Managing City Pipe Leaks through Community Participation Using a Web and Mobile Application in South Africa

Mpai Mokoena, Nsenda Lukumwena

Abstract—South Africa is one of the driest countries in the world and is facing a water crisis. In addition to inadequate infrastructure and poor planning, the country is experiencing high rates of water wastage due to pipe leaks. This study outlines the level of water wastage and develops a smart solution to efficiently manage and reduce the effects of pipe leaks, while monitoring the situation before and after fixing the pipe leaks. To understand the issue in depth, a literature review of journal papers and government reports was conducted. A questionnaire was designed and distributed to the general public. Additionally, the municipality office was contacted from a managerial perspective. The analysis from the study indicated that the majority of the citizens are aware of the water crisis and are willing to participate positively to decrease the level of water wasted. Furthermore, the response from the municipality acknowledged that more practical solutions are needed to reduce water wastage, and resources to attend to pipe leaks swiftly. Therefore, this paper proposes a specific solution for municipalities, local plumbers and citizens to minimize the effects of pipe leaks. The solution provides web and mobile application platforms to report and manage leaks swiftly. The solution is beneficial to the country in achieving water security and would promote a culture of responsibility toward water usage.

Keywords—Urban Distribution Networks, leak management, mobile application, responsible citizens, water crisis, water security.

I. INTRODUCTION

WATER is a valuable resource, essential to all living beings and a basic right. Unfortunately, it is regarded as a free natural resource and has been taken for granted and mismanaged for years. Despite the fact water is a free natural resource and a right to life, water should be protected and used responsibly. Instead, it has been poorly managed, worsened by a lack of understanding that water is not necessarily free from a consumer's perspective. Awareness and education need to be prioritized in this regard. Consumers need to be made aware of how much costs are incurred in water processing to be ready for supply including costs such as water treatments, storage, and infrastructure maintenance.

The world's population is increasing at a rapid rate, leading to increased water consumption, which negatively affects the water industry worldwide. It is critical that the world adjust its attitude towards water consumption, and this can be achieved through proper, inclusive planning and management of water resources. One of the biggest challenges in the water industry

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globally is water lost through leaking pipes in urban distribution networks, posing a threat to water security, and contributing to the increasingly unequal access to water and sanitation and sustainability. It is estimated that [1], "about 46 billion liters of drinking water are lost globally every day due to pipe leaks, water that can approximately serve nearly 200 million people [2]. Thus, securing urban water supply is crucial in order to accommodate the growing population in urban areas and to manage the increasing pressure on the scarce resource. Water issues are already visible in major cities globally due to increased population, and water issues are expected to grow from affecting 500 million people in 2000 to 1.9 billion in 2050 [3]. This is an indication that cities need to act quickly. Otherwise, it would be very difficult to supply water in the future, if water continues to be wasted at this rate, and not managed effectively.

South Africa is a water scarce country, facing high rates of water wastage. The water sector is affected by recurring droughts, insufficient water infrastructure, poor maintenance and management, increasing water demand due to increased urbanization and population growth. Pipe leakage is one of the major contributors to water issues that have been ravaging the country for years. It is reported that South Africa loses about 35% (1660 million m^3) of clean and drinkable water yearly, a hefty cost of over $70 million each year to the economy [4]. This paper recommends a solution that the South African government, plumbers and citizens can partake in solidarity to minimize the amount of water lost in urban distribution networks.

Pipe leaks contribute massively to the continued water crisis and affect the quality of water, access and the economy. Therefore, to minimize these effects, it is important to consider the involvement of plumbers, citizens and municipalities in order to achieve water sustainability and conservation. Given the rising penetration of the internet, the adoption of mobile and web applications is recommended. By adopting the above recommended involvement, which will help expedite the reports and attendance of pipe leaks by local plumbers. By doing so, the solution is likely to help the country to achieve its goals.

The paper is structured as follows: Section II outlines the South African water industry overview and policy framework. Section III covers the leakage overview. Section IV provides an overview of technical skills in the water industry. Section V highlights the importance of citizens' participation in water management and sustainability. Results and discussions are

discussed in Section VI. In Section VII, the proposed solution is discussed in depth. The last section presents the recommendations and conclusion to the study.

A. Research Aim

Research aim: To develop recommendations to deal with water wastage from pipe leaks in South African urban areas.

B. Objectives of the Research

- To outline water issues facing the South African water industry as a result of wastage;
- To propose collaboration between the government and private plumbers through the adoption of a mobile and web application created for that purpose; and,
- To propose community participation to conserve water, report pipe leaks and illegal water activities through a mobile and web application.

C. Methodology

A combination of fieldwork and literature review was conducted to highlight the water crisis in South Africa. The method allowed for more insights to be gathered and helped to acquire a body of knowledge needed for the recommendations. The qualitative method guided this study to gain an in-depth understanding of the water crisis in South Africa. Insights gathered are transformed into a practical solution to improve collaboration between the South African government, plumbers and citizens. As a result, a feasible solution, mobile and web application, is proposed to minimize water wastage and create a water responsible country.

The study is based on the assumption that one of the challenges facing the South African water sector is wastage as a result of leaking pipes. Additionally, preliminary reviews were conducted; the readings included research from other researchers and governments reports. Furthermore, the study is based on the assumption that efforts to attend to water leaks are limited in South African urban areas. Lastly, the study is working on the assumption that the citizen's role in reporting of leaks is minimal. Hence, citizen participation is an integral part of the solution.

Forty questionnaires were distributed and analyzed using Google forms. The participants were the general public (60%) and government officials (40%). The questions were based on the assumptions mentioned above. Additional questions were sent to the local municipality to get more insights from a water management perspective.

II. WATER SITUATION IN SOUTH AFRICA

Faced with various factors such as recurrent droughts, insufficient water infrastructure, limited number of skilled water engineers and poor planning [4], [5], South Africa is a semi-arid, water scarce country with an average rainfall of 450 mm per year, which is below the world average rainfall of 860 mm per year [6]. In the world rankings, South Africa ranks 30 out of 193 driest countries in the world [7]. The water crisis which began decades ago is not slowing down. The crisis worsens with the country's growing population of over 57

million, which is expected to grow to 62 million by 2020 [8]. It is also estimated that "water demand in South Africa will exceed supply by 2025" [9].

Currently, with a population of 57 million, it is reported that 14.1 million people do not have access to safe sanitation, while 1.98 million have infrastructure that is below standards, with only 64% of households (10.3 million households) having access to a reliable water supply service [4]. Furthermore, to maintain water supply for the next 10 years, [4], it is reported that the country will need to spend over $200 million each year.

The current supply of water in South Africa is mainly from four internationally shared rivers: Limpopo, Inkomati, Pongola and Orange Rivers, which accounts for 45% of the country's total river network [4]. South Africa has the total surface water available of 49,200 million m^3 per year, in which 4,800 million m^3 originates from Lesotho [10]. Despite the lack of proper maintenance and management, the country has a reasonable number of dams for water storage and security. There are about 5,000 registered dams and 3,832 small dams (less than 12 m) [4], enough to supply water to municipalities and farms.

Despite the scarcity of water, South Africans consume 233 liters per capita per day, which is above the global average of 180 liters per day [7]. It is clear that South Africans need to manage water resources and change their behavior towards water usage and compensate for the lack of water.

South Africa has achieved a lot in addressing the injustices, inequality of the past and improving the lives of its citizens. The achievements can be seen through an adequate supply of water and equal access. The South African National Water Act (No. 36 of 1998) was passed to ensure water supply throughout the country and is considered the best in the world. The Act is a framework that states water should be regulated, protected, managed and controlled in a sustainable manner [11]. Under the Act, the state has water ownership, with the Department of Water and Sanitation having authority [7]. It emphasizes the need for participatory processes at all levels.

The Act, which allowed for the expansion of water service provision, unfortunately, left negative results that could have been prevented. The water sector faced challenges resulting from poor planning, lack of maintenance and inadequate infrastructure. Lack of adequate technical skills to cope with expansion also played a role [11]. Water supply continues to be worsened by the increasing population and economic activities, with the country's economy largely depending on water. Agriculture, for example, consumes 61% of total water use, followed by municipal use of 27% (urban 24%, rural 3%), power generation, mining and bulk industrial use, livestock and conservation and afforestation using about 12% [4].

The existing water distribution system can no longer accommodate the growing demand. The declining and poor functioning water distribution system functioning has resulted in massive water and financial losses. The country needs a fresh outlook on managing and sustaining water, to ensure the continued supply of water that will not have devastating effects on economic growth and sanitation. Therefore, this

study recommends the inclusion of citizens in leak management to minimize the water that is lost.

III. LEAKAGE OVERVIEW IN SOUTH AFRICA

Despite having one of the best water frameworks in the world [11], the South African water sector saw increasing levels of leakage and non-revenue water and backlogs due to inefficiencies in the water distribution system. Municipalities having a high consumption rate of 27%, while 41% of its water does not generate revenue [4]. The sector is losing water at a high rate, posing a threat to the country's water security; 35% of South Africa's clean, drinkable water is lost through leaking and burst pipes. Leaking pipes can go for days or weeks without being reported or fixed.

South Africa needs a new approach to deal with water that is lost daily through leaking pipes in urban distribution networks. With demand already estimated to exceed supply in the coming years, the country would not be able to achieve water sustainability and security. Water would be expensive, unaffordable and inaccessible to the majority of the population.

In consulting with the municipality officers, it was indicated that the country has leak detection systems in place; the problem is, however, adequate skills. There are not enough plumbers and artisans to attend to leaks as quickly as possible from the public sector. Based on the limited number of plumbers, this paper brings in a smart solution which is the mobile application to locate the nearest plumber to the pipe leak, faster and efficiently. This smart solution in this paper helps identify the local plumbers from the private sector as well as to include them in the effort to attend to pipe leaks.

IV. INDUSTRY SKILLS CAPACITY OVERVIEW

Proper planning and infrastructure maintenance cannot be achieved without human capacity and technical skills. This has been the case of South Africa and has negatively impacted the sector for years. Both national and local authorities are unable to control and manage the leaks [12]. There are 230 municipalities in South Africa, and 79 have no civil engineers or technicians, while only 45 have civil engineers [13]. To address this lack of skills in the sector, the government introduced the "War on Leaks" program as part of the National Development Plan. The program was put forward in 2015 to manage and reduce non-revenue water. The program is set to train 15,000 unemployed youth yearly [15] and produce qualified water agents, artisans and plumbers by 2030 [14], [15]. The program aims to encourage a culture of conservation and cooperation between local communities and municipalities [16].

With high rates of lost water, it is unfortunate that the public sector and private sector work separately in leak attendance and management. As suggested above, using the proposed mobile application, both sectors would be able to work simultaneously in real-time in a monitored fashion. The private sector will contribute positively by adding the required skills needed to manage leaks and sustain water. The Institute of Plumbing of South Africa (IOPSA) for example, is a body that represents plumbers and plumbing organizations in the country [18]. The organization has a fair amount of numbers of plumbers and companies that can play a major role in minimizing and attending to pipe leaks. The organization has more than 765 plumbing companies, 3,500 qualified plumbers, and 10,000 semi-skilled persons working in the plumbing industry in the year 2008 [17].

V. CITIZEN PARTICIPATION

The amount of water wasted also reflects the attitude of citizens towards water usage, their willingness to report pipe leaks and illegal connections. Education and awareness need to be prioritized in planning and mitigating water loss. The more communities are involved, the more that they and cities will become sustainable and resilient to water-related issues. Citizens will have a better understanding of the challenges the country and industry are experiencing. A good understanding of risks and opportunities would develop as the results of being responsible citizens, who take pride in their communities. With a better understanding, citizens would be more accepting to new solutions, and willing to pay for services toward service provision and maintenance.

Citizen participation as described above is critical to fight water wastage. In order to increase their participation, this paper recommends the need for increased motivation through an incentivized system. However, the incentive system is not covered in this paper, but is a part of future works.

Citizen participation, if executed well, can be an effective tool in water management [19]. This paper recommends citizens participation through a mobile application to report leaks, get information on the state of the water industry, as well as improvements and updates. The platform will also allow for municipalities to communicate with the locals frequently regarding water-related issues.

VI. RESULTS AND DISCUSSIONS

The designed and distributed questionnaire had five sections. However, for the sake of this study, only findings from the three sections would be discussed. The first section to be discussed is the awareness section. Fig. 1 represents insights from the citizen's perspective regarding the wastage of water in the South African cities. In Fig. 1 (a), participants were asked to indicate their level of awareness regarding the amount of money and water the country is losing annually due to pipe leaks. Findings revealed that most of the participants were slightly aware. The response of those that were not aware is most alarming. Findings in Fig. 1 (b) also reveal the most worrying results. Citizens are not fully aware of the conservation methods that the country has taken to address water wastage.

Fig. 2 highlights awareness methods in relation to water wastage prevention. Fig. 2 (a) represents a variety of views regarding situational awareness in the country. The graph reveals the findings regarding which measures the citizens think should be considered to manage and sustain water

supply. The majority of the participants are in agreement with the effective monitoring of city pipes and more education and awareness following the conservation of water. As water is a basic human right, privatization of water was highly opposed to by the majority of the participants. With awareness created, in Fig. 2 (b), citizens were asked to indicate the importance of minimizing water loss through leaking pipes and illegal connections. The findings reveal that the majority consider minimizing water loss to be highly important through prevention.

Fig. 3 represents the third section of the paper findings, where participants were asked about their willingness to get involved in minimizing water loss. In Fig. 3 (a) participants were asked if they think the community's involvement produces better results in solving local problems. The findings reveal positive feedback. With the perceived positive community involvement, Fig. 3 (b) was about the willingness to report leaking pipes and illegal connections. The findings revealed that most of the participants are willing to take action and be part of the solution in minimizing the costs of water loss.
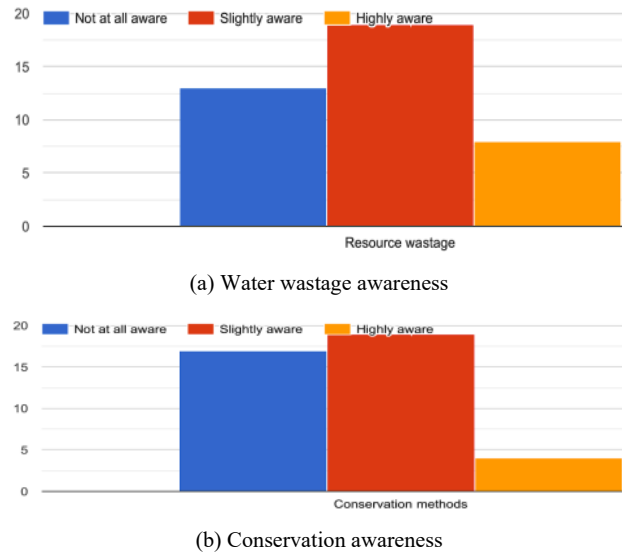
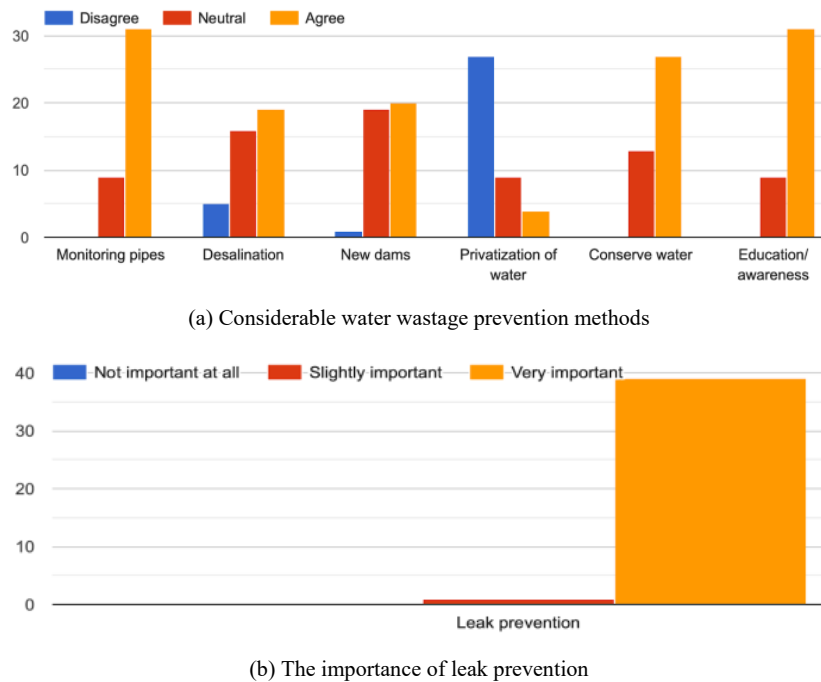

(a) Water wastage awareness

(b) Conservation awareness

Fig. 1 Citizen's water wastage and conservation awareness

(a) Considerable water wastage prevention methods

(b) The importance of leak prevention

Fig. 2 Water loss prevention

(a) The impact of community

(b) Community's willingness to participate
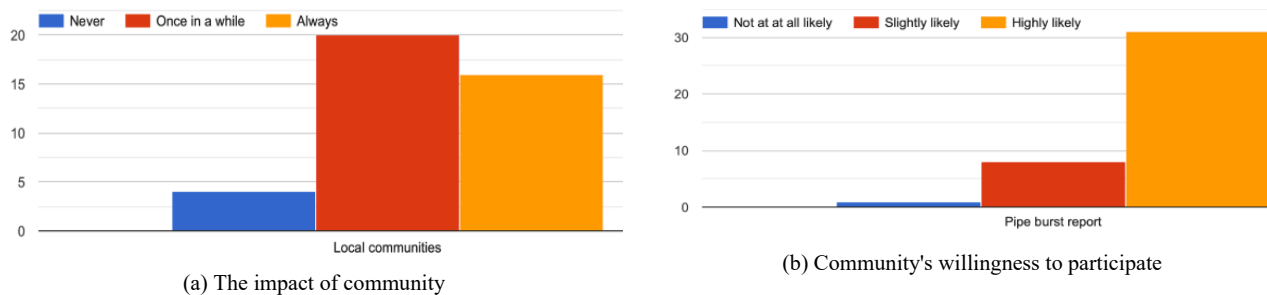
Fig. 3 The community role and willingness to report leaks
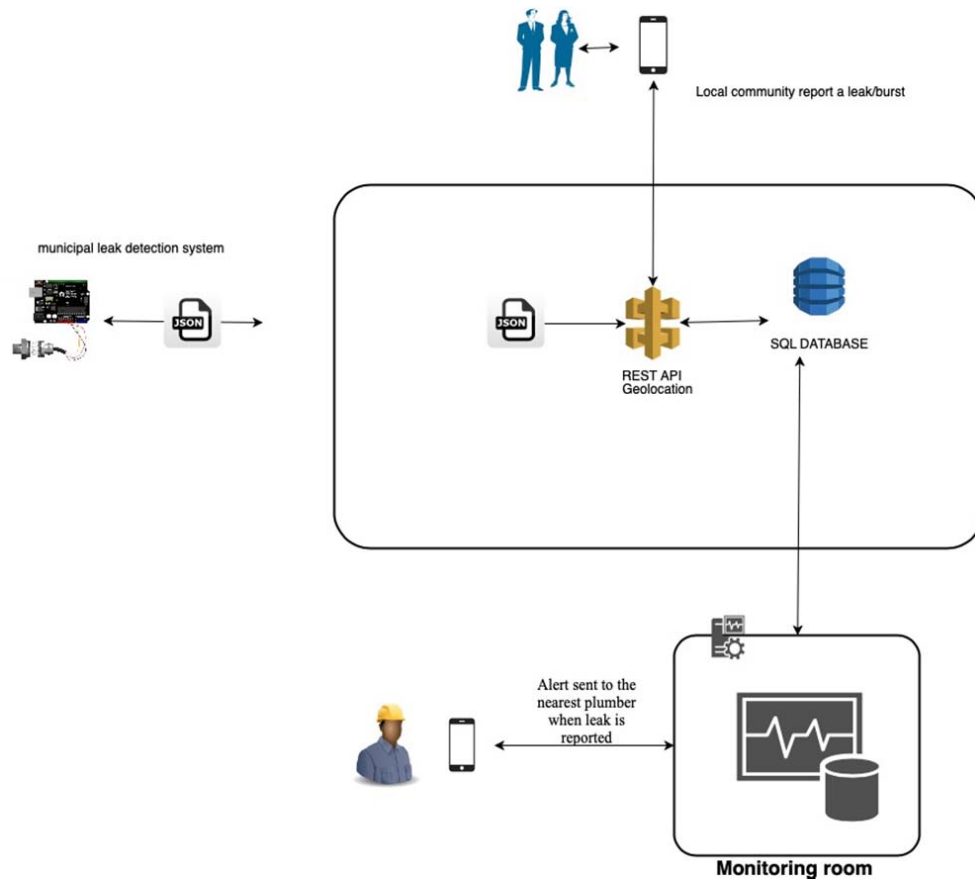
Fig. 4 The proposed system design

Questions	Municipal response
Current pipe leak detection methods	"Most leaks that are reported are visual in nature". "At present there is very little pro-active leak detection being performed, primarily due to resource challenges in the regional teams".
Frequency of pipe burst	"This varies substantially from region to region, but on average a total of 50,000 – 60,000 water leaks are repaired annually on the 11,500 km of water pipes in the city". "Almost every week".
System for reporting leaks and response time	"The current average response time for repairing a water leak in the city is 49% in 48 hours, which is substantially lower than in the past, and can primarily be attributed to resource challenges". "Regional response times also vary substantially".
Human capacity (available persons attending to leaks)	"There is an approximate shortage of 50% of staff in the various regions".

VII. THE PROPOSED SOLUTION

Fig. 4 illustrates the functionality of the proposed mobile and web application which has two parts, explained as follows:

1. A Web Application

a) Information from Water Distribution Networks (Pipes)

This part deals with receiving data from the current municipality system for leak detection. Noise leak detection is performed in specific cases where there is a certainty that leaks are present. The municipality also uses an advanced spatial infrastructure management query system. The system provides hydraulic information such as static and dynamic pressures, pipe flows and infrastructure elements from the pipe systems.

Data logging equipment is installed at various sites within the reticulation system to actively monitor critical pressures and flows, including reservoir levels. GSM-based systems and radio links are used to feed the information to a web-based system. Therefore, the system would be linked to the current municipal system, only present and visible leaks would be visualized on the new web platform for the general public.

b) Dashboard Visualization

The system emphasizes accessibility to expedite action to a leak location. As a result, *Geolocation APIs* (Application Program Interfaces) are widely adopted. *Google API* is used for data visualization, to create a simplified and interactive experience for the municipality and citizens. *MarkerCluster library* is used due to its capabilities to display a large number of markers on a map. It is used in combination with the *Maps JavaScript API,* to combine markers of close proximity into clusters and simplify the display of markers on the map.

Dash, a dashboard framework for *Python programming language* is integrated for graph data visualization. *Dash framework* is selected to update the graphs, displaying the status of pipe leaks that had been reported, and the plumber's progress. The underlying frameworks include *React, Plotly* (frontend), *Flask* (backend).

GeoJSON is used to import data reports from citizens and municipal system sources, and displayed on the visualization map.

The information would be updated constantly by the municipality. The municipality also oversees the registration and verification of plumbers in the system, which is a mandatory requirement.

2. A Mobile Application

Citizen participation is crucial, according to the municipality, most leaks reported are visual. A mobile application is therefore developed for plumbers and citizens. Citizens would use the application to report leaks, and plumbers use it to respond to requests from the municipality. A device-specific *Geolocation API* is integrated to identify the geographic location of a user's device. *Geolocation API* is useful for data collection services; it uses network routing addresses or internal GPS devices to determine the location.

Data from citizens would be retrieved using a *MySQL database* on a *Google Maps*, using the *Maps JavaScript API*. Data would be displayed on mobile and web platforms.

The municipality will use the system to send requests to plumbers to attend leaks. The *Places API* is preferred as it is suitable to query for place information on a variety of categories including geographic locations either by proximity or a text string. This *API* is critical for the municipalities to search for nearby plumbers based on the registered address information. It will return a list of plumber's place details based on proximity and availability.

A plumber would be required to update the leak status on-site and the response would be displayed on the web platform. This way, the system is encouraging transparency and urgency to attend leaks.

VIII. RECOMMENDATIONS AND CONCLUSION

The aim of this study was to highlight the water situation in South Africa and develop recommendations viable for the government and citizens to achieve water security, by minimizing water lost on a daily basis, and therefore annually. The proposed solution is to improve and expedite the response time and action to leaks. The proposed system hopes to engage citizens and encourage them to be responsible, by playing a crucial role in conserving water, and reporting leaks. Participants showed a willingness to get involved and report leaks. The study was not only able to provide an overview of water challenges, but it also managed to build greater awareness of the situation among citizens and to change their perspective.

On a broader level, the findings reveal the complexity of the water situation in South Africa. The situation goes beyond awareness and conservation, and world-class policy

frameworks. Due to limited human resources, this study proposes a feasible and effective solution. A smart solution that can deal with pipe leaks to minimize water and monetary losses.

The study proposes a mutual collaboration, engaging the government, private sector and citizens in responding to pipe leaks in urban network distributions, to be achieved through the use of mobile and web application created to manage report and attend to leaks swiftly. Simply put, the solution requires a minimum effort from both sides.

The recommended web-based solution, like in all other sectors, information and knowledge management plays an important role. Web-based platforms enable:

"…effective management, display, and retrieval of relevant information required by water managers/operators, urban planners, governments and the public all key factors to consider as part of urban water management" [20].

The integration of Web-based and mobile solutions enables effective communication, and connects more users at lower costs with minimal infrastructure required. The proposed system will enable the general public, plumbers and municipal offices to access relevant water information, providing visibility of the scale of current water that is lost through leaks in real-time. This way, associated activities are transparent, which helps in building trust, encouraging more citizens to get involved, and the plumbers and municipal officers to act as quickly as they can. As well, municipalities will have relevant information regarding leaks for decision making and planning going forward.

Managing leaks needs to be prioritized in order to achieve water security. This is crucial for the policy framework of 1998 to continue to serve its purpose and achieve the goals. This study emphasized the need for collaboration between the government, plumbers and citizens using cheaper mobile and Web technologies. Citizens and government need to realize the real value of water and efficient management of pipe leaks. To achieve this, the paper concludes that the adaptation of mobile and a Web application in reporting leaks is effective by working together to achieve the common goal of water security and continuation of the water supply.

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