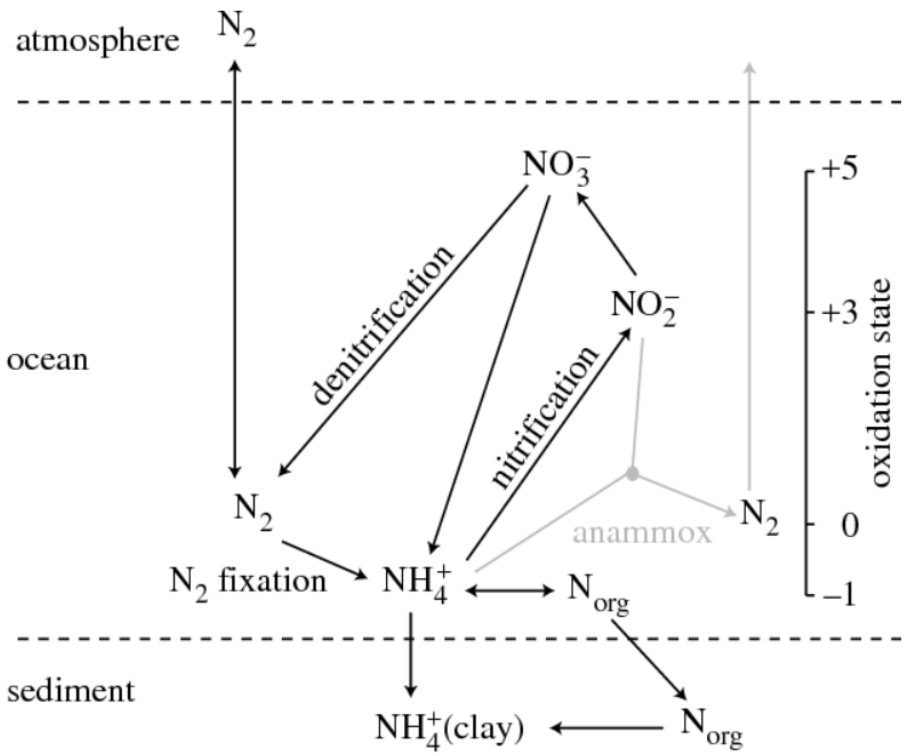

Figure 1: Nitrogen cycle depicting the nitrification and denitrification process [9].

and their energy requirement (catabolism) for biomass synthesis from oxidizing the ammonia nitrogen to nitrite and nitrate. The autotrophic nitrifying bacteria have much lower growth coefficients (1/5th) as compared to the heterotrophic bacteria which are also present in the activated sludge reactor for organic waste breakdown. Industrial effluent has a high concentration of nitrogen and a low C/N ratio. The main problems in maintaining high nitrification efficiency when treating low C/N wastewaters are changes in influent concentration and flow, which may also affect the dissolved oxygen level in the reactor, and pH due to fluctuating industrial operations [7]. The activated sludge process is the most commonly used technology for biological wastewater treatment [8].

Domestic wastewater is also relatively rich in phosphorus compounds. Wentzel et al. [10] suggested that the removal of this phosphorus in wastewater is achieved by encouraging the accumulation of P in the microbial cells in the form of polyphosphate (polyP) granules in excess of the levels normally required to satisfy the metabolic demand for growth. This storage process is commonly referred to as “enhanced biological phosphorus removal” (EBPR). This P uptake and polyP storage is done by organisms known as polyP accumulating organisms (PAO). Curtin et al. [11] reported that the PAOs under anaerobic conditions convert organic material into energy rich carbon compounds called Polyhydroxyalknoates (PHAs). Energy required for this process is generated through the breakdown of polyP which results in increase of P concentration in the anaerobic zone (Fig. 2). When the cells are removed from the process during sludge wasting then so is the P [12]. Under aerobic conditions energy is restored through P uptake [11].

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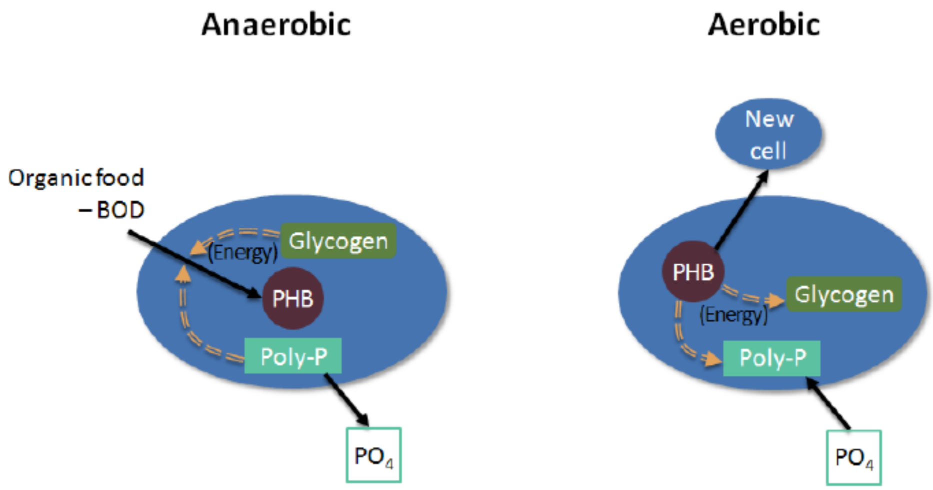

Figure 2: Mechanism of biological Phosphorus removal [11].

The consequences of contamination are the loss of aquatic life, upsurge of eutrophication, and potential loss of human life due to waterborne diseases [13]. Hence Rajasulochana and Preethy [13] attest that it has become an essential need for today's environment to protect water from getting polluted or to develop cost effective remedial methods for its protection to ensure that the water resources are maintained for future generations.

The operation of a WWW is subject to comply with the national legislative requirements of the Department of Water and Sanitation (DWS) in order to protect the water resources the WWW discharges into. Darvill WWW was used for this study. The plant is operated on the basic design of the conventional activated sludge configuration which consists of primary settling tanks (PST), activated sludge reactor and secondary settling tanks (SST). Darvill WWW discharges into the Umsunduzi River. The Darvill WWW discharge limits for NH_3 and SRP are 6 mg N/l and 1 mg P/l, respectively. It is situated in Pietermaritzburg owned by Umgeni Water. It has an average dry weather flow (ADWF) design capacity of 65 Ml/d; however, the WWW has been receiving wastewater inflow as high as 120 Ml/d for the period of 2016–2017. Darvill WWW has had a challenge with nutrient removal through this period and its legal compliance had decreased. The study seeks to evaluate the effects of the high inflows on the BNR process. The nutrients to be studied are ammonia and SRP.

As far as wastewater treatability is concerned Zhirong et al. [4] attest that conventional BNR activated sludge systems, such as the Johannesburg process, the University of Cape Town (UCT) process, and the Virginia Initiative Plant process, have been implemented with considerable success throughout the world as an effective means to remove, down to low levels, both nitrogen and phosphorus without, in many cases, the need for chemical dosing (ferric, alum, methanol, etc.) A nutrient removal efficiency study conducted by Adonadaga [8] compared influent and effluent values to determine the removal efficiency of various plants. He found that certain plants gave higher NH_3 removal efficiency (75%) for industrial wastewater than municipal wastewater (25%) The differences in removal efficiencies obtained by this study compared to results by other authors who reported efficiencies between 68% and 80% were suspected to be a result of differences in characteristics of the wastewater. Domestic wastewater is subject to wide variations in flow and load resulting in wide variations of influent nutrient ratios.

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2 MATERIALS AND METHODS

2.1 Wastewater works

Darvill wastewater works is used to conduct this study. The main focus area is the performance of the activated sludge reactor when subjected to flows above its design capacity of 65 Ml/d.

2.2 Sampling

A 1 litre representative grab sample of settled sewage and final effluent to the river was collected and appropriately labelled every morning at 8:00 am at Darvill WWW. Settled sewage is the supernatant sludge from the primary settling tank that goes into the activated sludge reactor. The collection times and sampling points were kept constant throughout the time of the study. Once samples were collected they were stored in a cooler box with ice and transported immediately to the laboratory where they were handled within three days after drop-off.

2.3 Laboratory analysis

The concentrations of ammonia and SRP were determined as outlined by the Standard Methods (1995) for ammonia and SRP determination. Briefly, the samples were centrifuged at 5000 rpm for 5 minutes (Megafuge 3.0 R) and the clear supernatants analyzed accordingly. The instrument used to determine the concentration of NH_3 and SRP was the DR900 Spectrophotometer.

2.4 Statistical analysis and calculations

The concentrations from the lab analyses were used to calculate the BNR efficiency of each parameter in the settled sewage and final effluent sample (eqn (1)). The plant inflow was recorded hourly and an average for the day was recorded

$$\text{Removal Efficiencies} = \frac{(Settled\ sewage\ concentration - Final\ effluent\ concentarion)}{(Settled\ sewage\ concentration)}. \quad (1)$$

Microsoft Excel, was used to plot the scatter plots for comparing the BNR efficiencies to the plant inflow.

3 RESULTS AND DISCUSSION

The plant flows for 2016–2017 were plotted and compared to the removal efficiencies of ammonia and SRP. This was done to establish the effects of hydraulic overloading on the BNR process of Darvill WWW.

The trend on the graph (Fig. 3) suggests that the removal efficiency of NH_3 has a predominantly inversely proportional relationship to the plant inflows. The average removal efficiency of ammonia during the period of 2016 and 2017 was 42% and 38%, respectively. Darvill WWW has a design capacity of 65 Ml/d, however it can be seen that there have been numerous periods where the plant was operating above capacity, with peaks as high as 120 Ml/d. November 2016 on average had the highest inflows (88 Ml/d) however the lowest removal efficiency was seen in June 2017 (23.2%) with a flow of 48.9 Ml/d. This was due to procurement delays of faulty subsurface aerators which resulted in process upsets. This could also be related to the cold Pietermaritzburg winter temperatures which could reach a

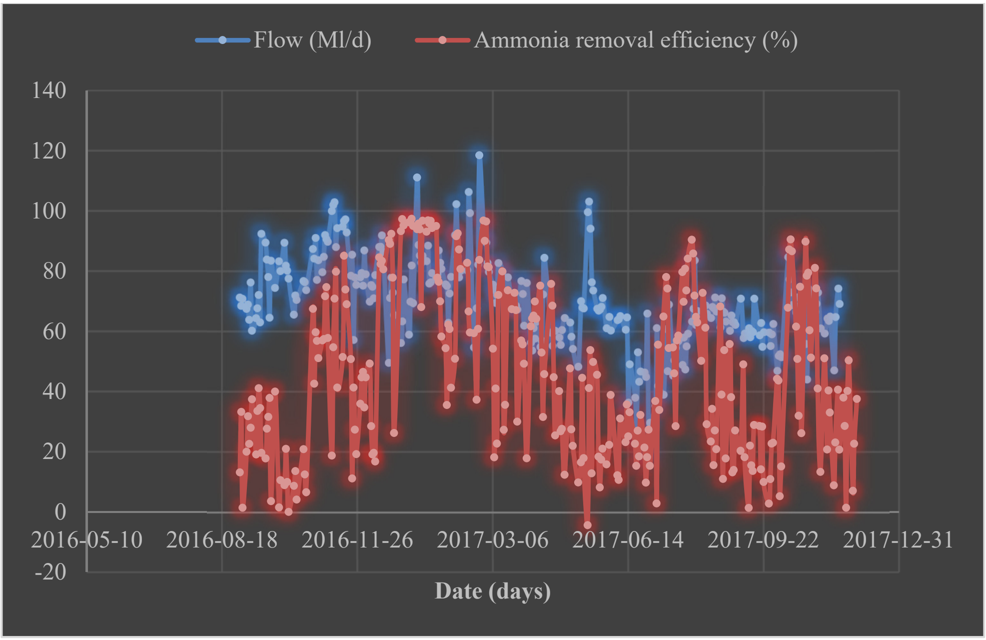

Figure 3: Ammonia removal efficiency and Darvill WWW inflow comparison.

minimum of 5°C. Previous studies indicated that denitrification rate was significantly affected by lower temperatures for biological treatments and denitrification rate at 5°C was decreased by 10 times linearly as compared to that at 20°C [15]–[17]. The temperature effects on BNR are primarily related to the low growth rate of the nitrifying bacteria at low temperatures [14]. Ydstebo et al. [18] however found that Nitrogen removal at low temperatures was achieved by operating at a high mixed liquor suspended solids (MLSS) concentration of 6000–8000 mg/l and with a sufficient supply of organic matter for denitrification. This however could not be observed for Darvill WWW as this concentration of MLSS led to other process challenges, i.e. sludge bulking. Wastewater treatability depends largely on the characteristics of the sewage and the activated sludge conditions [6]. A higher inflow comes with higher organic and nutrient loads hence compromising the BNR process. It was seen that for the most part of the months of the study the ammonia removal efficiency was below 75% (Table 1); this shows that the Darvill WWW treatment process was strained.

The average removal efficiency of SRP during the period of 2016 and 2017 was 61% and 67% for the two years respectively. The trend shows a predominantly inversely proportional relationship (Fig. 4). The results from this study suggest that higher flows have a higher detrimental effect on the removal efficiency of ammonia than SRP. This is largely due to the fact that ammonia is removed during the nitrification process in the activated sludge reactor. The amount of dissolved oxygen available in the system becomes inadequate and the growth of the autotrophic nitrifying bacteria is compromised when the plant receives flows above capacity. At flows above design capacity there is also a significant increase in organic loading which also requires and competes for the available dissolved oxygen in the activated sludge

Table 1: Average monthly inflow and ammonia removal efficiency values.

Month/Year	Flow average	Removal efficiency average
Sep-16	73.7	24.1
Oct-16	79.3	27.6
Nov-16	88	51.9
Dec-16	75	63
Jan-17	81.1	87
Feb-17	84.5	68.9
Mar-17	74.7	55.1
Apr-17	60.9	50.2
May-17	70.8	25.7
Jun-17	48.9	23.2
Jul-17	52.2	59.2
Aug-17	66.4	42.3
Sep-17	60.8	19.8
Oct-17	64.9	60
Nov-17	64.2	29

reactor. The PAOs are able to compete successfully with other organisms for substrate in completely aerobic activated sludge systems [10]. The removal efficiency of SRP is mostly affected by the hydraulic overloading as some of the PAOs get washed out with the final effluent.

Reddy et al. [19] also found reduced SRP removal at low temperatures which is related to reduced biological reaction rates however Darvill WWW SRP removal efficiency was not significantly adversely affected by temperature. In addition, it has been found that the monitoring and regulation of online parameters such as pH, DO, ORP and nutrient pollutants (phosphorus and NH^{4+}–N/NO^{2-}–N/NO^{3-}–N) can be helpful in achieving and maintaining high nutrient removal for treating real municipal wastewater [20]. Therefore, any process upsets can also affect the performance of the microorganisms in the activated sludge reactor.

The average monthly data (Table 2) shows that the highest removal of SRP (80.8%) was achieved in June 2017 at a flow low flow of 49 Ml/d. This shows that the process upset during this time had little to no effect on the PAOs ability to uptake the phosphorus in the system. This is mostly due to the fact that PAOs are facultative microorganisms which means they can survive in the presence and absence of oxygen.

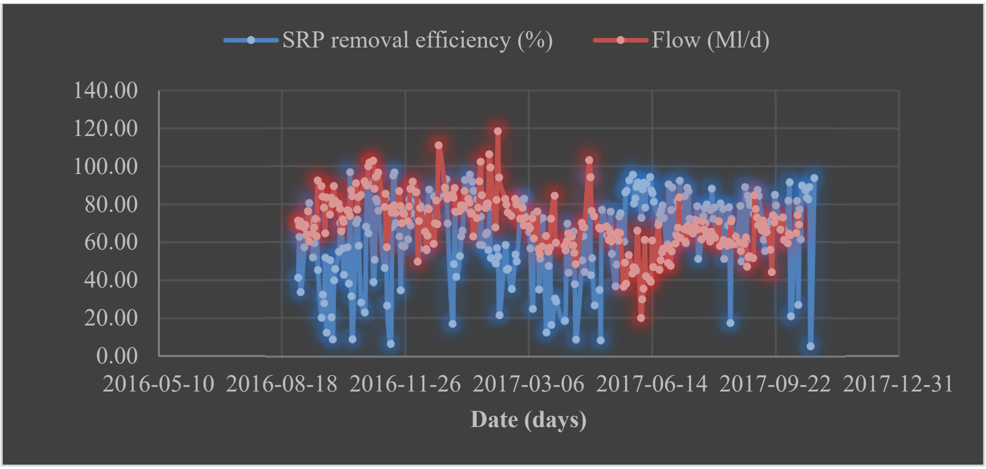

Figure 4: SRP removal efficiency and Darvill inflow comparison.

Table 2: Average monthly inflow and SRP removal efficiencies values.

Month/Year	Inflow average (Ml/d)	Removal efficiency average (%)
Sep-16	74.7	47.4
Oct-16	84.0	56.6
Nov-16	80.3	64.4
Dec-17	76.5	77.8
Jan-17	80.9	69.0
Feb-17	84.6	54.3
Mar-17	66.3	52.0
Apr-17	67.8	49.1
May-17	57.3	66.6
Jun-17	49.0	80.8
Jul-17	66.3	74.0
Aug-17	60.5	69.1
Sep-17	66.5	73.0
Oct-17	69.3	70.6

4 CONCLUSION

The study was aimed at understanding the effects of inflows to the biological nutrient removal process of Darvill WWW. The findings suggest that a plant operating above capacity becomes compromised in its ability to biologically treat the nutrients that come with the wastewater inflow. Darvill WWW has treated flows as high as 100–120 Ml/d which are almost double its design capacity. High flows reduce the nutrient removal efficiency and consequently the legal compliance in terms of the discharge limits set by DWS. This is largely due to the increased organic load and water that comes into the plant. The growth rate of bacteria and available dissolved oxygen in the biological reactor is reduced hence the poor BNR rate. Nitrification and denitrification were also predominantly influenced by temperature as there were observations of low flows but poor NH_3 removal during the winter months (June–August) at Darvill WWW with June 2016 having the lowest ammonia removal efficiency (23.2%). Radical measures should be undertaken to increase aeration capacity and overall plant capacity needs upgrading to improve the BNR process.

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URBAN WASTEWATER TREATMENT THROUGH A SYSTEM OF GREEN FILTERS IN THE MONTAÑITA COMMUNE, SANTA ELENA, ECUADOR

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ABSTRACT

In land application, soil is used as a natural filter to remove pollution from urban wastewater. The soil also has two other functions, first of all it's the receiving medium of wastewater and secondly it works as an active agent because physical, chemical and biological reactions are made in the soil–water–crops ecosystem. This non-conventional treatment is effective at removing pollutants such as suspended solids, organic matter, nitrogen, phosphorus and microorganism form effluent streams. The aim of this study is to design a pilot plant using soil as a natural filter for the treatment of wastewater discharge from oxidation ponds located in the Montañita commune through selecting and evaluating the site, calculating the design hydraulic load and the area necessary for system application. To take samples at different depths, a lysimeter was constructed that allowed to take samples at 30, 60 and 90 cm of depth. The variables that were measured in the treated water were total coliforms and BOD_5. These variables were related to the values calculated for the discharge of the oxidation ponds and the percentage of removal for each sample taken. As a result, high removal percentages were obtained at 90 cm depth with respect to the level of application of the residual water. Percentages of up to 79% for total coliforms and 80% for BOD_5 were obtained. These results are consistent with the limits established in the UTSLME (Unified Text of the Secondary Legislation of the Ministry of Environment). Finally, it could be concluded that soil in the area where the land application pilot plant was developed is suitable for efficient removal of the contaminants present in the discharge of oxidation ponds. This system contributed to the reduction of the pollution generated; in addition, the treatment of wastewater helps reforestation of this arid zone.
Keywords: green filter, Manglaralto commune, urban wastewater, BOD_5, lysimeter.

1 INTRODUCTION

There are different wastewater treatment systems, including a non-conventional method called green filters, which makes use of the soil. Soil is a complex, reactive, fertile, permeable medium and is the first water filter [1], these provide two environmental services: (i) as a buffer, to store water, carbon and nutrients as well as to host flora and fauna; and (ii) in filtration, allowing the passage of water, carbon and the ability to convert chemical compounds [2].

As filtering agent, the system is constituted by an area of land where plant species are established, which is irrigated by wastewater through an irrigation system, developing physical, chemical and biological processes that develop in the soil–water-cultivation ecosystem, in order to eliminate almost all water pollutants, including suspended solids, nitrogen and phosphorus, reaching a purification of up to 98% in the first centimeters of the soil [3].

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This type of water is used for irrigation since the last century in a controlled manner in several parts of Europe, Australia, India and the USA, when the "fields of application" were created, as Braatz and Kandiah point out in their article [4], while some treatment plants evacuate part of the effluent to irrigate golf courses and arid or semi-arid areas in those that exist shortage of water [5]. This has been generalized, for example, in China, more than 1.33 million hectares of farmland have been irrigated [6]. Part of this goes to rural areas where 67% of people live in this territory, so wastewater treatment systems have naturally increased, such as conventional land and septic ditch systems of land [7]. In California, USA, wastewater is largely applied to agricultural irrigation, these treated effluents are used in various food crops such as apples, broccoli, lettuce and cotton [8]. Arboreal species such as cascol (Enterolobium cyclocarpum) or guayacán (Guaiacum officinale) have a percentage higher than 90% of survival to irrigation with this type of water [6].

The criterion of water quality, generally applied in agricultural reuse, is mainly based on microbiological aspects due to the presence of pathogens [9], total dissolved solids and saline aspects [10]. Levine and Assano present more specific parameters for water re-use [11]. Based on this, the quality of the effluent is analyzed by means of total coliforms, which are the bacteria that produce fluorescent colonies when they are under ultraviolet light exposure [12], and the biological oxygen demand (BOD_5).

The parish of Manglaralto is located in the province of Santa Elena, Ecuador; with a territorial surface of 426 km^2, great part of this territory is arid, but apt for the agriculture, nevertheless, it is limited by the lack of precipitations [13]; it consists of a population of 33,633 inhabitants according to the National Institute of Statistics and Censuses (INEC, 2010), from which large amounts of urban wastewater are generated, which, according to the article written by Braatz and Kandiah, are the liquid waste that is discharged from households, commercial premises and industrial plants, in individual disposal systems or in the pipes of municipal wastewater networks [4]. These waters are treated by oxidation lagoons, which consist of square or rectangular shallow excavations surrounded by earth slopes [14], such as the oxidation lagoons located in the municipality of Montañita, where the effluent is unloaded in the Cucaracha stream and later goes to the Grande river to finally reach the sea.

However, problems with the design of the oxidation lagoons have caused the discharge to contain large concentrations of pollutants due to the increase in wastewater. This limitation allows the search for new techniques of natural treatment of wastewater that saves operating expenses and allows to contribute to the reforestation of the area, using the system of green filters, trying to eliminate as many pollutants from the water current as comes from the lagoons of oxidation of the commune, according to the maximum permissible limits established in the Ecuadorian environmental standards. Therefore, the aim of this study is to design a pilot plant using the soil as a natural filter for the treatment of the wastewater discharge from oxidation ponds located in the Montañita commune through selecting and evaluating the site, calculating the design hydraulic load and the area necessary for system application.

2 METHODOLOGY

To carry out this work, a methodology was used that considers the development of experimental works both in situ and in the laboratory. This schedule of activities is detailed on a map (Fig. 1).

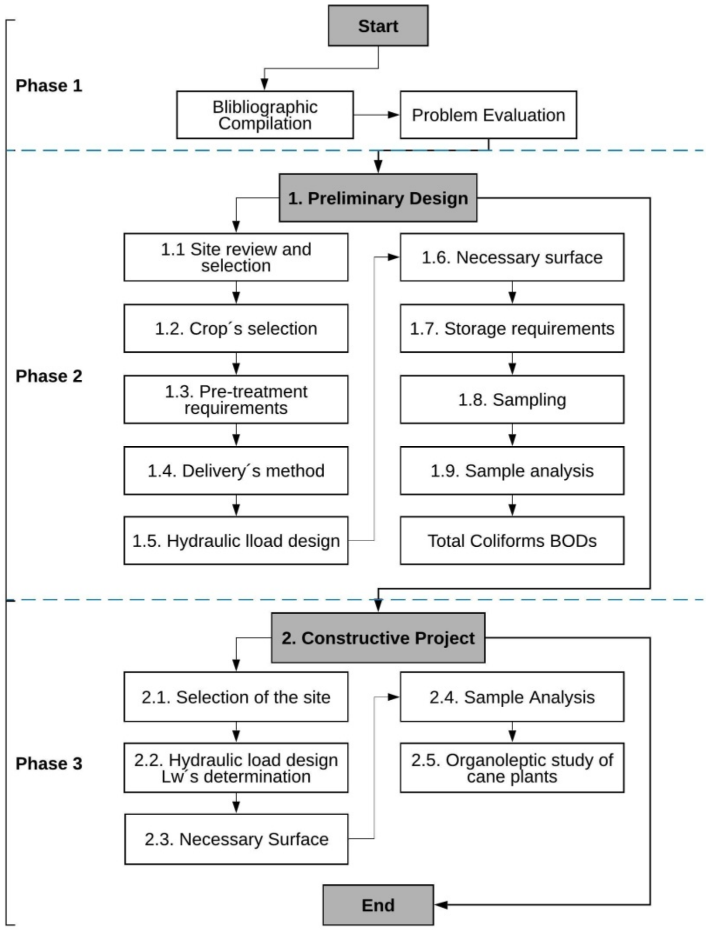

Figure 1: General project methodology.

2.1 Phase I

The work begins with the collection of bibliographic data that surround the problem through the research of books, scientific articles, magazines or related projects. Based on what has been collected, the problem is analyzed by studying all feasible techniques considering all the parameters in order to propose an optimal solution with their respective impacts.

2.2 Phase II

A sequence of processes described in the methodology of Fig. 1 was carried out for the design and analysis of a wastewater treatment plant, which complies with the scheme of Fig. 2.

2.2.1 Site evaluation and selection

The criteria used for the selection of the ideal site, in which the soil presents optimal conditions are [3]:

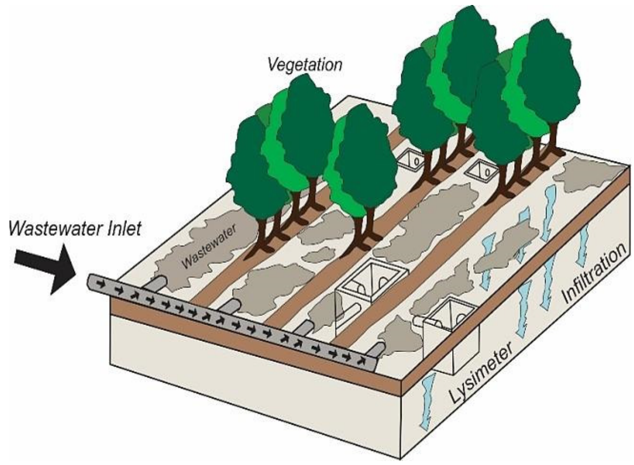

Figure 2: Scheme of wastewater treatment by green filters [15].

- The pH of the soil should be between 5.5 and 8.4 with conductivity lower than 4 mS/cm.
- The permitted soil permeability range should be between 5 and 50 mm/h.
- Groundwater should be between 0.6 and 1.5m deep.

These last two are preponderant factors for the election of the place.

2.2.2 Crop selection
The type of crop to be used was analyzed, based on the characteristics that a plant must have for the use of the green filter according to Álvarez [3]:

- High capacity of assimilation of nutrients and water consumption.
- High level of tolerance to soil moisture.
- Low sensitivity to wastewater components.

According to these guidelines, suitable plants are crops of forage, perennial, peat species.

2.2.3 Water pre-treatment needs
The need for water pre-treatment of the study sector was evaluated, considering public health issues, unfavorable effects and possible limitations of the distribution, cultivation or land system [3]. For this case, the water to be used comes from oxidation lagoons, which was treated through a primary treatment system, which basically consists of filters, grinding grids, grit chambers and degreasers.

2.2.4 Water distribution method
There are several methods of watering the wastewater in the plantation, such as [16]: sprinkling, surface irrigation, dripping and pulsing. The use of one or the other method will depend on the conditions in which it will be used in order to improve the efficiency of the application.

For this case, pulses were carried out since this method allows a better absorption of nitrogen by seeding [17], this occurs in cycles from a high to a low slope, so that the water penetrates both laterally and in depth to along the furrows.

2.2.5 Design hydraulic load

It is the volume of wastewater applied per unit area of land for a given time [16]. It consists of several requirements described below:

- According to the requirements of crop water: an estimate is made to replace the water consumed by the evapotranspiration plus the water necessary for washing the soil. It is defined by the following expression

$$R = (ET - P_r)x(1 + LR), \tag{1}$$

where:
R: net water required by vegetation (mm/month);
ET: Evapotranspiration (mm/month);
P_r: Precipitation respectively (mm/month);
LR: Water required for washing.

According to Álvarez, the water required for washing usually varies between 10 and 25% of the total water applied [3]. Since water is lost during irrigation as it is not applied uniformly over the work area, the hydraulic load is defined as

$$Lw(I) = \frac{R}{E_a}, \tag{2}$$

$$Lw(I) = \frac{(ET - P_r)x(1 + LR)}{E_a}, \tag{3}$$

where:
$Lw(I)$: Hydraulic load based on vegetation water requirements (mm/month);
E_a: Efficiency of application of the system.

In a pulsed irrigation system, the efficiency recorded in documents is 85% [18].

- Based on the hydraulic assimilation capacity of the soil–plant system: the expression that defines this is given by

$$Lw(I) = ET - P_r + P_w, \tag{4}$$

where:
$Lw(P)$: Hydraulic load based on hydraulic assimilation capacity soil–plant (mm/month);
P_w: Speed of percolation (mm/month).

In which, the percolation rate is based on the minimum permeability value under saturation conditions in the first 2.5 m of the stratigraphic column. For preliminary designs you can take a value between 2 and 6% of the minimum permeability of the soils present.

- Based on the assimilative capacity of the constituents: Each constituent of the wastewater can be a limiting factor of the hydraulic load depending on the concentration of this in the water, the assimilation capacity of the system and the environmental restrictions. For nitrogen, eqn (5) is used:

$$Lw(n) = \frac{Cp(P_r - ET) + Ux100}{(1 - f)Cn - Cp}, \tag{5}$$

where:
$Lw(n)$: Allowable hydraulic load based on the annual nitrogen load (mm/year);
Cp: Total concentration of nitrogen in the filtered water (mg/L);
Cn: Total concentration of nitrogen in the applied wastewater (mg/L);
f: Fraction of total applied nitrogen, eliminated by de-nitrification;
U: Nitrogen assimilation of the crop (kg/ha year).

The values of *U* and *f* can be obtained in tables [5]. It can also be calculated by eqn (6), described by Ou et al. [19]:

$$Lw(c) = (Mx10)C, \tag{6}$$

where:
$Lw(c)$: Hydraulic load based on the assimilative capacity of the constituent (cm/year);
M: Assimilative capacity of the constituent (kg/ha year);
C: Concentration of the constituent in the wastewater.

The values of M are found in several documents. In addition, it is known that forest plantations have a greater nitrogen assimilation capacity, with a maximum of 400 kg/ha year [19].

After calculating the hydraulic loads, the lowest value is selected for the design. In case this value is the hydraulic load based on the assimilative capacity of the constituents, it is recommended to check the monthly values choosing the lowest for the design [3].

2.2.6 Surface needed

For the calculation, it has been considered: the cultivated area, the one required for the facilities, access zones, buffer and storage tanks. The expression used for the calculation of the necessary surface is summarized in eqn (7)

$$A = \frac{Q \times 365 \times \Delta v_S}{10 \times Lw}, \tag{7}$$

where:
A: Area of the field (ha);
Q: Average residual water flow (m^3/d);
Lw: Design hydraulic load;
Δv_s: Net gains or losses of water stored due to precipitation, evaporation and leaks in the storage tank (m^3/year).

There is another equation to calculate the required surface

$$Aw = \frac{Q \times C}{12000 \text{ g/ha}}, \tag{8}$$

where:
Q: Average daily treatment rate (m^3);
C: Average BOD_5 concentration in wastewater (mg/L).

The value of 12000 is a factor that is equivalent to the amount in grams of BOD_5 assimilated in a hectare of land [3].

2.2.7 Storage needs

The analysis of the amount of wastewater is carried out. This is necessary when the residual water exceeds the hydraulic design load, which leads to two problems [3]:

- Production of anaerobic fermentations;
- Sludge formation as a result of the decanting of suspended solids.

Since the water comes from oxidation ponds, no extra storage facilities are required.

2.2.8 Sampling

For the study of the treated water, lysimeters are made at 30, 60 and 90 cm deep at the end of the furrows where the water will flow. These lysimeters allow the collection of water samples. Its shape is 1 m cubic with holes on one side of 5 cm radius (Fig. 3).

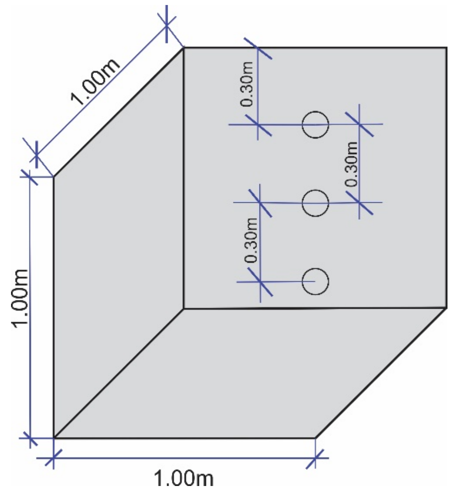

Figure 3: Scheme of a lysimeter.

2.2.9 Analysis of samples

Each sample taken by the lysimeter is analyzed for total coliforms and BOD_5 for 3 weeks at a frequency of one week. The analysis of these parameters follows the normative of the *Standard Methods for the Examination of Water and Wastewater* in its 22nd edition [20]. These samples were analyzed in the Water Laboratory of the Escuela Superior Politécnica del Litoral (ESPOL).

3 RESULTS

3.1 Place selection

Based on the criteria described in the previous phase, the appropriate terrain for the implementation of the system, the site chosen for the pilot plant is adjacent to the location of the oxidation lagoons, as defined by the Manglaralto Drinking Water Management Board (JAAPMAN), as shown in Fig. 4.

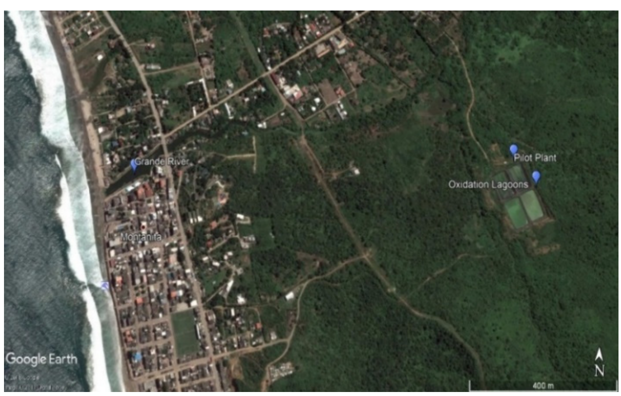

Figure 4: Pilot plant location map. *(Source: Google Earth.)*

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This land was subjected to several analyses for the determination of established parameters such as pH and conductivity. Among the properties of this terrain, it was found that at present edaphological levels consist of vertisol soils, whose predominant mineral is smectitic clay [16].

In addition, it was determined that the soil pH is 6.75, the conductivity of 3.65 mΩ/cm, is clay type, with a grain size of 400 μm.

3.2 Crop selection

The bamboo cane, besides being typical of the study sector, has been selected due to several benefits such as [17]:

- Provides protection to soils because their roots are large, they prevent soil erosion.
- It stores a large amount of water, in winter it can retain 25 liters of water, which it uses in summer due to scarcity.
- It captures around 110 tons of CO_2 per hectare.
- Can be used to recharge the Manglaralto aquifer.

3.3 Determination of the design hydraulic load

In order to make a monthly evaluation of the rainfall in the place, data were taken from the meteorological station located in La Libertad, Santa Elena province due to its proximity to the study area (Table 1).

Table 1: Precipitation recorded at the La Libertad weather station [21].

Month	Precipitations (mm/month)
January	65.6
February	344.9
March	211.5
April	23.7
May	3.6
June	1.6
July	1.5
August	0.6
September	0.2
October	2.4
November	0.3
December	0
Annual	655.9

The potential evapotranspiration values were obtained from the project "Generation of geo-information for the management of the national territory scale 1:25,000", prepared by the National Secretariat of Planning and Development (SENPLADES) for the meteorological station of Salinas [18] (Table 2). It is taken as a source because of its proximity to the study area.

From the data obtained, the hydraulic load is calculated for the requirement of crop water. Table 3 shows the values of evapotranspiration (*ET*), precipitation (*Pr*) and net water required by the vegetation (*R*).

Table 2: Potential evapotranspiration calculated using the Thornthwaite formula, for the Salinas meteorological station [18].

Month	Evapotranspiration (mm/month)
January	120.73
February	119.46
March	134.45
April	120
May	105.39
June	89.19
July	78.53
August	71.87
September	71.3
October	81.11
November	85.74
December	104.18
Annual	1181.95

Table 3: Water requirement of the crop.

Month	ET (mm/month)	P_r (mm/month)	$R = (ET\text{-}P_r)\ (1{+}0.25)$ (mm/month)	$Lw(I) = R/E_a$ (mm/month)
January	120.73	65.6	68.91	81.073
February	119.46	344.9	-281.8	-331.52
March	134.45	211.5	-96.31	-113.30
April	120.00	23.7	120.37	141.61
May	105.39	3.6	127.23	149.69
June	89.19	1.6	109.48	128.80
July	78.53	1.5	96.28	113.27
August	71.87	0.6	89.08	104.80
September	71.30	0.2	88.87	104.55
October	81.11	2.4	98.38	115.75
November	85.74	0.3	106.80	125.64
December	104.18	0	130.22	153.20
Annual				773.60

The annual hydraulic load based on the resulting cultivation requirement is 773.60 mm/year.

The hydraulic load based on the assimilation of the soil–plant system depends on evapotranspiration (ET), precipitation (P_r) and soil permeability (P_w). This data is obtained according to the type of soil, in this case, the soil is clay so it takes a value of 0.05 cm/h or 360 mm/month [22] (Table 4).

The hydraulic load based on the assimilation capacity of the annual soil–plant system is 4,846.05 mm/year.

The hydraulic load based on the assimilative capacity of the constituents can take values of 8 mg/L, with a nitrogen assimilation of 375 kg/ha year in order to obtain a total nitrogen concentration of 20 mg/L [16]

Table 4: Monthly assimilation capacity of the system.

Month	*ET* (mm/month)	P_r (mm/month)	P_w (mm/month)	$Lw(P) = ET-P_r+P_w$ (mm/month)
January	120.73	65.6	360	415.13
February	119.46	344.9	360	134.56
March	134.45	211.5	360	282.95
April	120.00	23.7	360	456.30
May	105.39	3.60	360	461.79
June	89.19	1.60	360	447.59
July	78.53	1.50	360	437.03
August	71.87	0.60	360	431.27
September	71.30	0.20	360	431.10
October	81.11	2.4	360	438.71
November	85.74	0.3	360	445.44
December	104.18	0	360	464.18
Annual				4846.05

Table 5: Calculated hydraulic loads.

Lw	Hydraulic load
Lw(*I*)	773.60 mm/year
Lw(P)	4846.05 mm/year
Lw(*n*)	4745.91 mm/year

$$Lw(n) = \frac{Cp(P_r - ET) + U \times 100}{(1-f)Cn - Cp},$$

$$Lw(n) = \frac{8\,\frac{\text{mg}}{\text{L}}\left(655.9\,\frac{\text{mm}}{\text{year}} - 1181.95\,\frac{\text{mm}}{\text{year}}\right) + 375\,\frac{\text{kg}}{\text{ha year}}\left(100\,\frac{\text{ha mg m}^3\text{ mm}}{\text{kg m}^2\text{ L m}}\right)}{(1-0.25)\ 20\,\frac{\text{mg}}{\text{L}} - 8\ \frac{\text{mg}}{\text{L}}},$$

$$Lw(n) = 4754.91\,\frac{\text{mm}}{\text{year}}. \tag{9}$$

In summary, the values obtained from the hydraulic loads are detailed in Table 5.

Based on the above, the lowest value corresponds to the load based on the requirement of crop water with 773.60 mm/year.

3.4 Necessary surface

The area assigned based on the space that the bamboo cane requires as a plant for its growth was defined as the configuration shown in Fig. 5.

The arrow indicates the direction of the wastewater until its arrival in the lysimeter for sampling. The area is 39.88 m^2 or 0.3988 ha. Based on this, the average daily flow is calculated from the equation

$$Aw = \frac{Q \times C}{12000\ g/ha}. \tag{10}$$

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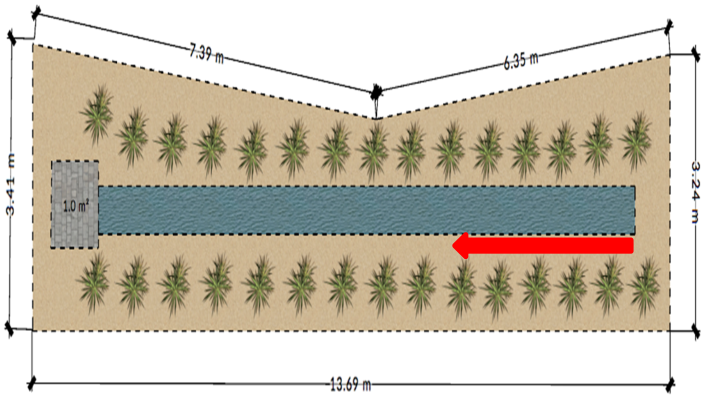

Figure 5: Configuration of the necessary surface.

For the use of this formula, an estimate was made of the average concentration of BOD_5 in the wastewater, whose value is 109.51 mg/L

$$0.3988\ ha = \frac{Q \times 109.51\ \mathrm{mg/L}}{12000\ \mathrm{g/ha}},$$

$$Q = 4.39\ \mathrm{m^3/day}.$$

The values calculated in Table 6 are shown below.

Table 6: Summary of the calculated values.

Hydraulic design load	773.60 mm/year
Necessary Surface	39.88 m^2
Average flow treated	4.39 m^3/day

3.5 Analysis of samples

The volume of water of the samples taken by means of the lysimeter at depths of 30, 60 and 90 cm, varies depending on the type of analysis to be carried out, as shown below.

3.5.1 Total coliforms

120 mL of water were taken in sterile containers and then mobilized at 4°C to the ESPOL Water Laboratory. These analyzes were performed the same as the sample was taken to avoid a significant variation of microorganisms. Given that there are high concentrations of coliforms, a 1:100 dilution is made in order to quantify the colonies of bacteria in the colony counter, as indicated by the *Standard Methods of Water and Wastewater* [23].

The nomenclature used for the samples is recorded as follows:

- M30 indicates the sample taken with the lysimeter pipe at 30 cm depth.
- M60 indicates the sample taken with the lysimeter pipe at 60 cm depth.
- M90 indicates the sample taken with the lysimeter pipe at 90 cm depth.

The data obtained are specified in Table 7, adding that the effluent of the oxidation ponds has a value of 2890 CFU/100 mL, which was obtained in the ESPOL Water Laboratory. At the same time, a value of 2400 NMP/100 mL was reported by the Laboratory Professionalism Laboratory Analysis Professionalism (PROTAL, acronym in Spanish).

Fig. 6 is a graph of coliform colonies as a function of depth in the different weeks of measurement.

Table 7: Water requirement of the crop.

Sample	Dilution	Coliforms (UFC/100 Ml)
Week 1		
M30	1:100	2350
M60	1:100	1960
M90	1:100	850
Week 2		
M30	1:100	2100
M60	1:100	1780
M90	1:100	630
Week 3		
M30	1:100	2060
M60	1:100	1650
M90	1:100	570

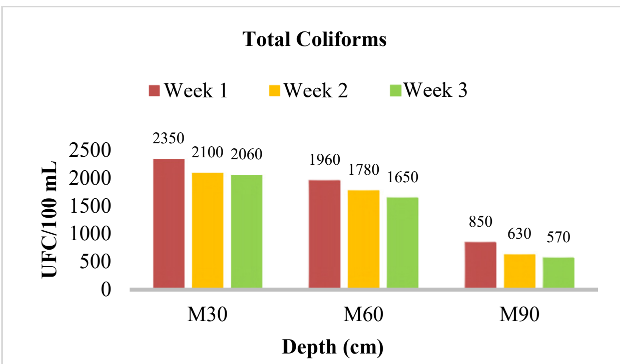

Figure 6: Total coliforms per week for samples M30, M60 and M90, expressed in CFU/100 mL.

Based on the graph, the decreasing behavior of the colonies is observed as the time increases. The regression model described by Cho et al. [24] was used to calculate the percentage of removal (Table 8).

The summer coefficients are selected due to the similarity between this and the work area. A model check is made with the data obtained by PROTAL, obtaining a relative error of 0.054%, which validates the model used for the chosen conditions. Table 9 details the percentage of removal according to the week and the depth.

Fig 7 is a graph of the removal percentages obtained for each study point.

As the week progresses, the percentage of removal increases, as well as the depth, reaching 80% removal at the third week at 90 cm below ground level.

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Table 8: Coefficients for regression model that allows converting concentrations of CFU to NMP [24]. (Modified by the author.)

		Spring	Summer	Autumn	Winter
Coliforms	ln a	1.27	-0.51	-1.23	2.09
	(std. error)	0.18	0.33	0.47	0.31
	b	0.80	1.04	1.36	0.36
	(std. error)	0.04	0.05	0.09	0.07

Table 9: Percentage of removal of total coliforms calculated with samples M30, M60 and M90 in the three weeks of study.

Sample	Week 1	Week 2	Week 3
M30	19%	27%	29%
M60	32%	38%	43%
M90	71%	78%	80%

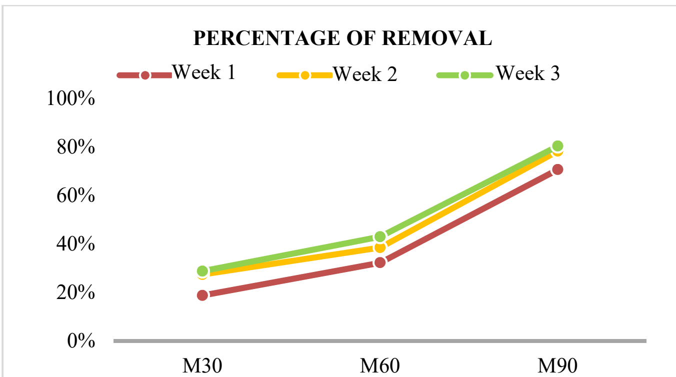

Figure 7: Percentage of removal of total coliforms per week, for samples M30, M60 and M90.

3.5.2 BOD_5

The analysis is carried out under the guidelines proposed by the "Standard Methods for the Examination of Water and Wastewater", taking water samples of approximately 500 ml per sample, in amber bottles. From this, the data described in Table 10 were obtained and displayed in Fig. 8.

The behavior of BOD_5 follows the same decrease trend as total coliforms. As time and depth increase, the BOD_5 values decrease. To calculate the percentage of removal, the BOD_5 calculated in the oxidation pond was used as data, which was 109.51 mg/L. The values are shown below in the Table 11.

Fig. 9 is a graph of the removal percentages obtained for each study point.

In both analyzes, high percentages of removal were obtained, reaching up to 80% fulfilling the description by Álvarez [3] in the publication "*Filtros Verdes. An ecological purification system*", where it is exposed that this type of systems can achieve a purification performance

Table 10: BOD_5 values recorded the first week.

Sample	BOD_5 (mg/L)
Week 1	
M30	106.91
M60	101.51
M90	96.41
Week 2	
M30	96.37
M60	87.07
M90	65.47
Week 3	
M30	83.68
M60	68.68
M90	22.48

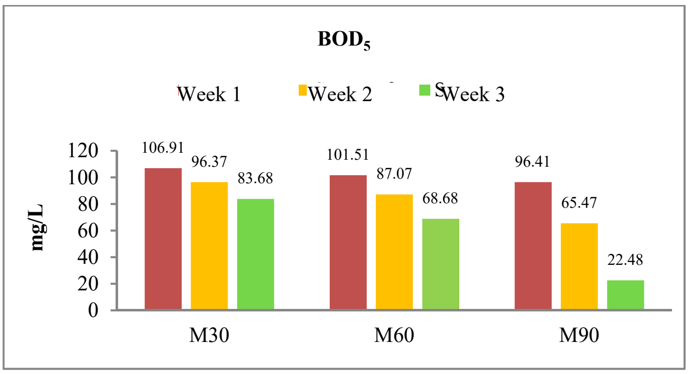

Figure 8: Total BOD_5 per week for samples M30, M60 and M90, expressed in mg/L.

Table 11: Percentage of removal of BOD_5 calculated with samples M30, M60 and M90 in the three weeks of study.

Sample	Week 1	Week 2	Week 3
M30	2%	12%	24%
M60	7%	20%	37%
M90	12%	40%	79%

of up to 98%. In addition, according to CONAGUA [16], in the "Manual of Drinking Water, Sewerage and Sanitation", it is commented that green filters can reach 85% in the removal of organic matter present in wastewater.

Regarding the *Environmental Quality Standard and Discharge of Effluents: Water Resource*, the limit allowed for agricultural use is 1000 NMP/100 mL in total coliforms and 100 mg/L of BOD_5 [25]. The pilot plant of green filters obtained values below the limit after the test time, complying with the standards established in the country.

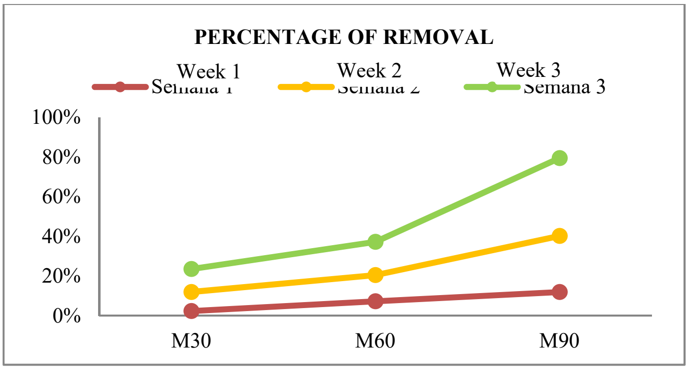

Figure 9: Percentage of BOD_5 removal per week for M30, M60 and M90 samples.

4 CONCLUSIONS

From the results obtained in the experiments carried out by the pilot plant, it is verified that the system is feasible, since it reduced the proposed parameters such as BOD_5 and total coliforms from the oxidation lagoons up to 80% at depths of up to 90 cm, complying with the Ecuadorian environmental quality regulations for both cases, contributing to the reuse of wastewater for reforestation of the arid study area with little access to fresh water.

The type of soil where the pilot plant was built is silt-clayey, with the necessary characteristics that allow a slow and effective filtration for the removal of contaminants. Based on the type of soil and the study area, it was determined that bamboo cane, being an endemic species of the country and typical of the place, is the one indicated for the treatment. This type of soil and crop, to perform the treatment of wastewater from the daily flow of the oxidation lagoons, needs a minimum area of 41.39 hectares.

Based on the analysis of total coliforms, it was found that the lowest percentage of total coliform removal was 19% for sample M30 in week 1, with a total of 2350 NMP/100 mL, and a maximum percentage of 80% for the M90 sample in week 3, with a total of 570 NMP/100 mL.

For BOD_5 the lowest removal percentage corresponded to 2% for sample M30 in week 1, with a total of 106.91 mg/L and a maximum percentage of 79% for sample M90 in week 3, with a total of 22.48 mg/L.

With the application of green filters, the reliability of the implemented system and its excellent response to different depths were demonstrated, which allows the establishment of a larger scale planning.

5 RECOMMENDATIONS

It is recommended to implement this project in several arid and semi-arid zones of the country to reactivate the soil and improve the living conditions of the villagers.

Perform a monitoring by means of the physical–chemical–biological analysis of the soil that is being used as a green filter, to determine the concentration of pathogens and contaminants, which allow evaluating its temporal efficiency.

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ANAEROBIC TREATMENT OF SLAUGHTERHOUSE WASTEWATER: EVALUATING OPERATING CONDITIONS

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ABSTRACT

The aim of the study was to elucidate the effect of process parameters on the performance of an upflow anaerobic sludge blanket reactor (UASB) that was treating slaughterhouse wastewater. The UASB reactor was operated continuously under mesophilic conditions to evaluate its performance with respect to the removal of organics and, at the same time, monitor biogas production. Organic loading rate (OLR) was varied while keeping the hydraulic retention time (HRT) constant. Chemical oxygen demand (COD) removal efficiency higher than 75% was achieved at an OLR of 9 kg.COD.m-3.d-1, with a HRT of 12 h. Bulking sludge problems were not observed during the reactor operation period. Stability of the treatment process was achieved by the natural buffering of the system due to the produced alkalinity and also due to the characteristics of the wastewaters which was found to be rich in proteins and fatty acids.

Keywords: anaerobic digestion, hydraulic retention time, organic loading rate, chemical oxygen demand, slaughterhouse wastewaters, biogas.

1 INTRODUCTION

The slaughterhouses are important sources of waste generation, especially wastewater [1]–[3]. Various stages are involved during the slaughtering of animals, viz. receiving of the livestock, slaughtering operations, and separation of the carcass from the offal products, cleaning of the stomach and intestines, utilities and other services. The quantity of water consumed by each stage differs with the slaughtering. The slaughter line contains the blood and wash waters from the killing operation. Thus, the wastewater is characterised by fats, proteins and fibres leading to high organics such as chemical oxygen demand (COD) and biological oxygen demand (BOD) [4].

Usually, the wastewaters contain high amounts of biodegradable organic matter, with soluble and insoluble fractions [2], [3], [5]. Treatment of these wastewaters from slaughterhouses therefore poses some problems when compared to other agricultural processing industries. Problems encountered during treatment are the high suspended solid fats and protein contents. Another issue is the fact that some of the fats are insoluble thus lowering the rate of degradation and increasing the tendency to form scums [3]. The most common practise for slaughterhouses is the discharging of their wastewaters after a preliminary treatment to the municipality sewage where it is further treated. However, this wastewater being discharged may contain blood, solids, hair, bone pieces, hooves, fats and grease and may result in high discharge costs through municipal effluent penalty charges. Others carry out onsite treatment to reduce the pollution loads, thus trying to meet legislative requirements before discharging into receiving bodies [3], [5]. Whichever way, there are always cost implications associated with the waste management, therefore for-profit optimisation and sustainability of the environment, it is best that cost effective methods of handling these polluted waters are utilised.

Anaerobic digestion (AD) is a complex and delicate biological treatment process. It involves the degradation and stabilisation of organic matters under anaerobic conditions by

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different microbial groups of organisms. It offers various advantages over other conventional biological processes such as the recovery of valuable products like biogas (mixture of carbon dioxide and methane). Fertilizers and nutrients harvesting are other important aspects of using the AD process [1], [6], [7]. Other advantages include low sludge production and low energy requirement, thus optimising the operational costs for wastewater treatment plants (WWTPs) thereby presenting an environmental footprint which is essential for present day WWTPs [7], [8]. AD occurs naturally which can be easily affected by the operational and environmental conditions, and as such, it is expected that the natural process is optimised so that the degradation of the organics is achieved [2], [9], [10]. Due to the complexity of the AD process, there is a substantial chance of it becoming unstable and an eventual breakdown could occur. It is therefore paramount to have an understanding of the operations of the AD process, which enables predicting the operation of the digester. Apart from the complexity of the AD process, the complexity of the wastewater is another issue that comes to play with regards to the efficiency of the AD process. High rate anaerobic digesters are built to treat low to medium soluble strength wastewaters. However, when complex wastewaters like those that contains partially soluble wastes and a high percentage of biodegradable solids, like in the case of slaughterhouse wastewaters, only partial treatment could be achieved [10]–[13].

Sayed and DeZeeuw [12] in their study stated that the consequence of treating complex wastewater is that a significant decrease in the methanogenic capacity of the AD process could occur as a result of the coarse non-biomass suspended solids being trapped from the wastewater in the sludge. The entrapment of inert suspended solids could lead to a dilution effect of the active biomass thereby leading to a severe decrease in the methanogenic bacterial concentration in the sludge and formation of scum at the liquid interphase in the settler compartment. Thus, AD has shown to be a complex process and stands the chance of becoming unstable and eventually breakdown in the long run if not monitored properly. It is therefore important to understand the kinetics of the AD process. This can aid with the prediction of the operation of the digesting system, contributing to the understanding of the biodegradation process [14].

Therefore, the aim of this study is to elucidate the effect of process operational parameters on the performance of an upflow anaerobic sludge blanket reactor (UASB) treating slaughterhouse wastewater. OLR which is a significant parameter in the monitoring of the UASB system was varied to monitor the performance of the UASB. The formation of biomass along the height of the reactor as well as the produced biogas during the different operational conditions were studied.

2 MATERIALS AND METHODS

2.1 Experimental set-up of the UASB reactor

The reactor was constructed from Plexiglas glass with an effective working volume of 4.5 L. This comprises of three zones: the feed entrance zone, the sludge and blanket zone and the settling zone as depicted in Fig. 1. An inverse cone which served as the gas-liquid-solid separator (GLS) was installed at the top portion of the sludge bed to enhance the separation of the biogas from the liquids and solids. To reduce variations in temperature, continuous recycling of cooling water through the water jacket of the reactor was carried out using the Grant stirred thermostatic circulators water-bath (GD120). The reactor had four sampling points which were used for the monitoring of sludge production and as well as desludging of the reactor and there was no recirculation of the effluent.

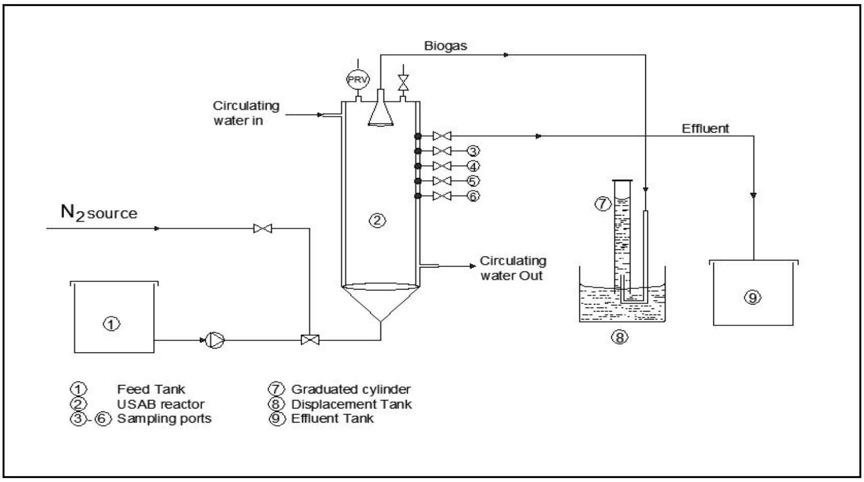

Figure 1: Schematic diagram of the experimental set-up.

2.2 Reactor feed

The wastewater used for this experiment was collected from a swine slaughterhouse. The samples consisted of the slaughtering operations (killing operations, wash waters from the intestines and stomach). Wastewater samples were collected twice monthly and were characterised within 24 hours of collection. Collected samples were thereafter stored at 4°C until the need for it. For the start-up of the reactor, it was necessary to dilute the wastewater to the required COD and this was carried out in different phases as shown in Table 1. Collected samples therefore contained lots of blood. The presence of the bloods and other substances such as fats and proteins contributed to the high organics in the wastewaters and the variations in composition as shown in Table 2.

2.3 Operation of the UASB reactor

The reactor was started with a digested sludge obtained from a wastewater treatment plant treating slaughterhouse wastewater from an abattoir in South Africa. The reactor was inoculated with 3 L of the activated sludge which was about two thirds of its working volume. Sludge was characterised to have a TSS of 19.4 g L^{-1} and VSS of 13.8 g L^{-1}. The digester was

Table 1: Operational phases of the reactor.

Operational phase (days)	COD (mgL^{-1})	OLR (kg m^{-3} d^{-1})	HRT
I (1–15)	2000–2500	2.8–3	First three days. 24 hours and 12 hours thereafter
II (16–48)	3000–3500	3.7–4.4	12
III (49–71)	4000–4900	5.1–6	12
IV (72–100)	5000–6000	6.1–7.2	12
V (101–150)	70000	8–10	12

Table 2: Characteristics of wastewaters resulting from various slaughterhouses (number of samples = 24).

Parameter*	Influent	Average	Standard deviation
Chemical oxygen demand (COD)	3000−6030	4326.3	±1163.4
Total suspended solids (TSS)	1500–4600	2352.4	±210.4
Total organic carbon (TOC)	200−950	667.68	±262.92
Volatile suspended solids (VSS)	1100−1500	1208.9	±103.6
Volatile fatty acid (VFA)	440–820	727.45	±143.56
Alkalinity	1100–2600	2193	±542.16
TKN	110–250	83.4	±35.8
Total nitrogen (TN)	50–95	79.52	±9.42
Total ammonia (TAN)	110–185	153.72	±20.73
Nitrates and Nitrites (NO_3–N+NO_2–N)	2.82−5.7	4.9	±0.3
pH	6.3−7.3	6.9	±0.13

*All units in mgL^{-1} except pH

fed on a continuous basis at a flowrate of 0.25 L/hr from the bottom of the reactor by the use of a Cole palmer masterflex peristaltic pump (Model 77521-50) at the rate defined by the HRT of 12 h. However, for the first three days of the start-up, the reactor was operated in a batch mode at a HRT of 24 hours and thereafter, the continuous mode was used. An OLR of 1.54 kg m^{-3} d^{-1} was used for the first 3 days to enable stabilisation of the reactor, and thereafter, the OLR was increased stepwise as the treatment efficiency of the reactor improved with time.

The biogas produced was channelled through the gas outline as shown in Fig. 1 and was passed through 3 M NaOH solution so as to capture the CO_2 present in the biogas [15]. The biogas present was measured volumetrically by the displacement of water as shown in Fig. 1. The produced gas was measured on a daily basis to enable the ease in which the system kinetics was followed. To obtain a stable operation of the reactor, the temperature of the reactor was maintained at 35˚C with the use of a water bath. Reactor efficiency was evaluated by monitoring the removal of organics using the eqn 1.

$$Reactor\ effciency = \left(1 - \frac{COD_{out}}{COD_{in}}\right) X\ 100 \qquad (1)$$

2.4 Analytical methods

The following physico-chemical properties were determined: chemical oxygen demand (COD), biological oxygen demand (BOD), total suspended solids (TSS), volatile suspended solids (VSS), total solids (TS), pH, nitrites (NO_2), nitrates (NO_3) and total ammonia nitrogen (NH_3-N), VFA and alkalinity. The parameters were evaluated following the procedure for standard methods for the examination of water and wastewater [15]. Both TSS and VSS were determined by the drying of homogenised samples at 103°C for 24 h for TSS and furthermore, VSS was obtained by incinerating the dried fractions in a muffle furnace at 550̊ C for 1 h. COD was determined using close refluxing according to the standard method 5220D. The pH and temperature were measured using a pH meter (Orion) and thermometer respectively.

The total nitrogen (TN), TKN and nitrates nitrogen (NO_3−N) and nitrites nitrogen (NO_2−N) concentration was determined using HACH kit (Simplified TKN TNT plus, TNT880, method 10242) and Total ammonia nitrogen (TAN) concentration was determined using HACH kit (Simplified TKN TNT plus, TNT832, method 10205) [16], [17]. VFA was by the distillation of sample and titrating the distillate with the use of 0.1 N sodium hydroxide to pH 8.3. Total alkalinity was determined by titration of the samples with sulfuric acid (0.1 N) to pH 4.0 [18]. The pH, temperature and COD were analysed every day during the start-up of the reactor, continuously even after the start-up. Once the reactors had stabilised, TSS and VSS were analysed weekly for the duration of the experiment. Other parameters such as VFA and alkalinity, TKN and TAN were determined biweekly.

3 RESULTS AND DISCUSSION

3.1 Reactor start-up

The reactor start-up is reported as the period taken for stable operation of the reactor to occur. During this stage, the microorganisms are being acclimatised to the new environmental conditions and substrate. An equilibrium is also slowly being established between the various microorganisms present in the system, until the biomass is stable and efficient to degrade the substrate at the targeted OLR [13]. Reactor start-up has been reported as a complicated process, and as such the monitoring of both environmental and operating conditions is important [19].

The VSS/TSS is significant because it is an indication of the amount of biomass in the total sludge measured as suspended solids. A high ratio of VSS/TSS in the inoculum to be used for the reactor start-up is important [20]. For the start-up, the VSS/TSS ratio was about 0.71. This ratio continued to increase (as observed in Fig. 7), which is an indication of microorganism's adaptation and multiplication. Feed concentration of less than 3000 mg L^{-1} of COD (2.8 kg m^{-3} d^{-1}) was used for the start-up to help in preventing and controlling the excessive generation of VFA since at this stage the microorganisms were still adapting to the new environment.

The wastewater samples collected were analysed and characterised and presented in Table 2. Results reported are averages taken in duplicates as well as the standard deviations. The performance of the reactor was assessed based on the biogas production and the reduction of organics. Other factors such as VFA, alkalinity, TSS and VSS were factors monitored to evaluate treatment efficiency of the reactor. The characterisation of the effluent in Table 2 shows that the wastewaters from the slaughterhouse can be regarded as high strength wastewaters according to the classification by Cao and Mehrvar [5]. Observable from Table 2 is the variation in the influent of the wastewater used for the experiment. The changes in the influent concentration have a great impact on the performance of the reactor (Fig. 1). The reason for such was attributed to the different processes involved during slaughtering as well as other housekeeping issues.

3.2 Performance of the UASB reactor

Following the successful start-up of the reactor with the low initial OLR (2.8 kg m^{-3} d^{-1}), the reactor was gradually loaded with a higher OLR with the slaughterhouse wastewater as the substrate by increasing the COD concentration and keeping HRT constant. Each loading rate was allowed a time of stability as shown in Table 1. To evaluate the optimum loading rate, OLR was increased to 10 kg COD m^{-3} d^{-1}. The performance of the reactor is presented in the following sections.

3.3 Effect of OLR on pH

Fig. 2 shows the daily pH and OLR in the reactor. In the AD system, the different microorganisms have different optimum pH values for maximum performance. The methanogenic bacteria, which are responsible for the production of methane, are more sensitive to pH, optimally between pH 6.5 and 7.5 [21]. The OLR rate describes the liquid flowrate and contaminants concentration and it is said to be the mass of the pollutants that is introduced into the given reactor at a time. Therefore, it combines the reactor characteristics, the operating characteristics and finally mass of the bacteria activity into the volume of media [22].

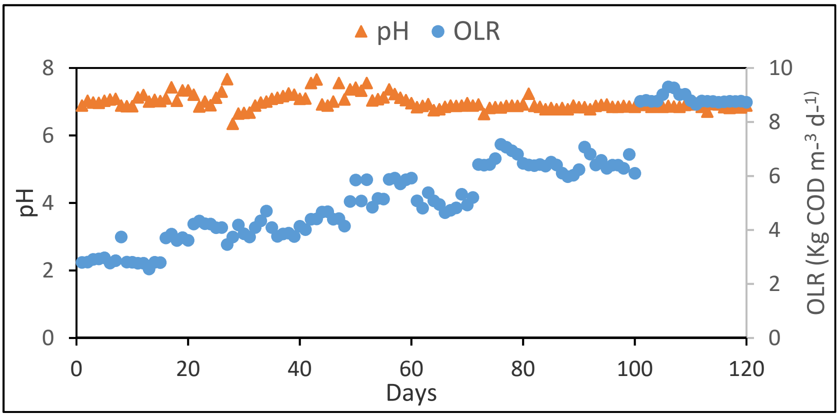

Figure 2: Daily pH and OLR of the UASB reactor.

The influent pH for the wastewater samples were relatively stable between 6.8 and 7.1, so the data is not presented. For the effluent pH, it was between 6.64 on the low and 7.67 for the high as illustrated in Fig. 2. The lowest pH was recorded on the 18th day as 6.64 while the maximum pH was 7.67 which was on the 27th day. Buffering of the system was not carried out because the reactor's pH was at most times within the required range for the organisms. The pH levels during the experimental period were favourable to the methanogens bacteria. Several authors have reported that methanogenesis in anaerobic digestion occurred efficiently at pH 6.5–8.2 while hydrolysis and acidogenesis occurred at pH 5.5 and 6.5. The ability of the system to perform to its capacity is much dependant on the pH such that reactor failure or underperformance could occur. Several studies have reported such occurrences [23], [24].

Fig. 3 shows the average weekly pH with respect to alkalinity. It was observed that the alkalinity of the reactor was above 1,000 mg L^{-1} $CaCO_3$ for the bulk of the time, however, for the first week of the reactor start-up, the alkalinity was below 1,000 mg L^{-1} $CaCO_3$. At this stage, the microorganisms were still adapting to the new conditions which they were exposed to. It was also observed that from the 14th week, the pH of the reactor had begun to decline even though the alkalinity was relatively stable. The drop in the pH values were, however, not detrimental to the reactor because it was still within the optimal limits suggested for the anaerobic processes.

Successively, wastewaters from the slaughterhouse have been indicated to be rich in proteins. The mineralisation of these proteins to ammonia is responsible for the increased alkalinity as the OLR increased as shown in Figs 3 and 4. Fig. 4 further elaborates the relationship between VFA and alkalinity of the reactor. The ratios of the VFA to alkalinity were found to be below 0.4 except during the start-up period where it was slightly above, however, it stabilised soon afterwards as the system became stabilised, indicating it was favourable [9], [15].

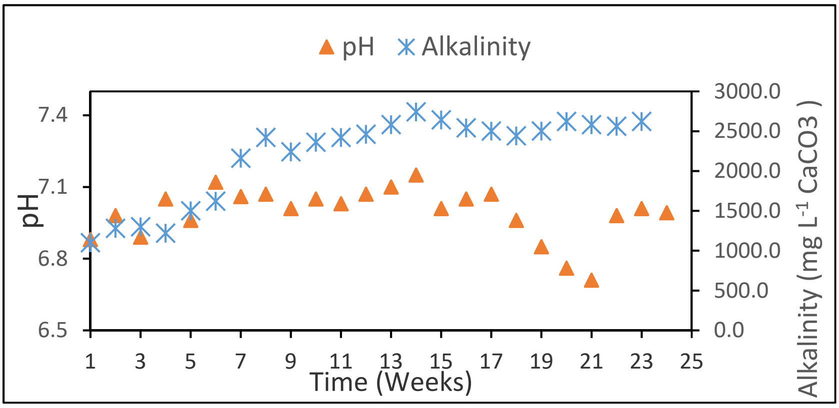

Figure 3: Weekly pH and alkalinity of the reactor.

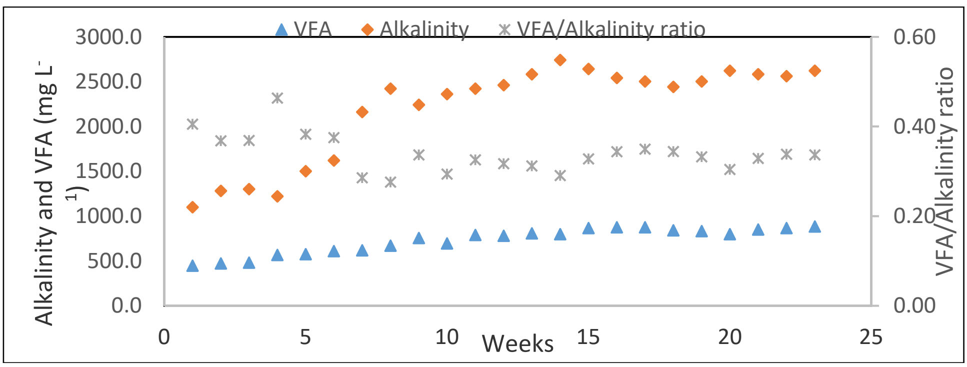

Figure 4: Weekly alkalinity, VFA and VFA/alkalinity ratio of the reactor.

VFAs in the system ranged from 445 on the first week to 882 mg L^{-1} on the 23rd week. The increase in the VFAs was attributed to the increase in OLR. Even though this increase was observed, the produced alkalinity was able to buffer the VFAs produced. The pH and alkalinity indicated that the system was able to produce enough $CaCO_3$ to be able to neutralise the volatile fatty acids (VFAs) in the system, thus acting as a buffer. Again, the continued increase in the production of biogas (Fig. 6) was an indicator that each of these factors had not impacted on the reactor to a point of inhibition, thus, indicating the activeness of the methanogenic bacteria. At this point it is worth mentioning that the methanisation of COD was rapid as compared to the particulate hydrolysis [13].

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3.4 Effect of OLR on COD reduction

Fig. 5 shows the influent and effluent of the total COD as well as the COD removal efficiency. The OLR was introduced in a stepwise manner from 2.28 kg COD m^{-3} d^{-1} to 9 kg COD m^{-3} d^{-1}. During the start-up of the reactor, the removal efficiency was low, below 30%, even at a low OLR rate of 2.28 kg COD m^{-3} d^{-1}. However, as shown in Fig. 5, COD removal efficiencies showed an increasing trend from a low 37% to a maximum of 86%, (day 42 and OLR 4.2–5 kg COD m^{-3} d^{-1}). At the start of each phase of OLR, there was a corresponding decrease in removal efficiencies. Observable also was the fact that as OLR increased from 5 to 9 kg COD m^{-3} d^{-1}, an obvious reduction in the COD removal to 60–70% occurred. The reduction in the COD removal efficiency indicated that the microorganisms could not flourish at a higher level of OLR. Chollom et al. [4] and Torkian et al. [25] in their studies observed that, as OLR increased, the adaptation of the microbial community to the new condition is retarded thus leading to a decrease in the performance of the system. But the recovery of this is usually within a period of 24 hours in most cases as can be seen in Fig. 5 for each new influent. OLR is said to play a significant role in the reactor efficiency.

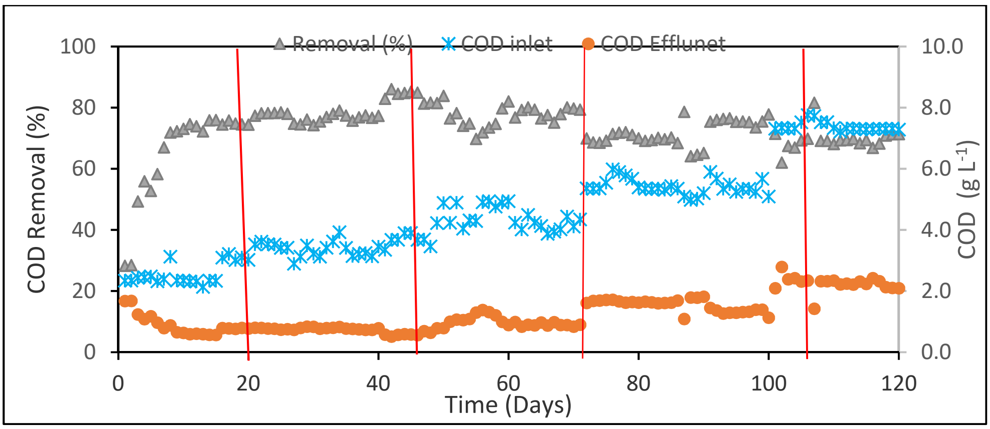

Figure 5: Influent and effluent COD and percentage of COD removal of the UASB reactor.

The average removal for the experimental period was 73% and the maximum COD removal of 80–84% was achieved at OLR of 4–5 kg COD m^{-3} d^{-1}. While removal in this study was said to be above the optimum required for anaerobic treatment units, the values obtained were below those treating similar wastewaters. Borja et al. [26] reported COD removal efficiencies of 64–99% at OLR values of 12–17 kg COD m^{-3} d^{-1}. Again, Ruiz et al. [22] reported a 92% soluble COD (SCOD) removal at 5.2 kg SCOD m^{-3} d^{-1} and HRT of 1.2 days. From day 100, when the OLR was changed from 6 to 9 kg COD m^{-3} d^{-1}, a slight sludge washout was observed and hence a lower efficiency of 70–75% was achieved. Higher removal rates of 76.2% have been reported by Borja et al. [27] at OLR of 17.8 kg COD m^{-3} d^{-1} when treating wastewaters from virgin olive oil.

3.5 Effect of OLR on biogas production

Fig. 6 illustrates the relationship between OLR of the reactor and the biogas produced. Biogas production during the start-up period is usually the lowest due to the fact that the growth rate

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of the methane generating microorganisms is slow as compared to the acid forming microorganisms. As seen in Fig. 6, however, an increasing trend of biogas over time was observed in the system indicating that as the days progressed, the microorganisms were stabilised and were thriving to the new OLR, hence, contributing to the increase of biogas production.

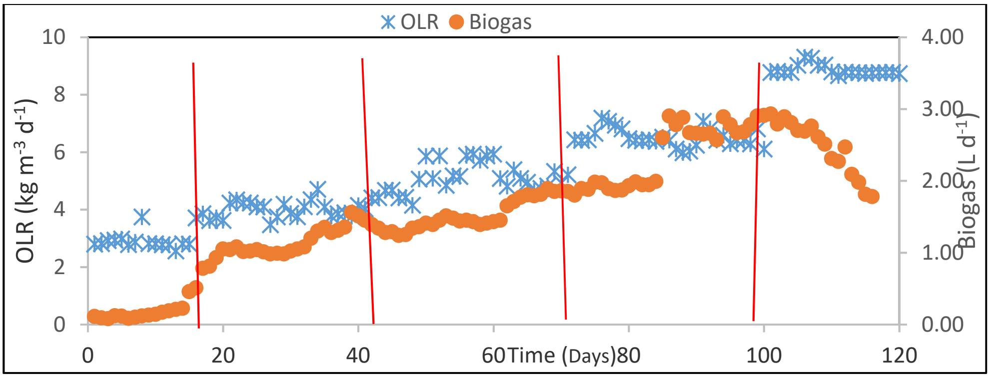

Figure 6: Applied OLR and the biogas production rate.

The results therefore indicated a strong relation between OLR and biogas production. Biogas production was observed to increase with the introduction of a new OLR indicating the availability of more substrate for digestion. However, just after the introduction of a new OLR, a decrease in biogas was observed, but picked up soon afterwards. The reason for that was the adaptation of the microorganisms to the new conditions introduced, as earlier indicated for the COD removal. Once the microorganisms were adapted, a gradual increase was observed which tends toward stability until the next phase of introduction.

Observable from Fig. 6 is the fluctuation in the biogas production. Such variation was reported to be as a result of the changes in the biological degradation of the effluent and the possible presence of different organic and inorganic materials that inhibited the treatment performance [22].

On days 100 and 101 the highest OLR of 9 kg COD m^{-3} d^{-1} was introduced and 8.63 L day^{-1} of biogas was produced. This was the maximum obtained, however, this gradually began to reduce, as seen in the following days. The reason was attributed to the increase in the VFA contents in the reactor and reduction in total alkalinity, as earlier indicated in Fig. 4 on the alkalinity and VFA of the reactor, the effect of which would have impacted on the production of the biogas. Ruiz et al. [22] attributed this behaviour to the attachment of gas bubbles at higher OLR, which was said to have contributed to the suspension of biomass and cell washout. This effect was more pronounced as the biogas production increased.

3.5.1 Biomass accumulation and sludge bed characteristics

The behaviour of the sludge bed in the reactor was analysed using the sampling points as shown in Fig. 1. There were four sampling points on the reactor, and each point showed distinct characteristics. Results of the weekly TSS and VSS are shown in Fig. 7. The sludge characteristics inside the reactor was found to settle easily. The rate of sludge production at the start-up of the reactor was slow but it picked up with time. This indicated that most of the soluble as well as settled matter in the wastewater were degraded during the treatment in the reactor. Similar findings were reported by Ruiz et al. [22]. Sludge washout became noticeable as the biogas production rate increased with the OLR. Even though this was experienced, it did not cause sludge bulking in the system. Some studies had indicated a few factors responsible for the sludge washout in their studies; increase in gas production due to high OLR and high relative content of coarse suspended solids in influent [27]. Ruiz et al. [22] reported on the floatation of sludge and an increase in the effluent solids at OLR values greater than 5 kg COD m^{-3} d^{-1}.

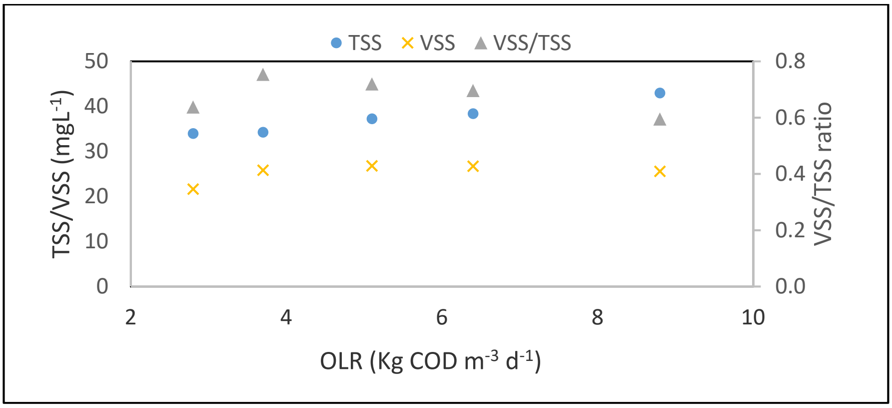

Figure 7: Weekly variation of TSS and VSS with OLR.

4 CONCLUSION

The result from this study demonstrated that the anaerobic treatment of slaughterhouse wastewaters from the slaughtering section is effective for the removal of COD and generation of biogas. Averagely, COD removal efficiency higher than 75% was achieved at OLR of 9 kg COD m-3 d-1, with a HRT of 12 h. Bulking sludge problems were not observed during the reactor operation period. Stability of the treatment process was achieved by the natural buffering of the system due to the produced alkalinity and also due to the characteristics of the wastewaters which is found to be rich in proteins. While this system exhibited the tendencies to produce bioenergy, it is necessary to carry out an economic analysis on the utilization of biogas, especially the methane produced as a source of energy.

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APPLICATION OF HEC-HMS AND IBER IN THE NUMERIC MODELING OF FLOODS IN THE RIO SAN SEBASTIAN OF THE MUNICIPALITY OF TOTOLAPAN, MORELOS, MEXICO

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ABSTRACT

In recent times, the floods in urban areas in Mexico have occurred frequently and one cause is the presence of extreme precipitation events. Recently, part of the urban area of the municipality of Totolapan, Morelos was flooded by the river San Sebastian's overflow. Consequently, the aim of the present work was to carry out a numeric modeling of the water behavior in the river San Sebastian in order to know the possible areas affected by flooding. The HEC-HMS hydrological method was used to calculate the runoff hydrographs for different return periods and the two-dimensional hydraulic model Iber was used for modelling the water run through the riverbed. Modelling showed the areas and the floodable surface in the return periods considered, indicating the degree of affectation using maximum flow depth maps. The results can be useful for disaster prevention caused by surface runoff.

Keywords: overflow of channels, hydraulic modeling, transient flow, drone application, surface runoff.

1 INTRODUCTION

Inadequate management of water resources is one of the most serious problems that modern populations have to face. Among the principal causes are poor urban planning, inadequate use of the soil and the presence of the extraordinary precipitation events [1], [2]. As a result, floods occur and damages of diverse nature, both material and health or even human losses.

Annually, in Mexico severe damage occurs by floods caused by different meteorological events (winter and summer rainfalls, hurricanes, tropical depressions, cyclones and cold fronts); in the period from 1943 to 2007, 4,183 deaths, 7,520,000 affected people and 5,532 millions of dollars are conservatively estimated as material damages [4], [5].

The municipality of Totolapan, Morelos, has been affected at different times by extreme hydrometeorological phenomena, causing the growth and overflow of the river which runs through the municipality, affecting different housing, mainly in San Sebastian and Totolapan neighborhoods. To prevent and mitigate disasters caused by extraordinary surface runoff in the San Esteban River, the hydrological response of the runoff area and the hydraulic behavior of the main channel must be known.

Mathematical modeling shows that it's a useful tool to prevent and minimize the losses caused by floods, because it allows to predict accurately the behavior of hydrological variables in runoff areas and the hydrodynamic behavior in free surface flow [6], [7]. Using hydrological modeling, the effects of the land use change and extreme precipitation events in

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the surface runoff can be represented [1], and, using hydraulic modeling, the temporal and spatial evolution of the flow and the depth in the riverbed and flood areas can be represented [8]–[10]. Therefore, the systematic application of tools for the physiographic representation of urban basins, together with distributed hydrological models and hydraulic models constitute a dynamic analysis instrument and hydraulic diagnosis, which would allow early decision making in order to avoid or minimize damages caused by the floods [6], [7].

The joint use of the HEC-HMS hydrological model and hydraulic models is one of the most used methodologies to represent the floods caused by channels overflow [11], [12]. The HEC-HMS model is applied in different parts of the world with acceptable results in the estimation of surface runoff in basins [13], [14] and it is proposed as an alternative for basins without hydrometry [15], also it can be applied in Mexico where the measurement is poor [16].

Recently, Iber numeric model was developed to model non-permanent two-dimensional turbulent flow in rivers and estuaries [17] and it is available for free on the internet [18]. Due to its recent development, it's little used and known about in America, but it's convenient to consider it because its results are similar to those obtained in the two-dimensional HEC-RAS model [19]. It's remarkable free obtaining contrasts with the expensive numerical models licenses with similar characteristics like FLO2D or MIKEFLOOD.

A numerical modelation with HEC-HMS and Iber models was done to quantify the affected area by floods and identify the vulnerable zones, in the municipality of Totolapan, Morelos, caused by river San Sebastian's overflow. This will allow planning urban growth and order land use, identifying river sites that hinder the flow of water and those where protection walls should be built, as well as evacuating the population likely to be affected by flooding, caused by extreme rainfall. The HEC-HMS hydrological model was used to obtain the hydrographs of direct runoff for different return periods and Iber hydraulic model was used to model the evolution of the depths spatially and temporarily.

2 MATERIALS AND METHODS

2.1 Description of the study area

The municipality of Totolapan is geographically located in the north part of the State of Morelos at an altitude between 1,700 and 2,700 meters above sea level and an average annual precipitation of 1,115.9 mm [20]. The specific study area is located between the geographic coordinates (98° 55' 41.53" W, 18° 58' 40.14" N) and (98° 55' 33.38" W, 19° 04' 43.62" N), in the San Sebastián River microbasin, named in honor of the name of the main stream.

2.2 Definition of the hydraulic model

The Iber two-dimensional model was used for hydraulic modeling of the study area, based on the two-dimensional differential equations of transient flow of Saint-Venant [17], obtained from the application of the conservation laws of mass (eqn (1)) and momentum (eqns (2) and (3)) in which they incorporated the effects of turbulence and surface friction due to wind:

$$\frac{\partial h}{\partial t} + \frac{\partial h\, U_x}{\partial x} + \frac{\partial h\, U_y}{\partial y} = 0, \tag{1}$$

$$\frac{\partial}{\partial t}(hU_x) + \frac{\partial}{\partial x}\left(hU_x^2 + g\frac{h^2}{2}\right) + \frac{\partial}{\partial y}\left(hU_xU_y\right) = -gh\frac{\partial Z_b}{\partial x} + \frac{\tau_{s,x}}{\rho} - \frac{\tau_{b,x}}{\rho} + \frac{\partial}{\partial x}\left(\upsilon_t h\frac{\partial U_x}{\partial x}\right) + \frac{\partial}{\partial y}\left(\upsilon_t h\frac{\partial U_x}{\partial y}\right), \quad (2)$$

$$\frac{\partial}{\partial t}(hU_y) + \frac{\partial}{\partial y}\left(hU_y^2 + g\frac{h^2}{2}\right) + \frac{\partial}{\partial x}\left(hU_xU_y\right) = -gh\frac{\partial Z_b}{\partial y} + \frac{\tau_{s,y}}{\rho} - \frac{\tau_{b,y}}{\rho} + \frac{\partial}{\partial x}\left(\upsilon_t h\frac{\partial U_y}{\partial x}\right) + \frac{\partial}{\partial y}\left(\upsilon_t h\frac{\partial U_y}{\partial y}\right), \quad (3)$$

where h is the water depth (m), U_x and U_y are the average flow velocities in the x and y directions (m s^{-1}), g is the acceleration due to gravity (m s^{-2}), ρ is the water density (kg m^{-3}), Z_b is the canal bottom elevation (m), τ_s is the friction in the free surface due to rubbing with the wind, τ_b is the friction due to rubbing with the canal bottom calculated with the Manning equation and υ_t is the turbulent viscosity.

For the numeric solution of these equations were defined: the topographical, geometrical and physical characteristics of the channel and the flood zones, initial and boundary conditions and a simulation period.

2.2.1 Initial conditions

As an initial condition, it was considered a zero flow in the channel because in recent years it has not presented a base flow. Manning's Roughness Coefficients were assigned according to the characteristics of the riverbed walls and the surface of the surrounding area [21], according to a detailed visual inspection of the water current and the flood zone.

2.2.2 Boundary conditions

Boundary conditions upstream were the hydrographs obtained by the hydrological modelation with the HEC-HMS model for return periods of 2, 5, 10, 25, 50, 100 and 500 years (T2, T5, T10, T25, T50, T100 and T500). As a boundary condition downstream was used a table of values of dimensions of the surface of the water and its corresponding flows, considering a normal subcritical flow, assumed by the conditions observed in the channel, obtained through field inspections and for the information provided by the villagers.

2.3 Topography of the channel of the Río San Sebastián and the flood zone

It was obtained by a combination of a digital model, generated from information obtained through a drone and a topographic survey with Total Station (Fig. 1).

Photographs of the study area, the channel and the surrounding and flood area were taken vertically with a DJI F550 drone, at one second intervals at 100 meters height, on sunny days and without wind. The drone was equipped with a Canon Power Shot camera with normal color cartographic and dual frequency GPS receivers with an accuracy (static method) of 3 mm ± 5 ppm and 5 mm ± 5 ppm, in planimetry and altimetry, respectively.

The photographs obtained were processed by Pix4Dmapper software, which is available for free on internet [22], to obtain a detailed topography of the land adjacent to both banks of the San Sebastián River and the location of the channel.

With Total Station, the geometry and topography of the principal channel was obtained because the abundant vegetation did not allow to have detailed information with the drone. Topographical surveys were made in the cross sections of the riverbed in sites with significant changes in the geometry (transverse direction to the flow and plan view) and bed slope.

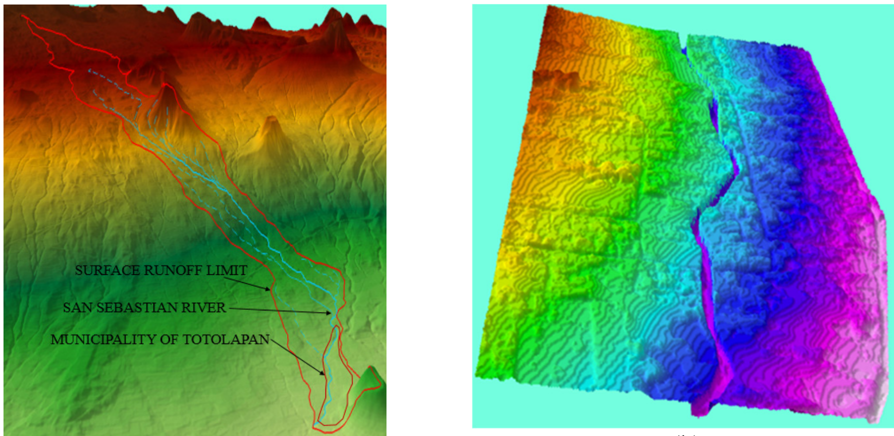

Figure 1: Topography of San Sebastían River watershed. (a) Drainage network; (b) Main stream at urban area.

2.4 Precipitation databases

For obtaining precipitation information, the inventory of weather stations and the daily climatological database of CLICOM of the National Weather Service of Mexico were consulted through web platform of the Scientific Research Center and Higher Education of Ensenada, Baja California [23].

Due to in several weather stations did not find full information of precipitation in some years, it was considered as a source of information only those which have a minimum of 15% of missing data.

2.5 Methods for estimating missing data

For estimating missing data, inverse distance weighting method was used, it was proposed by the US National Weather Service, which has been verified theoretically and empirically in hydrological and geographical studies [24], [25]. This method considers that the missing data in a certain station can be estimated based on the data observed in the surrounding stations and it can be applied on a daily, monthly or annual basis.

2.6 Obtaining the distribution of maximum precipitations for 24 hours

First of all, the maximum precipitations in 24 hours expected were calculated for each of the return periods considered and then multiplied by the coefficients proposed by [25] (Table 1), to obtain its cumulative distribution throughout the 24 hours.

Table 1: Coefficients to relate a rain to a rain of 24 hours of duration.

Duration of the rain (hours)	1	2	3	4	5	6	8	12	18	24
Coefficient	0.30	0.39	0.46	0.52	0.57	0.61	0.68	0.80	0.91	1.00

2.7 Generation of curves of intensity–duration–frequency

With the information of the previous paragraph an empirical functional relationship of intensity–duration–frequency (IDF) was obtained to explain the rain intensity (I) depending on its duration (*t*) and the return period (T) [26], [27].

2.8 Generation of design hyetographs

With the obtained IDF functional relation, IDF curves were generated for each of the return periods considered, for a one-hour duration that corresponded to the time of concentration of the runoff which was calculated with the Kirpich empirical equation [27], using the physical characteristics of the main channel.

With the IDF curves generated for one hour the design hyetographs were made and corresponded to the maximum precipitation events for the return periods considered. Alternating block method was applied, taking the rain intensity of the IDF curves to obtain the corresponding precipitation depth, multiplying the intensity of the rain by its duration [21]. In this way, the temporal distribution of rainfall corresponding to each of the analyzed return periods was obtained to determinate surface runoff in the form of hydrographs using hydrological modeling.

2.9 Definition of the hydrological model

Hydrological modeling of the study area was made through software HEC-HMS 4.1. In the model settings, the following aspects were considered: design hyetographs were used as input, evapotranspiration was considered null because they are short term events, retentions for foliage were considered null for lack of information; the retention by small depressions was considered null because of the slope of the ground surface is more or less uniform; and finally, the conversion of the runoff depth to an output runoff hydrograph was made through Synthetic Unit Hydrograph of the SCS because it is the suggested method for Mexico [27].

The runoff depth was determined by Curve Number (CN) method of the Soil Conservation Service of EE. UU. due to several studies show acceptable results [13], [15], [28].

The CN values were assigned according to the values suggested by SCS method, considering soil conditions, coverage and land use [21], [27], [29].

The initial abstraction (I_a) of the soil was considered about 20% of the maximum abstraction of the soil (S), suggested proportion by SCS [30] for runoff basins with high rainfalls like in Totolapan [20]. This concept refers to the portion of the precipitation that does not produce runoff and it was calculated with the eqns (4) and (5) [29], where I_a and S are in millimeters

$$I_a = 0.2 * \left(\frac{25400}{CN} - 254\right), \tag{4}$$

$$S = \left(\frac{25400}{CN} - 254\right). \tag{5}$$

SCS proposes to consider the delay time equal to 60% of the concentration time (t_c). It was calculated with Kirpich equation [31] that is recommended to use for Mexico, and it expresses like [27]:

$$t_c = 0.02 * \frac{L^{1.15}}{H^{0.385}}, \tag{6}$$

where t_c means concentration time (min), L means longest watercourse length in the watershed (m), and H means the difference in elevation between the outlet of the watershed and the hydraulically most remote point in the watershed (m).

3 RESULTS AND DISCUSSION

3.1 Design hyetographs

Only five weather stations within a radio less than 30 km from the supply basin of surface runoff to the San Sebastian River met the criteria of available information established in the methodology. One of them, called Totolapan, Morelos is located inside the basin and the rest is outside of it. Due to the remoteness of the weather stations located abroad, these were largely unrepresentative of the precipitation in the study basin, therefore only the Totolapan station information was considered with 3.6% of missing data.

The extreme precipitation annual values in 24 hours during the period of 1981 to 2011, were fitted to a function of Gumbel probability distribution [32], obtaining the corresponding values to the return periods analyzed (Table 2).

Table 2: Probable extreme precipitation in 24 hours in the study basin for different return periods.

Return period T (years)	Probability of occurrence	Precipitation (mm)
2	0.50	77.14
5	0.80	104.84
10	0.90	123.18
25	0.96	146.35
50	0.98	163.55
100	0.99	180.61
500	0.99	220.04

The empirical equation for rain intensity (I, mm h^{-1}), resulted on the basis of the return period (T, years) and the duration of the rain (t, minutes), with a good adjustment ($R^2 = 0.94$) and its expression is given by the eqn (7).

$$\mathrm{I} = \frac{291.5134 * \mathrm{T}^{0.184254}}{t^{0.61885}}. \tag{7}$$

With the eqn (7) IDF curves and design hyetographs were generated, using rain durations of 5 to 60 minutes, at 5-minute intervals (Fig. 2). At the beginning and the end of the 60-minute period the precipitations were low, observing maximum values at 30 minutes. In the IDF curves it was observed that the greater the duration of the storm, the lower its intensity, and as the return period increases, so does the intensity.

3.2 Hydrological modeling

Hyetographs in Fig. 2 were used for the runoff hydrological modeling and a concentration time of 56.7 minutes, as a result of replacing in the eqn (6) a length of 9,172 m and a slope of 740 m of the main channel of the River San Sebastian. It was used a numerical curve value weighted by the area of 66.8, as a result of three land uses with different surfaces (Table 3).

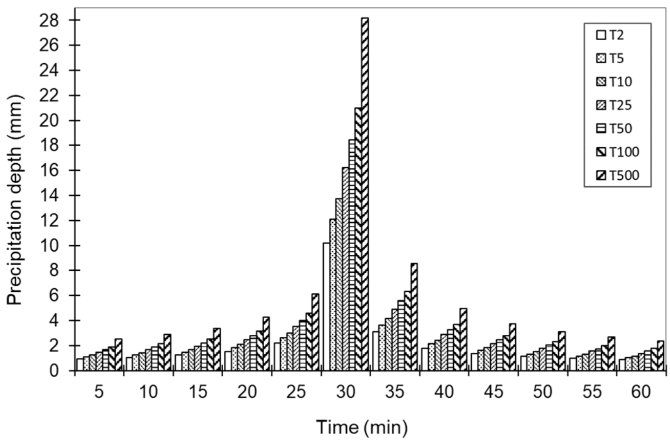

Figure 2: Design hyetographs for return periods (T) considered.

Table 3: CN values of the study zone.

Zone	Land use	Hydrological condition	Soil group	Area (ha)	CN	CN weighted
1	Forest	Regular	C	293	50.0	66.8
2	Urban area	Regular	C	30	79.0	
3	Farming	Regular	C	526	75.5	

As a result, maximum runoff hydrographs were obtained for the study return periods (Fig. 3); it is clearly shown that as the return period increases, the maximum runoff increases. As a result, maximum flow rates of 1.5, 2.1, 3.1, 5.4, 8.0, 11.6, 24.9 $m^3 s^{-1}$ for 2, 5, 10, 25, 50, 100 and 500 years of return period. The times of occurrence were 3.4 to 5.3 h, for return periods of 2 and 500 years, respectively.

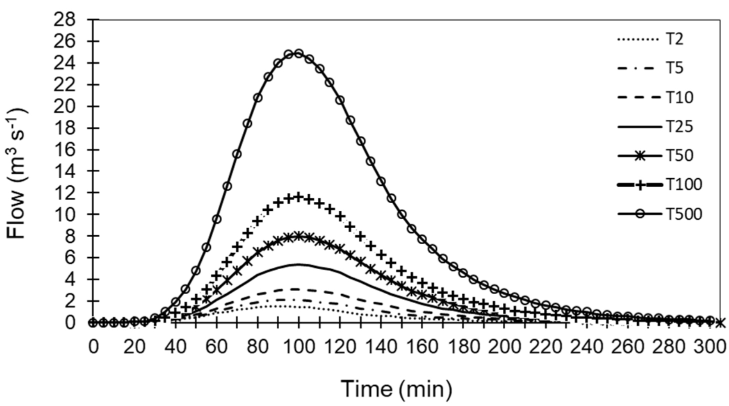

Figure 3: Maximum hydrographs expected for different return periods in the San Sebastian Riverbed.

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3.3 Topography and geometry of the San Sebastian riverbed

Georeferenced orthomosaics, digital surface models, digital terrain models and texture 3D models were obtained of the processing of the aerial images taken by the drone, with 3cm of resolution each pixel, which was much better than those generated with the INEGI lidar models, whose resolution is up to 1 m per pixel [33].

Orthorectification was made with an overlap of 90%, greater than 70% or smaller than the one used by INEGI due to the photos acquisition costs. This allowed to obtain an accuracy of millimeters on the vertical axis, while lidar business models offer at most an accuracy of 15 cm for Mexico [33].

Obtaining the topography with the support of a drone is a powerful and novel tool in Mexico, for the study of floods [34] because it allowed to identify with a good resolution the relief of the flood zone and the geometry of the channel, details that are impossible to obtain with the information offered by INEGI, and even more because it is a small river and some places with very flat surfaces.

3.4 Considerations in hydraulic modeling

With the identification of the physical characteristics of the surface of the riverbed walls and the surface of the ground of the adjacent area on both banks, shown in the Fig. 4, and that were obtained with the drone, Manning friction coefficients were assigned. A value of 0.025 was assigned to the river, 0.023 to the bare soil, 0.05 to the prairie, 0.12 to trees, 0.032 to urban vegetation, 0.08 to disperse vegetation, 0.18 to dense vegetation, 0.018 to concrete, 0.15 to residential area and 0.13 to agricultural surface [21].

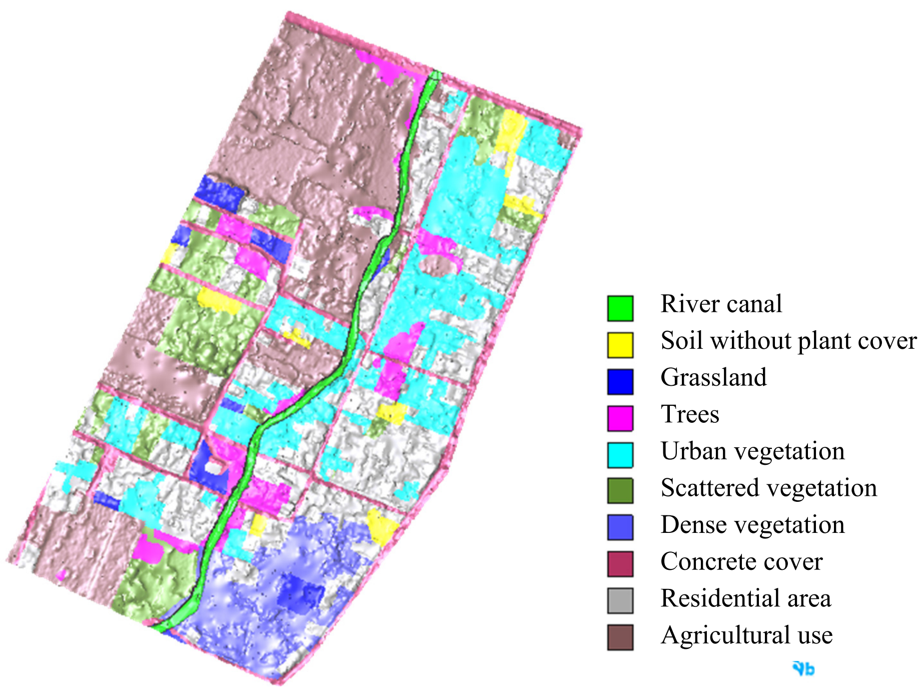

Figure 4: Channel physical conditions to assign the roughness coefficient.

Manning's friction coefficient, it is usually the adjustment parameter to calibrate hydraulic models, but in this study the assigned values were considered correct because the physical characteristics of the contact surface with water were identified with high resolution [35].

3.5 Result of hydraulic model

As a result of hydraulic modeling, flood depth maps for the return period considered were obtained. In them, the sites that would be affected by the Rio San Sebastian overflow were observed (Fig. 5). The affected areas are shown in the Table 4, that go from 0.63 to 2.77 ha, for return period of 2 and 500 years, respectively and correspond to 2.1 and 9.2% of the urban area of the municipality of Totolapan. As is evident, these values don't represent a large percentage of the total urban area; however, housings are located in the flood zone, currently occupied by the municipality people, who are very important.

Table 4: Affected areas and maximum depths expected in the urban zone of the municipality of Totolapan.

Return period (years)	Area (ha)	Maximum depth (m)
2	0.63	4.95
5	0.83	5.91
10	1.06	6.73
25	1.41	8.01
50	1.74	10.52
100	2.00	10.52
500	2.77	12.17

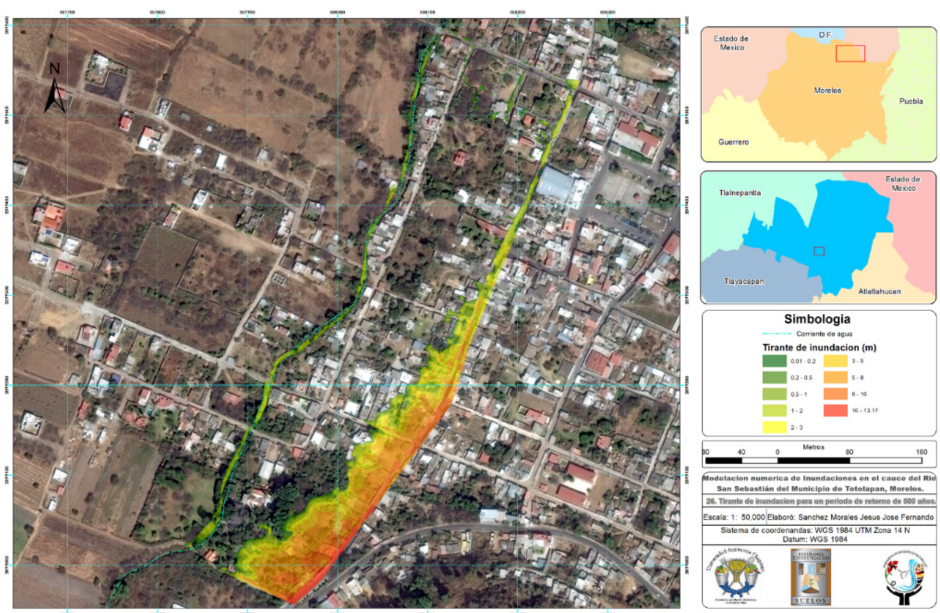

Figure 5: Flood depth for a return period of 500 years.

In all return periods considered, the houses located on both sides of the Alarcon Norte Street would be affected, located parallel to the left bank of the river, in the San Sebastián neighborhood. The affected zone is located between Niño Perdido and Huezario streets; and it was found that as the return period of the runoff events increases, the affected area increased between Lic. Benito Juarez and Alarcon Norte streets. Lic. Benito Juarez street is the one closest to the river, but it is in a higher area.

Added to the extraordinary runoff events, the river overflow was due to the loss of the capacity of the conduction of the channel by the accumulation of sediments, for the invasion of the river banks with civil works and by the obstructions to the flow by vehicular bridges in the Niño Perdido, Callejo Juarez, Calle San Miguel streets and 88 km highway. These aspects were represented in the flow simulation through the geometry and topography of the main channel, and one aspect to consider should be the obstruction caused by the dumped garbage.

It’s remarkable that even in the smaller extraordinary runoff events expected high depths would be presented (4.95 m) on Alarcon Norte street and represent a potential death threat to villagers.

The problems identified that increase flood risks suggest that we should make a territorial planning in the catchment, an improvement in urban planning and the adaptation of vehicular crossings. Different scenarios could be simulated with the support of the tool applied in this work so that its results, added to those obtained in this investigation, improve the prevention and mitigation of flood damages.

4 CONCLUSIONS

The surfaces and zones vulnerable to floods caused by the river San Sebastian overflow were determined, for hydrographs corresponding to seven return periods. The most vulnerable zone corresponded to the sites with the lowest topographic level, located on the left bank of the river and upstream of the vehicular crossing of the 88 km highway. The overflow causes were detected and should be attended to prevent and mitigate flood damages. A novel aspect of this kind of studies in Mexico, it was the inclusion of a much more accurate topography than that offered by government and the reliable assignment of friction coefficients, thanks to a drone support.

Under the current management conditions of the San Sebastián River watershed, the San Sebastián neighborhood of the municipality of Totolapan will be frequently flooded. To mitigate flooding, those responsible for planning and legislating water management should propose structural and non-structural actions in the watershed. They should: relocate the buildings that invade the banks of the river and ensure that they do not rebuild in this area, expand the cross-section of the vehicle bridges and study other alternatives to agricultural land use.

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EVALUATION OF THE SURFACE RUNOFF ESTIMATED BY THE MEXICAN OFFICIAL STANDARD AND SCS-CN MODEL IN TWO SMALL BASINS IN MEXICO

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ABSTRACT

The determination of the surface runoff depth in the microbasins of Mexico is carried out by estimation methods whose degree of accuracy is unknown, due to the information about temporal evolution of the precipitation and direct surface runoff is scarce. For this reason, it is necessary a revision of the accuracy of the available methodologies to estimate surface runoff for ungauged basins in order to identify the most appropriate for the mexican conditions. The aim of the present work was the evaluation of the Mexican Official Standard (NOM) and the Soil Conservation Service Curve Number (SCS-CN) methodologies to estimate the surface runoff depth in the microbasins Rio Chapingo and El Malacate, which are located in the state of Mexico and Michoacan respectively, with the measured information of precipitation and direct surface runoff of two recent years. With the SCS-CN method, the CN values were extracted by two ways: (1) with the tables of National Engineering Handbook (SCS-CN-NEH); and (2) with asymptotic functions (SCS-CN-AF) that associate the CN with precipitation, using ordered pairs method. According to the values of the statistics measures AE (mm), RE, RMSE (mm) and Nash-Sutcliffe index (NS), the best method in both basins was SCS-CN-AF (Rio Chapingo: AE=0.002, RE=0.01, RMSE=0.14 and NS=0.23; El Malacate: AE=-0.004, RE=-0.004, RMSE=0.50 and NS=0.36), followed by the NOM method (Rio Chapingo: AE=0.56, RE=4.11, RMSE=0.70 and NS=-17.94; El Malacate: AE=-0.06, RE=-0.07, RMSE=0.51 and NS=0.33) and finally by the SCS-CN method (Rio Chapingo: AE=0.37, RE=2.73, RMSE=1.18 and NS=-53.15; El Malacate: AE=-0.41, RE=-0.48, RMSE=0.99 and NS=-1.55). The results suggest establishing experimental basins in the hydrological regions of Mexico to obtain asymptotic functions in order to estimate the CN values or adjust the NOM surface runoff factors.
Keywords: direct runoff, curve number method, rainfall-runoff modeling, asymptotic function, watershed.

1 INTRODUCTION

Knowledge of surface runoff in a basin is transcendent to properly manage the water resource. An accurate estimate of its value can also result in an accurate estimate of the water balance, thereby allowing a balanced allocation of water between the amount available and demanded by users, avoiding for example the conflict over the resource between different sectors and the aquifer depletetion.

Its knowledge is important to design storage and protection works for the towns, and to implement management practices to minimize soil erosion and increase the infiltration of water into the soil. A very useful method to estimate surface runoff is by applying a runoff

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coefficient to the rainfall depth. The experimental determination of this surface runoff coefficient in the microbasins of Mexico is very difficult obtain because there is a little information on precipitation and surface runoff. Continuous measurement of surface flow implies a high cost caused by the acquisition, instalation, operation and maintenance of the infrastructure and measuring devices. In most basins is difficult to implement the measurement because of its remoteness, topographical conditions, insecurity or vandalism. For this reason, it is essential to review the accuracy of the methodologies applied to estimate surface runoff on ungauged basins and adapt them to the mexican basins conditions to improve the estimation of the results.

The method proposed by the Mexican Official Standard NOM-011-CNA-2015 (NOM) to estimate the surface runoff coefficient in Mexico is a function of a parameter K that depends on the use and type of soil [1]. Curve Number method (CN) proposed by the Natural Resources Conservation Service (NRCS), in the decade of the 1950 [2] it is also used to find a relation between surface runoff and precipitation depth for a rain event; this is based on a numerical curve value that depends on the type and use of soil, soil hydrological condition, vegetation, management practices and the humidity conditions that precede the event in study [3]. The K and Curve Number values can be consulted in tables, but they do not guarantee the representation of Mexican basins characteristics because most are taken from information generated in other countries, particularly from EE. UU., and therefore, strong estimation errors of the runoff coefficient can be generated.

Considering the antecedent, in this work the objective is to evaluate the NOM and CN methodologies for surface runoff depth in two small basins of Mexico, with information of rain-runoff events of two years. CN method was used in two ways depending on the methodology used to assign the value of the curve number; in one way the values were assigned from tables and in the other one they were adjusted with the functions proposed by Hawkins in 1993 [4] and Kowalik and Walega in 2015 [5]. This is intended to know the most appropriate methodology in the ungauged basins of Mexico, with similar conditions to those studied, and propose this study as a reference to policy makers on water management.

2 MATERIALS AND METHODS

This work was done in the microbasins Rio Chapingo and El Malacate located in Mexico and Michoacan states, respectively, with information taken from runoff generated en 2014 and 2016 in the first microbasin and in 2013 and 2014 in the second one. The microbasin Rio Chapingo has a surface of 1923.4 ha and El Malacate has 149.2 ha.

2.1 Considered rainfall-runoff events

In the microbasin Rio Chapingo, information of 20 rain events that produced runoff was used, from one to five occurred in 2014 and the rest in 2016. In the microbasin El Malacate, 14 runoff events were used, from one to five corresponded to 2013 and the rest to 2014 (Table 1). The precipitation information was taken from a site near the microbasins exit.

To compare the annual results of the observed runoff with those estimated, the 2.7 mm and 1.86 mm measured in microbasin Rio Chapingo in 2014 and 2016, respectively, were considered. These values were obtained by dividing the runoff volume between the microbasin area. The runoff volume was obtained from the total of the direct runoff hydrographs, and it was registered at the exit of the microbasins with an automated measurement system.

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Table 1: Characteristics of rainfall-runoff events analyzed.

Event	Microbasin Rio Chapingo			Microbasin El Malacate		
	P[1] (mm)	Q[2] (mm)	Antecedent rainfall depth[3] (mm)	P (mm)	Q (mm)	Antecedent rainfall depth (mm)
1	16.00	0.168	0.00	12.60	0.490	0.00
2	20.50	0.662	13.33	28.20	0.631	18.80
3	9.50	0.088	12.00	26.80	1.370	12.80
4	4.70	0.057	3.06	35.80	0.873	16.00
5	2.90	0.015	1.89	10.60	0.858	14.60
6	19.90	0.291	1.00	10.80	0.360	0.00
7	28.70	0.449	14.00	4.00	0.181	7.80
8	12.00	0.090	15.00	15.20	0.270	3.00
9	10.40	0.046	6.76	17.60	1.225	9.00
10	9.60	0.008	6.24	15.40	0.539	11.00
11	5.60	0.034	3.64	14.60	0.505	7.00
12	6.20	0.114	4.03	28.60	2.404	14.00
13	20.10	0.075	4.00	11.60	0.459	5.00
14	1.10	0.068	13.00	22.20	1.850	11.00
15	34.60	0.259	1.00			
16	5.40	0.038	15.00			
17	6.40	0.076	4.16			
18	8.70	0.063	5.66			
19	7.20	0.038	4.68			
20	22.80	0.073	14.82			

[1]Rainfall depth; [2]Surface runoff depth; [3]Accumulated rainfall depth of 5 days before the event.

2.2 Runoff depth with Mexican Official Standard method

The method proposed by the Mexican Official Standard NOM-011-CNA-2015 (NOM) [1], is used to estimate the mean annual runoff depth using eqn (1):

$$Q = C_e P, \tag{1}$$

where C_e is the mean annual runoff coefficient, Q is the runoff depth [L], and P is the mean annual precipitation depth [L]. Surface runoff coefficient is a function of K parameter that depends on the use and type of soil (permeability) and the mean annual precipitation. A weighted K value was used for each study microbasin. This coefficient was calculated with the eqns (2) or (3), according to the weighted K value

$$C_e = \frac{\mathrm{K(P-250)}}{2000} \text{ for } K \leq 0.15, \tag{2}$$

$$C_e = \frac{\mathrm{K(P-250)}}{2000} + \frac{\mathrm{(K-0.15)}}{1.5} \text{ for } K > 0.15. \tag{3}$$

Eqns (2) and (3) are valid for annual precipitations between 350 and 2150 mm.

2.3 Runoff depth with Curve Number method

Curve Number method (CN) proposed by the Natural Resources Conservation Service was used [1], [6]. Surface runoff depth was calculated with eqns (4), (5) and (6):

$$Q = \frac{(P-I_a)^2}{(P-I_a)+S} \text{ valid for } I_a \geq P, \text{ otherwise } Q = 0, \quad (4)$$

$$I_a = \lambda S, \quad (5)$$

$$S = \frac{25400}{CN} - 254, \quad (6)$$

where Q is the generated runoff depth (mm) by the precipitated depth P (mm) by rain event, I_a is the initial abstraction (mm), S is the maximum soil moisture retention potential (mm), λ is the initial abstraction radius, assumed as 0.2 for this study (dimensionless) as indicated by National Resources Conservation Service [6] and Woodward et al. [7], and CN is the numerical curve value obtained from tables (CN_{tab}) [6], corrected by the antecedent rain condition, being able to take the value of CN_I, CN_{II} or CN_{III} as explained below.

Antecedent rain condition was defined with the accumulated precipitated depth of 5 days before the runoff. A dry condition (CN_I) was considered if the antecedent accumulated depth was less than 12.7 mm, moderate condition (CN_{II}) if it was between 12.7 and 38.1 mm, and wet condition (CN_{III}) if it was higher than 38.1 mm. Correction for antecedent precipitation conditions was made with eqns (7), (8) and (9) [8]

$$CN_I = \frac{[4.2 CN_{tab}]}{10-0.058 CN_{tab}}, \quad (7)$$

$$CN_{II} = CN_{tab}, \quad (8)$$

$$CN_{III} = \frac{[23 CN_{tab}]}{10+0.13 CN_{tab}}. \quad (9)$$

2.4 Runoff depth with asymptotic functions (SCS-CN-AF)

This methodology consisted of applying NC method, but using curve number values adjusted with the asymptotic functions (AF) proposed by Hawkins [4] in 1993 and Kowalik and Walega [5] in 2015. First, curve numbers observed by rain event (CN_{obs}) were calculated, corresponding to the observed precipitated (P) and runoff depths (Q) of the event, ordered as suggested by Hawkins [9] in 2002, applying eqns (10) and (11) [10]

$$CN_{obs} = \frac{25\,400}{(S+254)}, \quad (10)$$

$$S = \frac{P}{\lambda} + \frac{Q(1-\lambda)}{2\lambda^2} - \frac{1}{2\lambda^2}\left[Q^2(1-\lambda)^2 + 4\lambda PQ\right]^{\frac{1}{2}}. \quad (11)$$

Then, the observed curve number values were analyzed together with the observed precipitated depths (P-CN_{obs}) with the TABLE CURVE 2D software [11], to obtain the adjustment parameters of the Hawkins standard function (eqn (12)) and Kowalik and Walega function (eqn (13)):

$$CN(P)_H = CN_\infty + (100 - CN_\infty) \times e^{(-k_1 P)}, \quad (12)$$

$$CN(P)_{K-W} = CN_L + \left[b^{1-d} + c \times P(d-1)\right]^{\frac{1}{1-d}}, \quad (13)$$

where $CN(P)_H$ is the curve number value of the Hawkins function, $CN(P)_{K-W}$ is the curve number value of the Kowalik and Walega function, CN_∞ is the value that the curve number acquires when the precipitated depth tends to infinity, CN_L is the curve number value when the precipitated depth acquires a large value, k_1, c, b and d are adjustment parameters, and P is the precipitation of the event (mm).

2.5 Characteristics of the study microbasins

Microbasin Rio Chapingo presented a mean annual precipitation of 598.6 mm, in the period 1981 to 2010, according to the records of Chapingo weather station located in Texcoco. In the years 2014 and 2016, 932.4 and 619.3 mm were registered, respectively. It has an average height of 2520 m, average slopes of the basin and main channel of 18.5 and 6.7%, respectively, and a length of currents of 38.33 km. The microbasin is very long since its shape index is 0.07.

Microbasin El Malacate registered a mean annual precipitation of 920.3 mm between 1969 and 2007 [12]; in 2013 and 2014, 769.6 and 841.0 mm were registered, respectively, with a HOBO RG3-M ® pluviograph. It has an average height of 2351.5 m, average slope of 28.8%; main channel average slope of 18.6%, shape index of 0.29 and 4.29 km of surface currents.

According to the hydraulic conductivity to saturation of the soils, associated with the texture [13] obtained from 18 sites sampled in the microbasin Rio Chapingo and from 7 sites in the microbasin El Malacate, types of soil were defined: A (greater than 8 mm h^{-1}), B (4 to 8 mm h^{-1}) and C (1 to 4 mm h^{-1}).

The hydrological condition of the soil was defined according to the vegetation cover: good for greater than 75%, regular for 50 to 75% coverage and bad for a cover lower than 50%. With the uses, hydrological conditions and soil type, the curve number values and parameter K of NC and NOM methods were defined (Tables 2 and 3). For calculations, values weighted by the area of the curve number and K were used, assigning a proportional value to the area covered by each land use.

Table 2: Characteristics and land uses of the microbasin Rio Chapingo.

Land use	Area (ha)	Surface (%)	Hydrological condition of the soil	Soil type	CN_{tab}	K
Irrigation agriculture	95.75	4.98	Bad	C	84	0.24
Rainfed agriculture	719.77	37.42	Bad	C	88	0.24
Oak forest	214.19	11.14	Regular	A	73	0.07
Fir forest	179.88	9.35	Regular	A	73	0.07
Pine forest	64.75	3.37	Regular	A	73	0.07
Pine-oak forest	204.75	10.65	Regular	A	73	0.12
Water bodies	2.94	0.15	Bad	C	100	0.30
Bare soil	42.47	2.21	Bad	C	91	0.27
Urban zone	398.92	20.74	Bad	C	91	0.26
Weighted value					83.3	0.19

Table 3: Characteristics and land uses of the microbasin El Malacate.

Land use	Area (ha)	Surface (%)	Hydrological condition of the soil	Soil type	CN_{tab}	K
Rainfed agriculture	1.77	1.19%	Bad	C	88	0.30
Areas without vegetation	7.37	4.94%	Bad	C	91	0.30
Eroded forest grassland	2.74	1.84%	Bad	B	86	0.30
Forest	91.31	61.18%	Good	A	70	0.24
Forest-grassland	19.39	12.99%	Regular	A	77	0.28
Grassland-forest	24.86	16.66%	Regular	B	79	0.30
Reforestation of eroded areas	1.80	1.20%	Regular	C	91	0.30
Weighted value					74.2	0.11

2.6 Evaluation of the methods for estimating runoff

The goodness of precision of the models to estimate the considered surface runoff was done with the mean error (AE), relative error (RE) the root mean square error (RMSE) and the Nash-Sutcliffe coefficient (NS), with eqns (14) to (17)

$$AE = \frac{\sum_{i=1}^{n}(Q_{sim,i} - Q_{obs,i})}{n}, \tag{14}$$

$$RE = \frac{\sum_{i=1}^{n} Q_{sim,i} - \sum_{i=1}^{n} Q_{obs,i}}{\sum_{i=1}^{n} Q_{obs,i}}, \tag{15}$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(Q_{sim,i} - Q_{obs,i})^2}{n}}, \tag{16}$$

$$NS = 1 - \frac{\sum_{i=1}^{n}\left(Q_{obs,i} - Q_{sim,i}\right)^2}{\sum_{i=1}^{n}\left(Q_{obs,i} - \overline{Q_{obs}}\right)^2}, \tag{17}$$

where $Q_{obs,i}$ is the i-th observed value, $Q_{sim,\,i}$ is the i-th simulated value and $\overline{Q_{obs}}$ is the average value of the n observed values.

3 RESULTS AND DISCUSSION

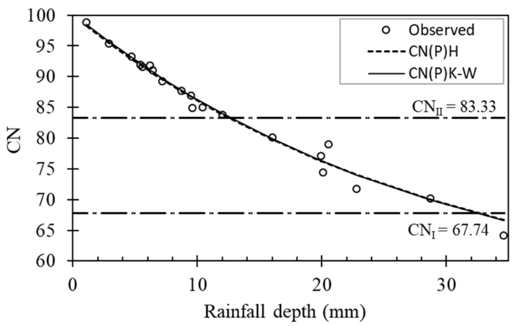
3.1 Asymptotic functions to estimate the value of the curve number

The functions of Hawkins and Kowalik and Walega resulted with an excellent fit in the two microbasins, slightly better in the microbasin Rio Chapingo. In the two microbasins, the two models resulted with the same value of R^2; of 0.997 in the microbasin Rio Chapingo and 0.993 in El Malacate (Table 4).

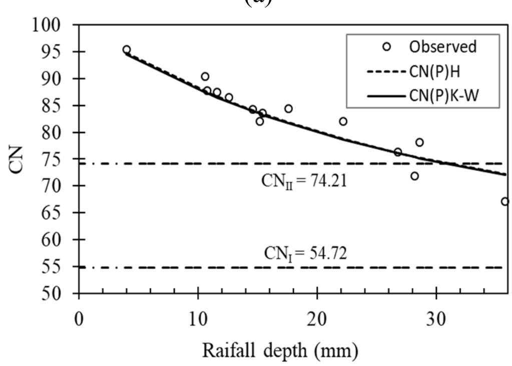
Table 4: Asymptotic functions of Hawkins (1993) [4] and Kowalik and Walega (2015) [5].

Model	Microbasin Río Chapingo	Microbasin El Malacate
$CN(P)_H$	CN_∞ = 51.82; k_1 = -0.034	CN_∞ = 62.72; k_1 = -0.038
	$=51.82 + (48.19) \times e^{(-0.034P)}$	$=62.72 + (37.28) \times e^{(-0.038P)}$
	R^2=0.997	R^2=0.993
$CN(P)_{K\text{-}W}$	CN_L = 51.40; b = 48.78; c = 0.033; d =1.0073	CN_L = 54.48; b = 46.54; c = 0.0065; d =1.42
	$= 51.40 + [0.972 + 0.033 \times P(0.0073)]^{-136.986}$	$= 54.48 + [0.199 + 0.0065 \times P(0.42)]^{-2.364}$
	R^2=0.997	R^2=0.993

In both basins, it is observed that as the precipitated depth increases, the curve number decreases with an asymptotic tendency for large precipitations as observed [5] (Fig. 1). In the microbasin Rio Chapingo the CN_∞ and CN_L values were very similar (51.82 and 51.40) but lower than the value of the dry antecedent condition (CN_I = 67.74), a condition presented in 14 of the 20 analyzed events. In the microbasin El Malacate, CN_∞ value (62.72) was higher than the most frequent antecedent condition (CN_I = 54.72), whereas CN_L was very similar (54.48) to the value of that condition.



(a)



(b)

Figure 1: Pairs of observed and estimated CN values and rainfall depth. (a) Microbasin Rio Chapingo; (b) Microbasin El Malacate.

3.2 Annual runoff with NOM method

Annual runoff calculated with NOM method overestimated those observed in the two years of study of the two microbasins (Fig. 2). In the microbasin Rio Chapingo the differences were 3059.6 and 1951.6% in 2014 and 2016, respectively. the differences were much smaller in microbasin El Malacate, with values of 258.7 and 32.1% in 2013 and 2014, respectively.

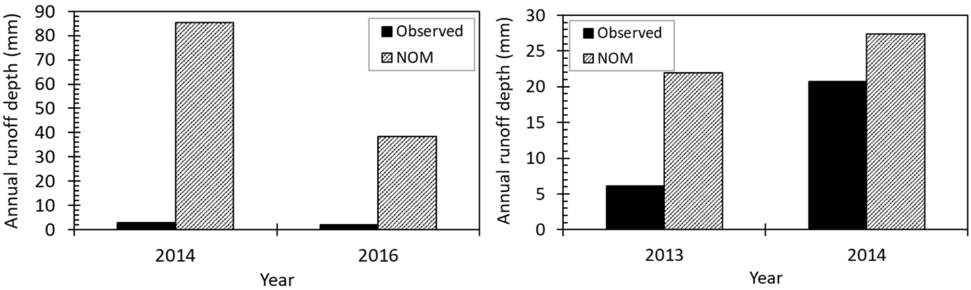


Figure 2: Annual runoff depths observed and estimated with the NOM method. (a) Microbasin Rio Chapingo; (b) Microbasin El Malacate.

3.3 Evaluation of the methods

In the two studied microbasins, CN method was the least accurate in the estimation of runoff depths. In both microbasins, the methods based on the functions of Hawkins and Kowalik and Walega were the best with very similar results, slightly better the second of them. It is important to note that the estimates per rain event made with the NOM method in the Malacate microbasin results very close to those obtained with the Hawkins and Kowalik and Walega functions, although it is recommended for annual estimates (Tables 5 and 6). In the microbasin Rio Chapingo, CN method produced runoff events in only five of the rain events with a total depth of 10.11 mm, while in the 20 events studied 2.71 mm were observed. This method drastically overestimated the runoff depth observed in the events that resulted in runoff. NOM, Hawkins and Kowalik and Walega methods showed runoff in the 20 studied events with values of 13.87, 2.57 and 2.75 mm, respectively (Fig. 3).

Table 5: Statistics of the quality of adjustment of the models to estimate the runoff depths by event in the microbasin Rio Chapingo.

Model	AE (mm)	RE	RMSE (mm)	NS
CN	0.37	2.73	1.18	-53.15
NOM	0.56	4.11	0.70	-17.94
Hawkins (1993)	-0.007	-0.05	0.14	0.22
Kowalik and Walega (2015)	0.002	0.01	0.14	0.23

Table 6: Statistics of the quality of adjustment of the models to estimate the runoff depths by event in the microbasin El Malacate.

Model	AE (mm)	RE	RMSE (mm)	NS
CN	-0.41	-0.48	0.99	-1.55
NOM	-0.06	-0.07	0.51	0.33
Hawkins (1993)	-0.08	-0.09	0.50	0.34
Kowalik and Walega (2015)	-0.004	-0.004	0.50	0.36

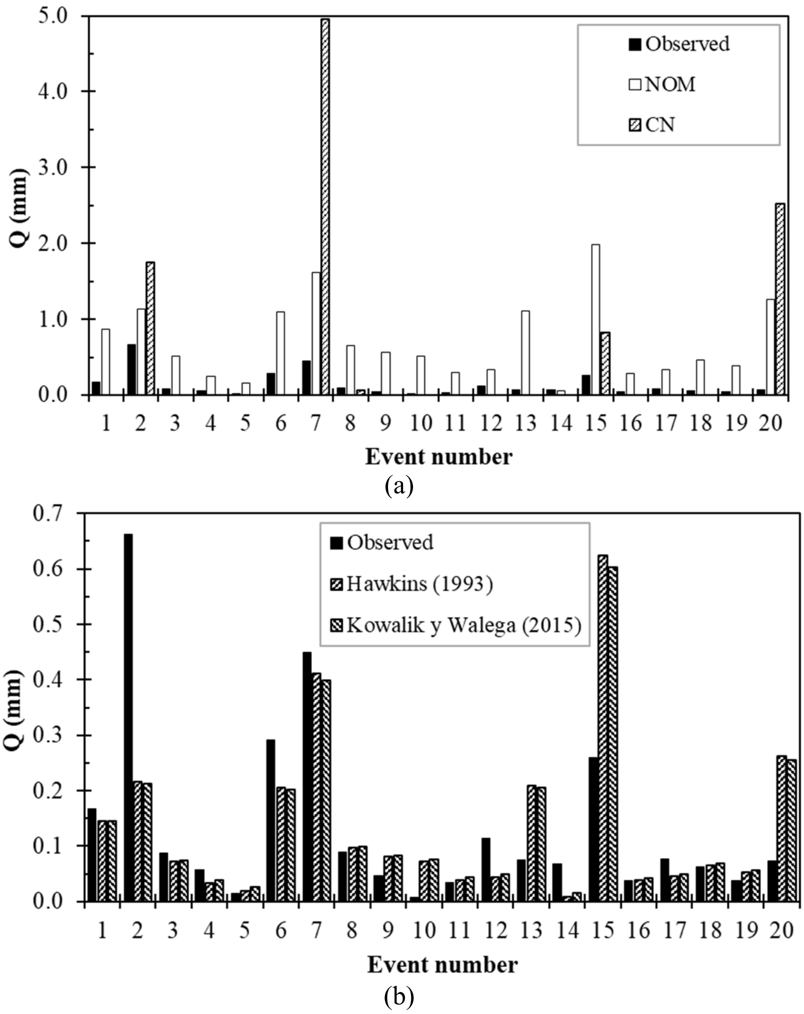


Figure 3: Runoff depths observed and estimated in the microbasin Rio Chapingo. (a) NC and NOM methods; (b) Methods based on the functions of Hawkins (1993) and Kowalik and Walega (2015).

It is observed that the Hawkins and Kowalik and Walega methods compensated for the errors of the events since the sum of the estimated runoff depths from the total of events contemplated was very close to that observed with errors of -5.2 and 1.5%, respectively.

In the microbasin El Malacate, CN method produced runoff events in only four of the rain events with a total depth of 6.29 mm, while in the 14 studied events, 12.02 mm were observed. NOM, Hawkins and Kowalik and Walega methods showed runoff in the 14 studied events with values of 11.20, 10.94 and 11.97 mm, respectively (Fig. 4). NOM, Hawkins and Kowalik and Walega methods compensated for the errors of the events since the sum of the runoff depths estimated from the total of events contemplated resulted in differences of -6.8, -9.0 and -0.4%, with respect to the observed.

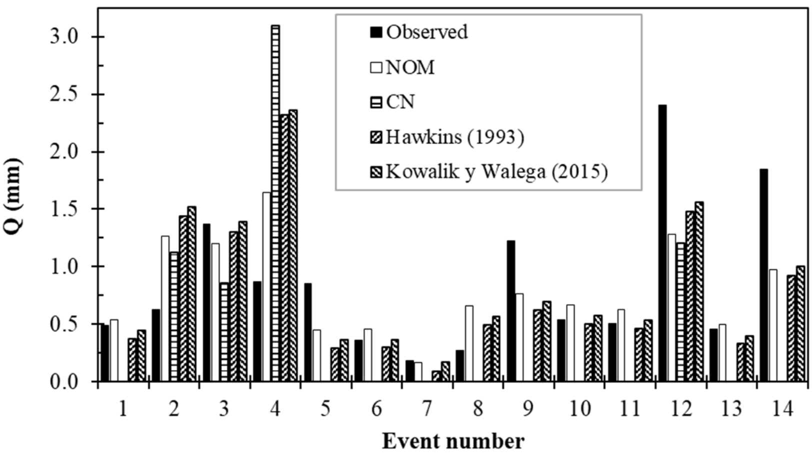


Figure 4: Runoff depths observed and estimated with NOM, CN methods and with the methods based on the functions of Hawkins (1993) [4] and Kowalik and Walega (2015) [5] in the microbasin El Malacate.

The methods were more accurate in the microbasin El Malacate than in the microbasin Rio Chapingo, and it is attributed to the fact that the precipitated depths used were more representative of the entire runoff area in the first case. This is explained by the fact that the precipitated depths registered at the exit of the microbasin Rio Chapingo may not have occurred at other sites of the microbasin due to their elongated shape, while those registered in the microbasin El Malacate probably occurred over their entire surface because it is small and has a pear shape. Consequently, it should be measured in more places inside the microbasin Rio Chapingo, at least in the middle and upper part.

The poor accuracy of CN method, without the adjustment with the functions of Hawkins and Kowalik and Walega, is due to the fact that the antecedent rain condition does not adequately represent the initial states of soil moisture or water storage by the foliage of the vegetation. In the microbasin Rio Chapingo. 15 of the 20 events corresponded to the dry condition of antecedent rain (CN_I) and six to the moderate condition (CN_{II}); however, the observed runoff indicates that the antecedent conditions should be dry for large precipitations, moderate for intermediate ones and wet for small ones (Fig. 5(a)). With this, there would be smaller depths in the events that estimated runoff different to zero and would produce runoff in those where it was null, since four of the five event that produced runoff

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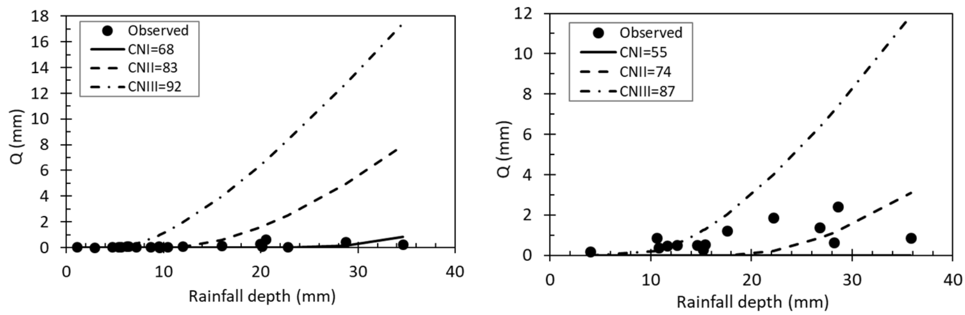
corresponded to the moderate condition and three of them registered high precipitated depths (from 20.5 to 28.7 mm).

In the microbasin El Malacate, 9 of the 14 events resulted in the dry antecedent condition and five in the moderate one. In this microbasin the results were better than in the microbasin Rio Chapingo, because four of the moderate antecedent conditions corresponded to four of the five events that estimated a runoff different from zero and corresponded to the four highest precipitations (Fig. 5(b)). However, the precipitation events with precipitated depths less than 20 mm should correspond to the condition of wet antecedent precipitation, generating non-null runoff.



(a) (b)

Figure 5: Runoff depths observed and estimated for dry (CN_I), moderate (CN_{II}) and humid (CN_{III}) condition. (a) Microbasin Rio Chapingo; (b) Microbasin El Malacate.

Although the functions of Hawkins and Kowalik and Walega were excellently fitted, NC method based on them resulted in inaccuracies in some rain-runoff events because the estimated runoff depth is very sensitive to the value of the curve number. Curve number value is difficult to assign because this parameter depends on several aspects and even experienced people may have difficulties, especially in microbasins where information is scarce. The method does not consider the dynamic of water infiltration in the soil or the initial condition of humidity [14], [15] and the retention by foliage of the vegetation is integrated in the abstractions which can vary according to water depth retained by the canopy and shaft at the beginning of the rain and its saturation conditions [16]–[18].

4 CONCLUSIONS

CN method based on asymptotic functions of Hawkins (1993) [4] and Kowalik and Walega (2015) [5] (SCS-CN-AF) was the most appropriate to estimate the runoff depths in the two studied microbasins. CN method was the least accurate to estimate the runoff depths in the two studied microbasins. In 70% of the events the runoff was null, and in the rest the observed values were drastically overestimated.

NOM method was better to estimate the runoff depths per event despite being a suggested method for annual estimates. Estimation methods of analyzed runoff depths were more efficient in the microbasin El Malacate than in the microbasin Rio Chapingo because the precipitated depths were more representative of the entire runoff area.

Policy makers for the water resources management in watersheds must rethink the methodology for carrying out water balances in Mexico, supported by research such as the one presented in this paper.

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FLOODING SIMULATION AND CHANNELING IN THE VALLEY OF THE ANDES MOUNTAIN RANGE IN THE SOUTH OF PERU

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ABSTRACT

For this investigation, a maximum flow was generated with a hydrological simulation of extreme events in the southern zone of Peru of the Andes mountain range. The flow was reported to be 1,215.80 m^3/s for the river Tambo. This flow was used to obtain the flood map of the valley. Subsequently, an earth dam has been designed to channel the flood. Finally, the flow of water was simulated again until the size and stability of the dam was adequate. The physiographic characteristics of the watershed were made with satellite geography and the GIS system. Probabilistic models and rainfall-runoff models were used for the frequency analysis. To simulate the flood, the two-dimensional differential equations of Saint-Venant were solved with the finite volume method; in order to do this, a net was made (networks), with the sizes of the cells being smaller than 5.0 m by 5.0 m, resulting in a total of 70,455 cells. In the flood zone, a direct topographic survey was carried out, along with measurements of other field data.

Keywords: river, simulation flooding, earth dam.

1 INTRODUCTION

According to the National Meteorology and Hydrology Service, summer seasons in the Andes Mountains are characterized by very intense rainfall [1]. In recent years these intensities have increased due to the effects of climate change. Water flows from peaks of more than 6,000 m above sea level to low valleys full of agricultural land, located at 205 m. above sea level, and generate floods in those valleys damaging agriculture and infrastructure.

The objective of this work was to simulate the flood for a maximum flow and for a set return period, design a dam to channel the simulated flood, and finally simulate the flow of water considering the proposed dam already built.

2 METHODOLOGY AND MATERIALS

2.1 Location of the study area

The study area is located in South America, specifically in the South of Peru in the department of Arequipa, in the sector of the Andes Mountain. Fig. 1 shows the high peaks of the mountain range to the shores of the Pacific Ocean.

2.2 Hydrology

As mention before, this zone is characterized by intense rains in the summer season, since it belongs to the high part of the Andes Mountain Range, where there are mountains with heights of more than 6000 meters above the sea. This zone is where rivers are born. As these

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rivers descend from the Andean mountain range, they converge to form higher order rivers. These higher order rivers cover several hundred kilometers and eventually flow into the Pacific Ocean.

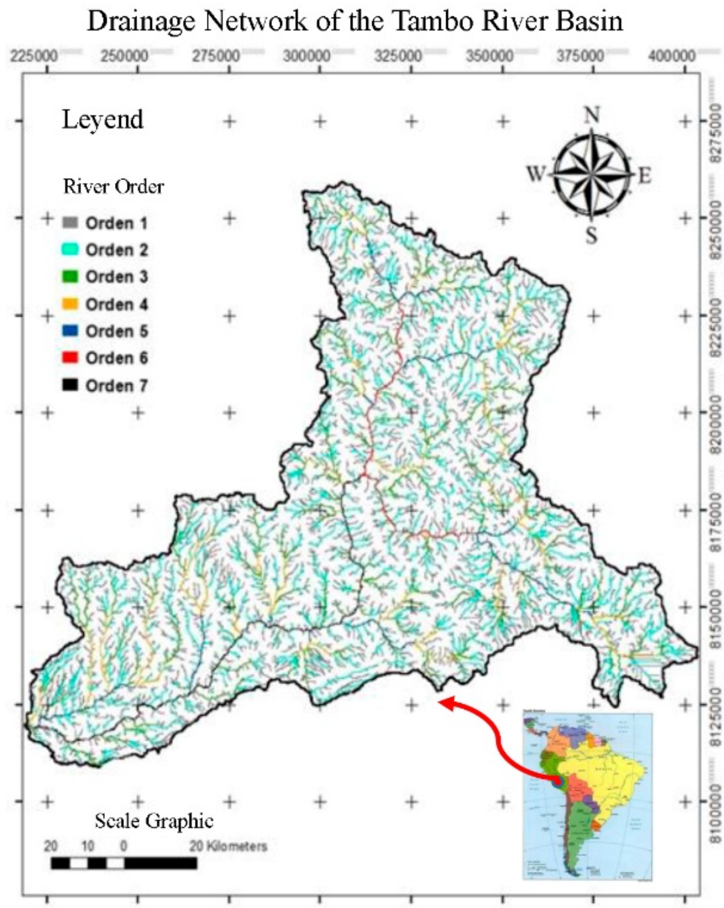

Figure 1: Location map of the study area.

The flood zone occurs in the lower part of the basin, starting at a 205 m elevation, where the river flow is large because the drainage basin is also large. The determination of the physiographic characteristics of the basin and its correct geographical location in UTM WGS84 coordinates was made with the satellite digital elevation system and later with the Geographic Information System (GIS).

The calculated values of the basin are area of the basin (11 838.58 km^2), perimeter of the basin (1 094.26 km), length of the main channel of the river (305 km), starting point of the area of flood 205 m [2].

2.2.1 Maximum design flow hygrogram

After defining the physiographic characteristics of the basin, the hydrograph, which is fundamental data for the simulation, was determined. In order to calculate this hydrograph, the concept of the model of "maximum rainfall of 24 hours" was considered (this is the only data that is available). To do this the basin was divided into 105 sub-basins and a hydrological simulation procedure was carried out, as well as the rain frequency analysis and probabilistic models of extreme events for the calculation of the flow.

In the study basin, there is a regulation dam called Pasto Grande, which was considered to determine the hydrograph.

To determine this hydrograph, a percentage of risk of failure of the hydraulic structure (channeling dam) was considered; in this case the value is 20%. Additionally, it was necessary to consider the expected life of the dike, in this case was 100 years, defined by Chow et al. [3]. A return period of 449 years was obtained, and this return period was used to determine the maximum flow which is reported to be 1,215.80 m3/s. The hydrograph is shown in Fig. 2.

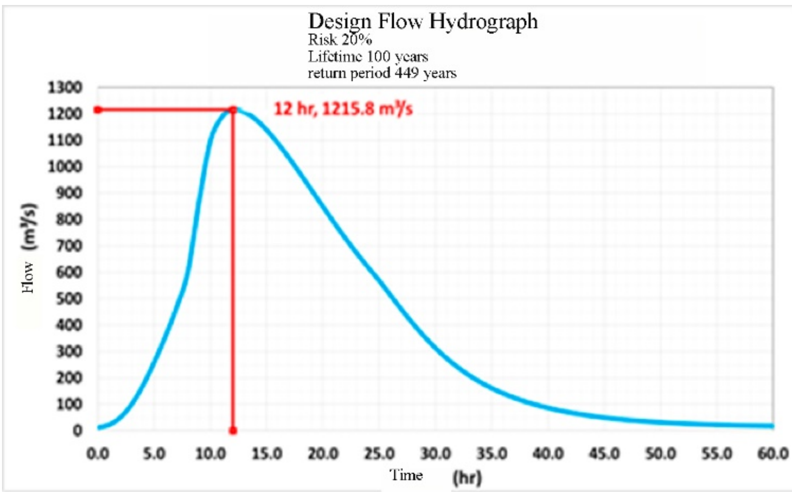

Figure 2: Hydrogram of maximum design flow is 1,215.80 m^3/s.

2.3 Governing equations

The basic equations that govern the flow of water on rivers are the equations of continuity and momentum of Saint-Venant two-dimensional defined in Chaudhry [4].

2.3.1 Continuity equations

The law of the conservation of mass of water flows is expressed using the equation of continuity as follows

$$\frac{\partial H}{\partial t} + h\frac{\partial u}{\partial x} + h\frac{\partial v}{\partial y} + q = 0, \tag{1}$$

where H: elevation of the surface free of water; h: water depth; u: velocity on the "x" axis; v: velocity on the "x" axis; t: time; q: infiltration in the riverbed.

2.3.2 Equations of movement amount

The second law of Newton for water flows can be expressed with the equations for the amount of movement in two-dimensional form; it is expressed for either the x or y axes.

The equation of momentum in the x-axis is as follows:

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = -g\frac{\partial H}{\partial x} + \nu_t\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) - c_f u + f v. \quad (2)$$

The equation of momentum in the y-axis is as follows:

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} = -g\frac{\partial H}{\partial y} + \nu_t\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) - c_f u + f u, \quad (3)$$

where c_f: coefficient of background stress; ν_t: kinematic viscosity of water; *f*: Coriolis coefficient. The two equations of movement amount consider: the viscous efforts of water, pressure, bottom resistance efforts, acceleration of gravity, as well as the effect of the rotation of the earth called the Coriolis effect. The bottom resistance effort is represented by the roughness coefficient of the channel of the river.

Eqns (1), (2) and (3) do not admit an analytical solution; consequently, these are solved with the finite volume method.

2.4 Coefficient of roughness of the river channel and floodplain

These roughness coefficients were taken directly from the river channel, considering the concepts of roughness proposed by Manning and defined by Chow [5], and taking into account: roughness of the bottom of the channel, resistance to flow due to vegetation, degree of sinuosity of the channel, irregularities of the channel, existing obstructions in the channel, etc. The concept proposed by Cowan was followed and the results can be seen in the map shown in Fig. 3. This data map is essential for the simulation.

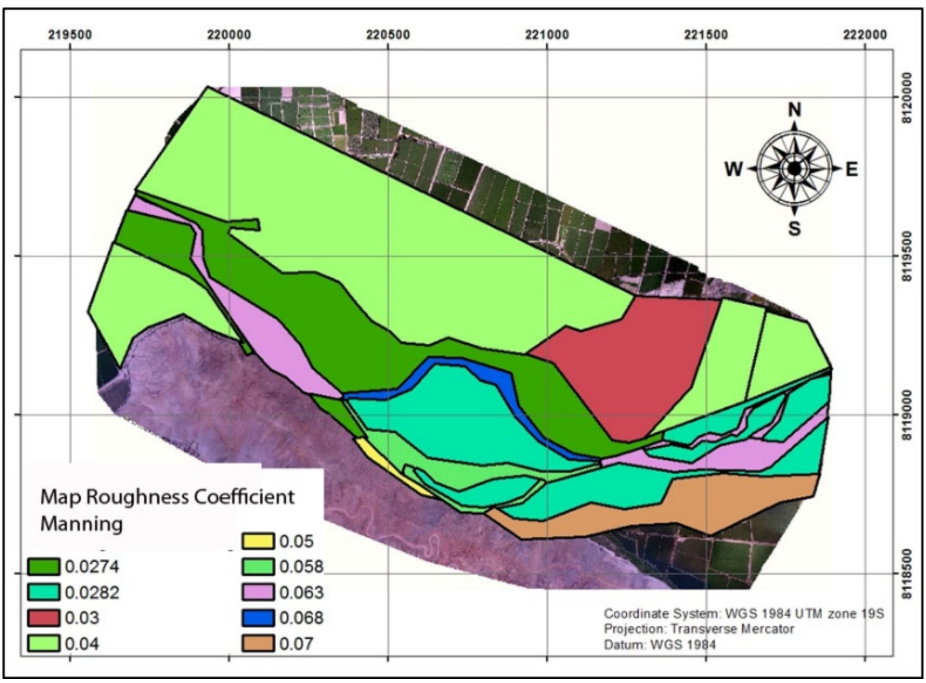

Figure 3: Manning roughness coefficient for the flood zone of the Tambo River, Arequipa, Peru.

3 RESULTS

3.1 Flood simulation of the plain

This simulation was carried out with specialized software that uses the finite volume method to solve eqns (1), (2), (3) (Chung [6], Anderson [7], Perez and Perez [8]) with border and initial conditions that where measured at the field. The computational step time in the flow modeling for two dimensions was based on the Courant number-Hec [9]. First, the digital terrain model was generated with a direct topographic field survey in UTM-WGS84 coordinates. Next, the Manning roughness coefficient map was considered for the river channel and the flood plains. Then the geometry or domain of the model was generated in structured nettings with the following characteristics: the netting dimensions $\Delta x = 5$ m and $\Delta y = 5$ m; the number of nettings/cells generated is 70.455; and the computational time step of Δt, 2 seconds. With these values, the conditions of the Courant number were met. Finally, the boundary and initial conditions were introduced, being the hydrograph upstream and the slope downstream. For the calibration process, a suitable section where the values of the hydraulic variables are as uniform as possible was chosen. The simulated values were compared with the values obtained with other methods until these values are similar. The results of the maps are shown in Fig. 4 and Fig. 5.

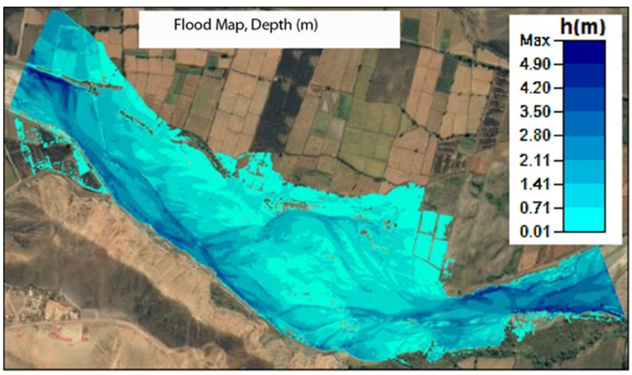

Figure 4: Depth result (m) of flood simulation for the maximum flow of 1,215.80 m^3/s.

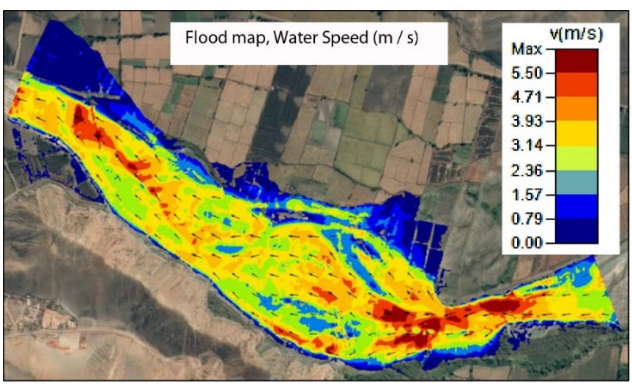

Figure 5: Velocity result (m/s) of flood simulation for the maximum flow of 1,215.8 m^3/s.

3.2 Design of the earth dam to channel the flow

In order to protect the floodplains of this valley from flooding, an earth dam was designed along the Tambo. To do this, the calculated design flow was used so that other hydraulic variables were determined, such as the depth of flow, speed in both directions, erosion and sedimentation. The stability of the dam was analyzed (Perez [10]). A representation of the dam is shown in Fig. 6.

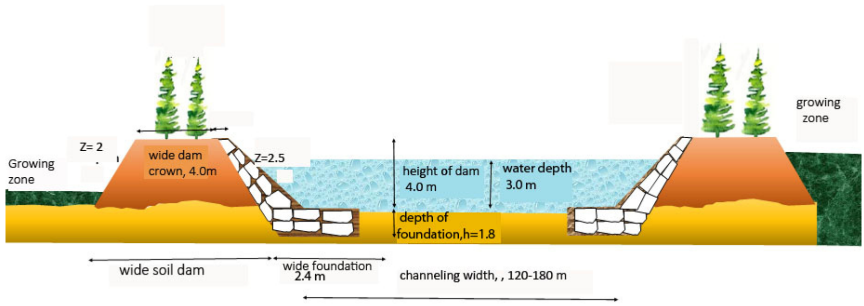

Figure 6: Diagram of cross section of channeling with earth dam.

Due to topographic conditions of the area like dam stability, erosion, etc., the dike height presents a value around 4 m, agreeing with values from previous simulations. Moreover, the width of the crown was set at 4 m with slopes of 1 m in vertical and 2 m in horizontal. Those values were established based on the material presented at the area and the stability of the dam. The general scour was determined with hydrodynamic simulation and compared with empirical methods (Graf [11]).

3.3 Simulation results with the proposed dam

After the proposed dimensions of the dam were implemented and the dam was designed with these improvements, the simulation was run again using the maximum flow reported above. Floods no longer occur in the agricultural lands and the dam does not collapse; Figs 7 and 8 show the results.

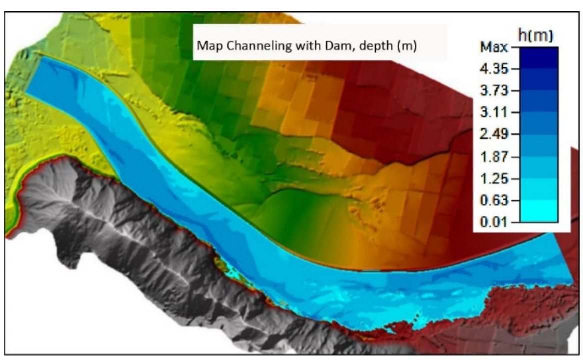

Figure 7: Result of simulation depth (m) after channeling, for a flow of 1215.80 m^3/s.

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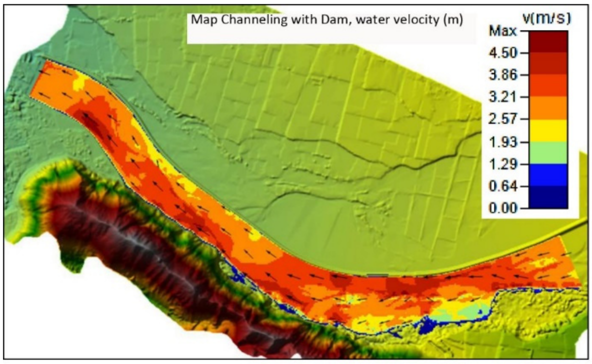

Figure 8: Simulation result of flow velocity (m/s) for flow 1,215.80 m^3/s after channeling.

4 CONCLUSIONS

The variations of rainfall intensities in the Andes Mountains in southern Peru are great, with rainfall records of more than 50 mm during 24 hours in the high peak areas, and rainfalls of 0 mm for a 24 hours range in the lower parts. When conducting the frequency analysis study, rainfall is much greater. The lower part of the watershed near the Pacific Ocean is arid; therefore, irrigation with upstream water is necessary. Hydrological and hydraulic simulations in the Andes Mountain range are challenging due to the lack of records of river flows. There are only limited rainfall records. Currently, a research for an area with extreme rains is being carried out in the Andean mountain range of Peru.

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PATH MODELLING ANALYSIS OF NATURAL RADIOACTIVITY IN DRINKING WATER AND PUBLIC HEALTH IMPACTS

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ABSTRACT

In 2015, the United Nations announced the Sustainable Development Goals, to achieve a better and more sustainable future for all by 2030 and promoting global attention about groundwater protection through Goal 6 (clean water and sanitation). The coefficient of determination of the structural model of total non-mineral water (n=72) is extremely low for radon contamination in groundwater (R^2=0.083). These results are not consistent because it is unlikely that all exogenous latent variables explain only less than 1% of radon contamination in groundwater. This discrepancy occurs because the total dataset is represented by several types of rocks with different radiological profiles. In this scenario, the complete dataset should not be singly applied in the structural equation modelling-partial least squares (SEM-PLS) model but somewhat separately in four lithological groups. From all studied lithologies, the structural model for Group V presents the highest coefficient of determination (R^2=0.987), mainly due to the application of hydraulic turnover time. This feature addition improves this contamination model and also confirms that the water of deeper circuits has a lower radon concentration due to its short half-life. Future studies tend to expand knowledge about other hydrogeological features that can effectively influence the radon transfer from rocks to drinking water, improving the contamination model of radon to develop a radon risk map. This study is crucial for policymakers because the radon contamination into the aquifer systems may raise concerns for the general public, requiring the continuous monitoring for the assessment of harmful health effects to humans caused by the radionuclide's exposure.

Keywords: radon, drinking water, SEM-PLS, harmful effects.

1 INTRODUCTION

Natural radioactivity from geological materials, in particular, the radon gas (^{222}Rn) exposure, is considered a risk factor for human health. Regarding exposure to radon gas, health impacts are strictly related to its stable progeny. When these solid isotopes aggregate to the environmental aerosols, can be inhaled and deposited in the epithelial lung's tissues, causing neoplasms. According to clean water goal from 2030 Agenda, several other targets were established with the purpose of water quality improvement, ensure the water-use efficiency, management, protection, and restoration of water resources. On the other hand, a study carried out by Martins et al. [1], alerts against the lack of the Portuguese Plan of Action for Radon or even the existence of any reference about the contamination of geogenic source in the Portuguese Water Plan. Radon contamination in drinking water is invisible to human sense, and as such, should be given particular attention when a high radioactive exposure in drinking water occurs. For a practical assessment of aquifer contamination risk, it is useful to establish a conceptual model that explains the production and transport of radon from rocks

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to drinking water [2]–[5]. For instance, when there is not mobilization of radon from rocks to water, it becomes crucial to understand which factors may be preventing this transfer process. Previous studies in fractured aquifer systems have reported that there is not a direct relationship between high-radon contents in rocks and the significant contamination of groundwater [2], [6], [7]. Then, how is it justified when in this comparison there is a high-radon production in rocks and a reduced radon concentration in groundwater? A study by Martins et al. [2] shows that a high-emanation or high-radon production in rocks may not always represent an efficient transport into the intergranular space and consequently an increased risk of groundwater contamination. For the assessment of the risk of groundwater contamination, it is crucial to conduct a survey about the connection between several factors that may increase the radon diffusion from rocks to the water such as, the weathering rate of U-bearing minerals under certain specific pH conditions [8]–[13], rock hydraulic diffusivity [14]–[16], and the emanation coefficient [17]. Several environmental studies used the structural equation modelling-partial least squares (SEM-PLS) models to establish common approaches in large flood management [18], ecological surveys [19], [20], and radiological impact in groundwater [2]. The application of cluster analysis with complex structural models was previously performed by Martins et al. [2] to study the effect of some factors on radon contamination in the aquifer system. This study aims to develop a simpler structural model, although much more robust than the previous one [2].

On the other hand, this study presents basic structural models considering only lithological grouping. The application of these structural models using the complete dataset, as a whole, was also ineffective as in Martins et al. [2]. This new approach is, therefore, crucial for the assessment of radon in aquifer systems, to prevent the radiological effects of radon exposure in drinking water consumers. The main purpose of this study is understanding the dynamics behavior of radon in aquifer systems using simple structural models that justify the presence of radioactive isotopes of geogenic source on drinking water. In addition, these radiological studies also alert policymakers about factors that enhance radiological contamination in water used for human consumption and facilitate the general public's awareness of this environmental problem by warning on the effects of exposure to ionizing radiation.

2 METHODOLOGY

2.1 Study area

The study area is located in the north of Portugal (Fig. 1) with a contrasting topography composed by lowlands, craggy reliefs, and nearby hillslopes. The geology of the study area is extremely complex, being represented by several types of granites and metasediments. The two-mica granites were separated into two different groups: one group with high-radon production potential and another with low-radon production potential. The biotitic granites were divided from the remaining granites by their installation age. This division, based on the geochronology and radiological profile, become crucial for SEM-PLS analysis.

2.2 Conceptual model of radon contamination risk

For the development of structural equation models, the six steps depicted in Fig. 2 describes the methodology used. The study area was selected based on an excellent cartographic representation of the lithologies of the Portuguese territory (Step 1). As in Martins et al. [2], when structural models were used for the overall data (Step 2), the R^2 is not significant. Thus, all data collected were grouped into four clusters. Therefore, these clusters represent the main geological units of the study area and its potential to produce radon (Step 3). After the building of the data matrix (Step 4), the structural models (Step 5) were developed according to the conceptual model depicted in Fig. 3.

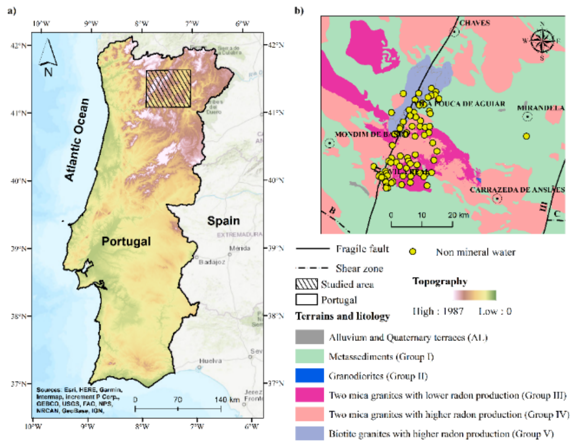

Figure 1: Location, geological units, topography and drainage network of the study area. (a) Digital elevation/drainage network models; (b) |Simplified geological map based on the geological map of Portugal, scale 1:500,000 and 1:50,000, available at LNEG [21] and Gomes et al. [22]. The tectonic structures were drawn from Dias et al. [23], being identified as ductile shear zones (B – Vigo-Régua) or fragile faults (II-Penacova-Régua-verín; III-Vilariça).

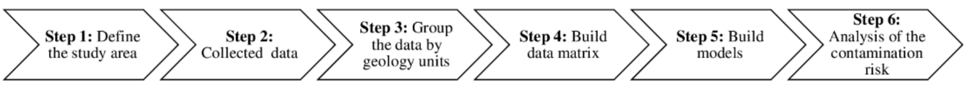

Figure 2: Methodology steps for the model of radon contamination risk.

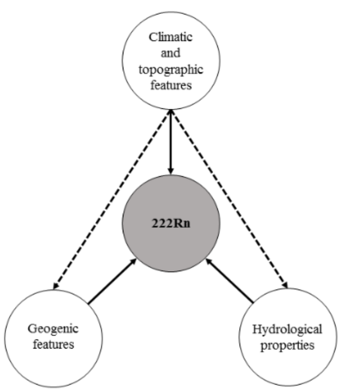

Figure 3: Conceptual model of radon contamination risk in drinking water.

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The geogenic features are essential to define the radiogenic profile of several lithologies for the entire region under study. Being a radioactive gas with origin in the decay series of uranium (^{238}U), forming from the disintegration of ^{226}Ra, it is natural, therefore, that radon distribution is conditioned primarily to the radioactive element that initiates the chain. Uranium is widely distributed in mineralogical substrates, although it is more abundant in igneous rocks. In the subsoil, when the primary mineral-bearing uranium is subject to weathering, the chemical element is transported from the host mineral and precipitate into fractures and microfractures, on the mineral surface, or even be mobilized through groundwater flows. Depending on the specific circumstances of each study area, the radon contamination risk (^{222}Rn) may be influenced by the geogenic, climatic, topographic features, and hydrological properties. A primary constructor (black arrows) was developed to understand the interaction between each of these systems and to show the impact of these three crucial latent variables on the radon contamination in drinking water (Fig. 3). However, it is also essential to generate a secondary construct (dashed black arrows) to demonstrate the impact of climatic and topographic features in hydrological properties and geogenic features (Fig. 3).

For the geogenic features (Fig. 3), five measured variables that describe the radon production capacity from rocks to interconnected rock pores were used. Pereira et al. [24] widely describe the radon production potential methodology. The isotopes K_2O, U, and Th were analyzed by gamma spectrometry with thallium-activated sodium iodide detector (NaI(Tl)) and 3-inch diameter, branded ORTEC. A total of 72 springs and boreholes used for water supply was sampled for radon analysis and hydrological properties. Martins et al. [2] give a more detailed description of the gamma spectrometry methodology and radon analysis used. The hydrological properties define the physical-chemical conditions of drinking-water (electric conductivity, temperature, and pH) and the time of water-rock interaction (hydraulic turnover time). However, due to financial difficulties was not at all possible to evaluate the hydraulic turnover time for all the collected sites. A combination of streamflow discharge rate (Q, Q, m^3/s) and a_1 and a_3 constants extracted from a scatter plot of $\ln(\Delta Q/\Delta t)$ *versus* ln(Q) was developed to estimate the hydraulic turnover time (t,s) as proposed by Pacheco [25]:

$$t = \frac{1.98}{Q\sqrt{a1a3}} \qquad (1)$$

The a_1 and a_3 constants were taken by intercepting y values with straight lines with slope 1 and 3, representing the lower envelope to the scatter points. The streamflow discharge rate and a_1, a_3 constants, only used for Group V structural model, were removed from Pacheco and Van der Weijden [15]. The climatic and topographic features may also contribute to radon dilution, being represented by two variables: the altitude and precipitation.

2.3 SEM-PLS

The Structural Equation Modelling-Partial Least Squares (SEM-PLS) technique was applied using the SmartPLS. SmartPLS is a prominent software application, gaining popularity since its launch in 2005 [26]. As well as being visually appealing software and freely available to research community across the globe, it has also a simple user-interface with an advanced report on the analytical depth of SEM-PLS.

After the compilation of all dataset, for each lithological group, a matrix was built, where columns are variables and each row is a water collection point. All variables were used respecting the multicollinearity rules (Pearson correlation coefficient <0.8 and VIF <5) [27].

In SEM-PLS the latent variables (LV) represented by the blue circles of Fig. 4 are considered the operators, according to the conceptual model of radon contamination risk in drinking water. Otherwise, the measured variables (MV) represented in Fig. 4 by yellow squares are the collected variables that explain the latent variables. The SmartPLS was used to build four formative models. In the interactive procedure, the algorithm attributes weights (w) for MVs and path coefficients (pc) for LVs, to achieve for each LV the highest determination coefficient (R^2). This algorithm also calculates a measured score for LVs, based on the MVs (eqn 2). On the other hand, for LVs that are composed by other LVs, the Smart PLS calculated a predicted score (eqn 3)

$$LV_j = \sum_{i-1}^{n}(MV_i \times W_i), \quad (2)$$

$$LV_{p,c} = LV_A \times pc_{ac} + LV_B \times pc_{bc}. \quad (3)$$

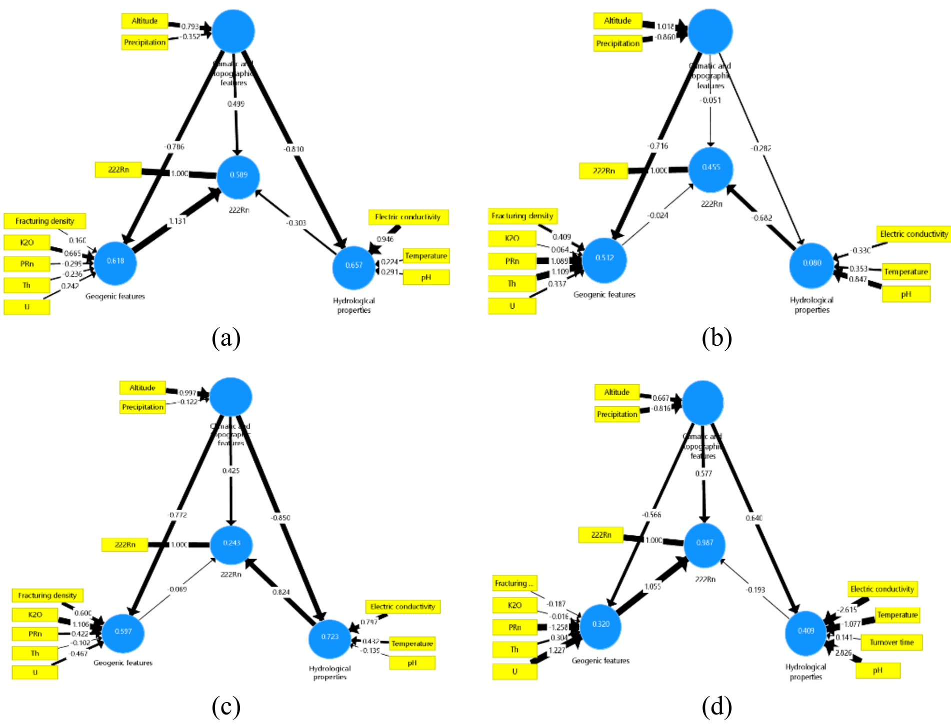

Figure 4: Diagrammatic representation of path models for different lithological groups that are outcrops in the studied region. (a) Group I; (b) Group III; (c) Group IV; and (d) Group V. ^{222}Rn-radon contamination in drinking water; PRn-Radon production potential in rocks.

3 RESULTS AND DISCUSSION

The determination coefficient of the structural model for the total dataset (n=72) was insignificant (R^2=0.083). For an independent check, this low determination coefficient shows that all exogenous latent variables (geogenic, climatic and topographic features, and hydrological properties) explain only less than 1% of radon contamination in groundwater.

When the SEM-PLS is simultaneously applied to all lithologies, this same discrepancy is verified, as in Martins et al. [2]. This weak path model occurs because the radiological profile of all lithologies is quite distinct. In this scenario, the total dataset was grouped according to the geochronology and radiological profile of each lithological type. To develop more reliable path models, a multicollinearity test was carried out among the several measured variables. When R-squared for a formative factor is less than 0.80, the multicollinearity is not a problem by the criteria of VIF>5 (Fig. 4(a) and (c); Table 1 [28]). The results of this reliable model are depicted in Table 1, which shows that there is not a multicollinearity problem because the variance inflation factors (VIF) slightly exceeds 5.

Table 1: Inner VIF values for the studied models.

		^{222}Rn	Geogenic features	Hydrological properties
Group I	Climatic and topographic features	5.389	1.000	1.000
	Geogenic features	2.723		
	Hydrological properties	3.030		
Group III	Climatic and topographic features	2.080	1.000	1.000
	Geogenic features	2.077		
	Hydrological properties	1.010		
Group IV	Climatic and topographic features	5.509	1.000	1.000
	Geogenic features	2.503		
	Hydrological properties	3.644		
Group V	Climatic and topographic features	2.117	1.000	1.000
	Geogenic features	2.869		
	Hydrological properties	4.495		

In the first group composed by metasediments, the structural model for radon contamination in groundwater is moderate (R^2=0.589; Fig. 4(a)). It means, therefore, that the combination of three latent variables is responsible for almost 60% of radon concentration in drinking water. A more comprehensive analysis of this structural model shows that the collection sites with the highest concentration of radon are located in areas with higher altitude (w×pc=0.793×0.499; Fig. 4(a)). However, the precipitation has an inverse effect, because the high precipitation causes a lower radon concentration in the water (w×pc=-0.352×0.499). This model clearly shows the dilutive behavior of rainwater in radon concentration.

On the other hand, these climatic and topographic features harm the geogenic factors and the hydrological properties (pc=-0.786 and pc=-0.810, respectively). In general, the geogenic construct plays the main role in radon contamination for the metasedimentary lithologies (Fig. 4(a)). The structural model of two-mica granites with lower radon production (PRn) presents a moderate coefficient of determination (R^2=0.455; Fig. 4(b)). It means, therefore, that the exogenous latent variables explain almost 50% of this radon contamination in water used for human consumption. The thorium (Th) and the radon production potential (PRn) have a substantial impact on the geogenic features (w=1.109 and w=1.089, respectively). In the hydrological properties, the pH is highlighted from the other features (w=0.847); Fig. 4(b)). Despite the R^2 for this structural model becoming insignificant (R^2=0.080), it has a significant negative impact on radon contamination (pc=-0.682; Fig. 4(b)). It should also be noted that the geogenic, climatic, and topographic features almost do not influence the radon contamination in the water (pc=-0.024 and pc=-0.051; Fig. 4(b)).

Unlike the previous structural models, the algorithm for two-mica granites with high-radon production computed a weak coefficient of determination (R^2=0.243). It is an acceptable R^2, although it is difficult to provide for this work other measured variables that improve this structural model. This weak-developed path model explains only 24% of total radon contamination in groundwater. Nonetheless, it is important to highlight the great influence of hydrological properties on the radiogenic contamination of drinking water (pc=0.824; Fig. 4(c)). The K_2O, fracturing density, altitude and electric conductivity was the key target constructs for latent variables geogenic, climatic and topographic features, and hydrological properties, respectively (w=1.106; w=0.997; w=0.600; w=0.797; Fig. 4(c)). The model path of group V was effectively the most robust of all because it represents the major contribution of geogenic, climatic, and topographic features (K^2=0.987) into radon transfer for water (Fig. 4(d)). In this scenario, the radon production potential acquires a negative effect on geogenic features and consequently to the radon contamination in drinking water (w×pc=-1.258×1.055). On the other hand, for springs with extended hydraulic turnover time, there is a reduced transfer of radon (w×pc=0.141×(-0.193); Fig. 4(d)). It should also be noted that a simulation was performed without the inclusion of the hydraulic turnover time. The results clearly show a decrease in the coefficient of determination (R^2=0.840). This insertion was representing, therefore, a high R^2 in the radon contamination, being explained by all of the exogenous constructs linked to it (Fig. 4(d)). The R^2 is calculated as the squared correlation between specific endogenous constructs actual and predicted values. According to these results, it would be beneficial to apply the flow rate and hydraulic turnover time in these structural models with reduced R^2. Currently, due to lack of funds, it is not possible to do this type of analysis at all. In future studies, it is expected that these works will be accomplished, among others.

A radar mesh was developed to present the summary of all constructs generated by SmartPLS software. In Fig. 5(a) the summary constructs comprise three segments used for primary constructs (non-shaded area) and two other sections of a secondary construct (shaded area). An overview of these results shows that in the primary construct, the model path of Groups I and IV almost overlap for all coefficient paths. It means, therefore, that these two groups overlap in the primary construct of the radon contamination in water because the radon transfer to drinking water was affected equally by the same latent variables. Nevertheless, the path model of group V provides a functional overlap between predicted and measured scores (R^2=0.987), while the group I produce a predicted value that is almost half of measured scores (R^2=0.589; Fig. 5(b)). In these circumstances, for a realistic comparison between these groups, other measured variables should be included in the constructs of Group I to improve the model.

In the primary constructs of Group III, there are more reduced path coefficients than in all other groups. Moreover, in Group IV, the hydrological properties have a more significant impact on radon contamination in drinking water than in all other groups (Fig. 5(a)). For an independent check, the geogenic features have a more significant impact on groups I and V, mainly due to the high positive effects of U (w=1.227) in group V, and K_2O for Group I (w=0.665; Figs. 4(a), (b); Fig. 5(b)). In general, in such different geological contexts, the effect of all these measured variables on radon contamination in water may be similar or different, i.e., there is no single rule that explains radon contamination in water. This complex system that explains radon contamination in drinking water can be applied to other areas, although with other parameters applicable to the topographic, climatic, geological, and hydrogeological contexts, among others in the study area.

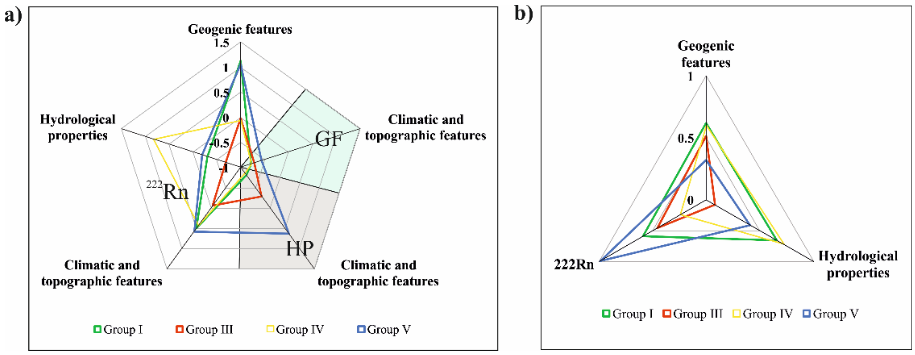

Figure 5: Summary of all path models computed by algorithm PLS-SEM. (a) Path coefficients with positive and negative effects for all studied lithological groups; and (b) Coefficient of determination for latent variables. ^{222}Rn is the radon contamination in water; GF is the climatic and topographic effect in the geogenic features; HP is the climatic and topographic effect in hydrological properties.

4 CONCLUSIONS

The entire radon transfer system from rocks to water and the processes involved are extremely complex. The application of algorithm PLS-SEM to the study area proved to be efficient and supports the knowledge about the features can influence the radon contamination in drinking water. The path model of several lithological groups under study indicates the well-predicted variables of the construct. Thus, in the path model of Group V, almost 100% of the primary construct is explained by the indicators, representing a higher level of predictive accuracy. On the other hand, for a secondary construct of groups I and IV, the climatic and topographic features present a noticeable negative effect in geogenic and hydrological processes. Therefore, when using this new methodology of path modeling in the analysis of radon contamination in water, we can anticipate that in similar geological contexts, there may be different concentrations of radon in water and vice versa. This means that the geological context alone is not preponderant for radiological contamination in water. Therefore, depending on the geological setting, the several processes of water-rock interaction, the physicochemical properties of the water, the climatic and topographic conditions together with the hydraulic turnover time have different performance in the radon transfer to the water. This work clearly shows that this innovative method should not be applied generically in several regions with similar geological context, as these areas may have different risks of contamination and consequent harmful radiological exposure to human health. Thus, this advanced tool can be useful to explain the contamination risk of regional scope in water used for human consumption. This study also alerts to the importance of hydraulic turnover time in the transfer of radon to drinking water. This concern is more pertinent because the Sustainable Development Goals of 2030 Agenda alert the policy-makers to the implementation of mitigation measures in anomalous springs, thus promoting safe water intake within the pre-established deadline.

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WASTE MANAGEMENT STUDY IN THE LAKE BUHI PERIPHERY, BUHI, CAMARINES SUR, PHILIPPINES

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ABSTRACT
Piggery and solid wastes monitoring was undertaken along ten (10) lakeside areas namely : Sta. Elena, Sta. Clara, San Buena, Tambo, Cabatuan, Ibayugan, Salvacion, Iraya, Ipil and Sta. Cruz of Lake Buhi in Buhi, Camarines Sur, Philippines. Key findings include: (1) a total of 331 pigpens (with an average of two heads per pigsty) proliferate the lakeshore; (2) piggery wastes are intentionally washed directly into the lake through flushing; (3) estimated volume of wastes produced is 2,019 L/day with corresponding organic loading of 0.05 mg/L which is far below the tolerable limits of 5 mg/L for class C water or lakewater; and (4) presence of municipal ordinance No. 03040 provides a framework for regulating piggery and other wastes. The findings suggest that wastes from piggery alone cannot be generalized as culprit for water pollution. This is validated by water quality monitoring quarterly report of the Department of Environment and Natural Resources (DENR) which reflects that water conforms to the standard set in terms of Biological Oxygen Demand (BOD) and other significant parameters. While it is true that nature has a self-purification process, however, if not given due attention, piggery wastes may have significant cumulative impact on the lake. However, to ensure the health of the lake and conserve the environment, the following is suggested: (1) aggressive and continuous implementation of above-mentioned ordinance; (2) initiate charging of environmental user fees system (EUFS) especially for major fish cage operators as contributors to lake eutrophication due to fish feeds overload in the course of rehabilitating the lake based on the organic loading (Polluter Pays Principle); (3) pollution prevention/cleaner production (P2/CP) options by establishing biogas systems and composting methods may be considered; and (4) strengthen integrated watershed management practices among stakeholders.
Keywords: waste management, piggery wastes, solid wastes, lake management.

1 INTRODUCTION

Solid waste is a waste type that includes predominantly household wastes (domestic wastes) with sometimes the addition of commercial wastes collected by a municipality within a given area. They are either solid or semisolid in form and generally exclude industrial hazardous wastes.

Sadly, lakes are not spared from being a dumping ground for these solid wastes especially domestic wastes arising from animal production, thus, resulting to poor water quality.

To date, few of the Philippine lakes have been classified according to their water quality. Of the fifty-six (56) lakes monitored by Environmental Management Bureau offices, only three (3) have been officially classified: Lake Lanao, Lake Nauja and Lake Taal. All are classified as Class B. The largest lake in the country, Laguna de Bay, has not been officially classified.

Lake Buhi is the lake under study and is found in Buhi, Camarines Sur. It has an area of 18 km^2 and has an average depth of 8 m. The lake lies in the valley formed by two ancient volcanoes, Mt. Asog and Mt. Malinao. The lake was created in 1641, when an earthquake caused a side of Mt. Asog to collapse. The resulting landslide created a natural dam that blocked the flow of nearby streams. Another theory suggests that it was created by the eruption of Mt. Asog, which is now dormant [1].

The lake is famous since it is one of the few bodies of water that contain the sinarapan (*Mistichthys luzonensis*) which is the world's smallest commercially harvested fish.

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To this day, it has been declared Water Quality Management Area (WQMA) by Department of Environment and Natural Resources. As such, interventions should be geared towards the protection and conservation of the lake as a significant body of water.

2 METHODOLOGY

2.1 Description of study site

The study site included ten (10) barangays in the periphery of the Lake Buhi, namely; Sta. Elena, Sta. Clara, San Buena, Tambo, Cabatuan, Ibayugan, Salvacion, Iraya, Ipil and Sta. Cruz.

2.2 Data collection

Primary and secondary data were collected for the study.

Primary data pertains to the perspectives and experiences of residents in the lake periphery, and other primary actors in the field, who are implementers “or receivers” of the laws and policies.

Primary data collection was done through conversational interviews, key informant interviews and focus group discussions. The data gathered focused on the community members’ awareness of the various policies.

Secondary data gathering was carried out through document analysis.

2.3 Method of analysis

This study mainly involved quantitative and qualitative data analyses. Whenever necessary and depending on availability, supporting data are presented in tabular forms, using frequencies and percentages.

Module of Philippine Agricultural Engineering Standards (PAES 414-1:2002 for Waste Management Structures for Agricultural Liquid and Solid Wastes) was used as yardstick for the volume of wastes generated by pigs and the corresponding organic loading or Biological Organic Demand equivalent.

The volume of wastes generated was calculated using the PAES formula:

$$\text{Volume} = \text{manure production, l/day} \times \text{total number of pigs.}$$

Volume of solid wastes generated based on per capita wastes generation was estimated using the following formula:

$$\text{Volume of solid wastes generated} = \text{per capita waste generation rate} \times \text{total population.}$$

2.4 Profile of respondents and key informants from the study sites

Majority of the respondents and key informants were barangay officials from the ten (10) lakeside barangays and heads of agencies like the Department of Agriculture, Department of Environment and Natural Resources, Municipal Health Office, Municipal Planning and Sanitation Office.

2.5 Scope and delimitations

This study focused on piggery wastes generation and management. It also attempted to consider other solid wastes but was limited to identifying common solid wastes found in tributaries which ultimately led to the vast open area of the lake.

3 RESULTS AND DISCUSSION

Piggery pens dotted the lakeshore of Buhi Lake in Buhi, Camarines Sur as shown in Fig. 1. The figure revealed that most pigpens operators construct their piggery structure along the periphery of the lake for obvious reason that wastes is just being flushed into the lake. Sometimes lakewater itself was used to flush wastes into the lake. Thus, water is accessible for cleaning purposes.

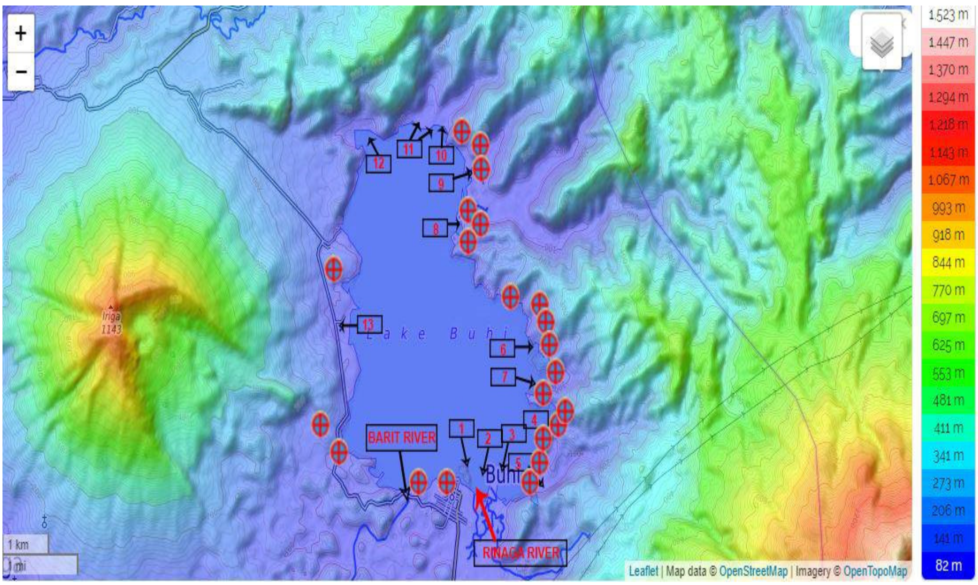

Figure 1: Map of pigpens along the lakeshore of Buhi Lake.

3.1 Category of production

Typically, for family-owned operations, each pigpen contains an average of two heads. Thus, it is considered as backyard category. Backyard production is set for less than 20 heads of swine [2]. This is validated by a report by Department of Agriculture that in the hog industry, 77% of hog inventories remain in backyard production system [3].

Pigpens commonly consist of makeshift open-sided buildings made up of nipa shingles roof and bamboo sidings. Others have corrugated G.I. sheets and CHB wall. All pigpens are placed on concrete slabs.

Commonly made of two cubicles, each pigpen measures 2 m x 3 m which is partitioned symmetrically with bamboo fence.

Farmers typically clean out these facilities by flushing the floor manually with water. The clean-out water is then discharged directly into the lake as slurry.

Table 1: Piggery production on lake periphery.

Barangay	No. of pigpens	Category of production	Type of wastes	Waste disposal	Type of housing
Sta. Elena	15	Backyard	Slurry	flushing	Makeshift; concrete floor
Sta. Clara	20	Backyard	Slurry	flushing	Makeshift; concrete floor
San Buena	45	Backyard	Slurry	flushing	Makeshift; concrete floor
Tambo	40	Backyard	Slurry	flushing	Makeshift; concrete floor
Cabatuan	30	Backyard	Slurry	flushing	Makeshift; concrete floor
Ibayugan	47	Backyard	Slurry	flushing	Makeshift; concrete floor
Salvacion	28	Backyard	Slurry	flushing	Makeshift; concrete floor
Iraya	40	Backyard	Slurry	flushing	Makeshift; concrete floor
Ipil	39	Backyard	Slurry	flushing	Makeshift; concrete floor
Sta. Cruz	27	Backyard	Slurry	flushing	Makeshift; concrete floor
	331				

Raising pigs is a means of supplementing family's income and a quick way to make extra money. Likewise, pigs are raised in anticipation for fiesta celebration.

3.2 Type of wastes generated

Pigs generate waste about 5% of their body weight. The waste consists of 65% faeces and 35% urine. Thus, the combined faeces and urine makes up the slurry. Slurry is high in organic content [4]. Organic wastes are recycled into nutrients that can nourish the tiny forms of life that fed the fish. However, when discharged to water in large quantities, they compete with dissolved oxygen in the process of decomposition. Oxygen is consumed by the decaying matter making the water uninhabitable by fish.

Likewise, pig manure is also high in nitrates and phosphates which may contribute to cultural eutrophication. Eutrophication comes from the Greek word "eutrophos" which means "well nourished". Thus, cultural eutrophication means the over-nourishment of the lake due to cultural practices of man [5].

In an over-nourished lake, too many water plants like water hyacinths and algae grow. These plants later envelope the surface of the water, hampering sunlight to penetrate deeper.

When this layer becomes too thick for light to penetrate, the deeper-lying plants and algae eventually die off and sink to the bottom in a thick brown soup. As a consequence, the lake may die.

3.3 Volume of wastes generated

The volume of wastes was estimated based on the Philippine Agricultural Engineering Standards. The estimated volume of wastes produced for all the pigpens along lakeshore is 2,019 L/day with corresponding organic loading of 0.05 mg/L [6] which is still far below the tolerable limits of 5 mg/L for class C water [7]. This means that the number of pigpens along the lakeshore is still within the carrying capacity of the lake.

3.4 Other wastes in the lake

It was also observed that petroleum products from navigational boats spillage coat the surface of the lake inhibiting the lake's oxygen intake. Hazards of catching fire may be inevitable, too, posing danger to human life.

Other wastes were also noted in lakeshore and nearby tributaries (Table 2). At the time of the gathering the data, it was noted that majority of the solid wastes were non-biodegradable, meaning they do not decompose in the environment, thus they need proper disposal and not in the lake itself.

Table 2: List of prominent solid wastes on lakeshore and tributaries.

	Category
Worn-out fish nets	Non-biodegradable
Pesticide container	Non-biodegradable
Old jeans	Non-biodegradable
Shells (bugitis)	Non-biodegradable
Worn-out rubber slippers	Non-biodegradable
Bath/Shampoo sachets	Non-biodegradable
Checheria food packs	Non-biodegradable
Plastic shopping bags	Non-biodegradable
Household items like plates, bowls	Non-biodegradable
Baby diapers	Non-biodegradable
Sacks (cement, fertilizer)	Non-biodegradable
Crude oil	Non-biodegradable
Dead fish	Biodegradable
Dead water lily	Biodegradable
Dead animals	Biodegradable
Animal/Human feces	Biodegradable
Kitchen wastes (banana peelings, vegetable trimmings)	Biodegradable
Dead algae	Biodegradable

The municipality of Buhi generates about 0.48 kg/day per capita [8] as per survey conducted by Save our Future Foundation in 2009. Thus, for the communities within the lake periphery with a total population of 28,255, it is estimated that about 13,562.4 kg/day solid wastes is generated.

Table 2 shows solid wastes generated, which are mostly non-biodegradable.

As an offshoot to Republic Act 9003, otherwise known as Ecological Solid Waste Management Act, Municipal Ordinance #03040 which instills to the people the practice of solid waste segregation to facilitate re-use, recycling and reduce the cost of collection and disposal of garbage. Also littering was prohibited to conserve the natural resources and avoid wasteful consumption of goods. This also limits hog production to only two heads per household with septic tank. However, there are still grey areas in the policy implementation which needs to be polished, thus, as of this publication, proliferation of wastes in the vicinity of the lake is still visible.

4 HIGHLIGHTS OF FINDINGS, CONCLUSION AND RECOMMENDATIONS

An investigation of the present state of the environment for Buhi Lake in Buhi, Camarines Sur, Philippines was undertaken. Locale of the study include ten (10) lakeshore barangays namely: Sta. Elena, Sta. Clara, San Buena, Tambo, Cabatuan, Ibayugan, Salvacion, Iraya, Ipil and Sta. Cruz.

4.1 Findings

Key findings are: (1) a total of 331 pigpens (with average of two heads per pigsty) proliferate the lakeshore; (2) piggery wastes are intentionally washed directly into the lake through flushing. (3) estimated volume of wastes produced is 2,019 L/day with corresponding organic loading of 0.05 mg/L which is far below the tolerable limits of 5 mg/L for class C [8] water and (4) Municipal ordinance No. 03040 is already in place which served as a policy for regulating piggery and other waste producing sources in the area.

4.2 Conclusion

The findings suggest that wastes from piggery alone cannot be generalized as culprit for water pollution. This is validated by Water Quality Monitoring Quarterly Report of DENR which reflects that water conforms to the standard set in terms of biological oxygen demand and other significant parameters. While it is true that nature has a self-purification process, however, if not given due attention, piggery wastes may have significant cumulative impact on the lake.

4.3 Recommendations

To ensure the health of the lake and conserve the environment, the following is suggested: (1) Implement aggressive and continuously pursue the implementation of the Municipal Ordinance # 03040 which instills to the people the practice of solid waste segregation to facilitate re-use, recycling and reduce the cost of collection and disposal of garbage. Also littering was prohibited to conserve the natural resources and avoid wasteful consumption of goods. This also limits hog production to only two heads per household with septic tank (2) Initiate charging of environmental user fees system (EUFS) for piggery owners and fish cage operators in the course of rehabilitating the lake based on the organic loading to the lake (Polluter Pays Principle) (3) Consider Pollution prevention/ cleaner production (P2/CP) options such as establishment of biogas systems and composting methods may be considered for piggery production, and (4) Strengthen integrated watershed management practices among key players in the area.

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Author index