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# Smart Water Leakage Detection and Metering Device

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**Abstract:** Water is a scarce and valuable resource hence proper management of this resource is essential for social and economic development of any country because it is an input to almost all production in key sectors like Agriculture, Industry, Energy and Transport. Smart devices have transformed nearly every aspect of our home and this paper is presenting a practical low-cost Smart Water Meter Device which is capable of determining possible leakages in the customer's property and reporting current household water consumption levels in real time. Flow meter sensors have been deployed to measure the quantity of water consumer by a consumer. In turn, the flow rates and the amount of litres consumed will be displayed on the LCD display and they will also be sent through the GSM/GPRS module to the website. The system has been efficiently and carefully designed to minimise commercial losses.

**Keywords:** smart water meter, water leakage detection, Arduino, flow meter sensor.

## 1. Introduction

South Africa is a semi-arid country with an average annual rainfall of approximately 492 millimetres a year with most water used for agriculture and irrigation (60%), environmental use (18%), urban and domestic use (11.5%) and mining and industrial use (10.5%) [1]. The main uses of water in domestic households are shown in Table 1. Domestic and industrial users can lose significant amounts of water due to undetected leaks. It is estimated that South Africa's nonrevenue water loss is approximately 37%, of which a quarter is considered to be losses through physical leakage [2]. Water leakages can result in high domestic and industrial water consumption rates. These leakages occur on a daily basis but they often unnoticed from the consumer’s side. A sudden increase in the consumer’s water consumption level can potentially create imbalances in the water pressures of the distribution system thus causing the department to spend money to meet a demand that is in actual fact caused by losses from the consumer’s side.

*Table 1: Water Use in Households [1]*

| | Low-Income | Mid to High-Income |
|---|---|---|
| Toilets | 73% | 37% |
| Baths & Showers | 19% | 32% |
| Washing Machine | N/A | 17% |
| Other e.g. cooking, washing dishes and clothes, drinking, etc. | 8% | 14% |

Commercial water loss has proven to be on the rise and the two major contributions have been billing errors and high water consumption [2]. Billing errors occur as a result of inaccurate water meter readings and at times due to a lack of man power to acquire the actual water consumption rates which leads to poor data handling. An increase in water consumption levels in many cases are caused by dripping taps, running toilets and pipe leakages [3]. These leakages in the long run could bring about pressure imbalances in the



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water distribution system. To restore the pressure balance in the water distribution system financial input for infrastructure is required to meet the increased water demand.

Current technologies used to keep track of the amount of water consumed by the consumer are the old analogue water meter readers. The department hires people to go house to house to take the readings from the water meter in order to issue the bill to the customer. This approach can result in infrequent monitoring of the water meters and inefficient systems to alert the department in real-time about any inconsistencies with the water meter readings. Inconsistencies bring about billing errors that may result in the customer paying an unrealistic bill or the department losing money over the errors.

This can also make it difficult to write accurate reports about the country's actual annual water consumption and losses. In most cases consumers do not like reading their analogue water meters; they mostly rely on the bill itself to see their monthly water consumption. Thus consumers have no system that would alert them of their daily water consumption or if any possible leakages around the house have occurred.

We propose the design of a smart water leakage detection and metering (SWLDM) device that is able to detect and alert both the department and customer of any possible leakages in the customer's property. A system to determine possible leaks and also report current household water consumption levels in real-time could potentially result in lower consumption rates and also provide early detection of any leakages such as dripping taps, pipe leakages and running toilets. It will also make it easier for the department to keep track of accurate water consumption levels as well as to enable the department to determine the efficiency of the water distribution system but most importantly solving the problem would help conserve the world's most precious resource.

## 2. Objectives

High water consumption due to running toilets, dripping taps and pipe leakages and billing errors are two of the major contributions to water commercial losses. In the attempt of solving the problem two sub-objectives were identified.

The first objective was to create a system that will automatically and continuously inform the consumer about the water consumption levels at their designated households and the system should be able to detect if there are any possible water leakages in the consumer's property.

The second objective is to develop a system that will send data of the consumer's water consumption levels to the water municipality for that area, for billing purposes and also to help determine the current water consumption of the area in real-time. Through these two sub objectives the aim is to decrease the water losses that contribute to the high water consumption and losses.

The SWLDM device must also be low-cost to ensure its commercial viability for large scale deployment as well as make it less vulnerable to possible theft. One of the device's abilities is notifying the consumer should there be any possible water leakages in the house thus the consumers would need to fulfil their part by attending to the alerts, otherwise the efficiency of the device might be questioned.

## 3. Methodology

As part of the methodology in designing the SWLDM device a review of exiting research activity in the current literature was undertaken, after which various design alternatives were considered before the optimum design was implemented and various experiments conducted to determine the design's efficacy. Reviewing related work provides us with a better understanding of the problem as well as allowing us to develop with better designs and solutions.



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Masia et al [5] conducted a survey to determine if there are policies and strategies in place to reduce Non-Revenue Water (NRW) loss at the municipalities in South Africa. A key outcome of the survey was that municipal officials agreed that the adoption of smart metering technology was critical to reduce NWR losses.

Britton et al [3] analysed water consumption in order to identify the types of water leakages and the cost of leak repair in a selected metered district area situated in Australia with an aid of a smart meter device. The system used commercial automated meter reading technology implemented by a water Company in Australia to collect the water consumption data. This device collects water flow data and records it in a memory flash drive which can be accessible through a USB port or through a drive by unit. The project results revealed the common sources of water leakages as running toilets, dripping taps and supply pipes (plastic, galvanized and copper pipes). The analysis provided a water use profile of the metered residential properties, the types of leaks encountered and the cost of leak repairs. The key difference in our proposed system is the real-time updating of water consumption levels through an Internet interface.

Mudumbe et al [6] developed a smart water meter system using ZigBee and open source software to monitor and report on water consumption. The key difference in this design is that the authors developed a meter interface node to obtain data from an existing digital water meter and then uses a wireless ZigBee node to transmit data to the gateway. No cost information of the final product is provided.

Most electronic equipment in South Africa is imported and thus prone to currency volatility. In the development of the SWLDM device all components were obtained from local electronics shops and the cost of components was a key design decision criterion.

## 4. Technology Description

Flow meter sensors can be used to measure the amount of water consumed by a consumer. Flow meters come in small sizes and can be fitted with water pipes if they adhere to the South African Bureau of Standards (SABS). The SWLDM device uses a water flow meter to measure water consumption. Water flow meters are designed to measure the flow rate of water passing through a point. These meters use a pinwheel attached to a tiny magnet, every time the pin wheel makes a full rotation, the Hall Effect magnetic sensor sends out a signal to a reader (Microcontroller) [8]. The microcontroller then converts the signal to a water flow rate (Litres/time). The microcontroller converts the signals into flow rates (Litres/Hour) and the amount of water consumed (Litres). The number of litres consumed will be stored in the Electrically Erasable Programmable Read Only Memory (EEPROM) in the event of a power failure.

The flow rates and the amount of litres consumed will be displayed on the LCD display and they will also be sent through the GSM/GPRS module to the website using Website tools. The web-site will receive information from the database through the GSM/GPRS module. The LED indicators will indicate the system power status and possible water leakages. The keypad will be used to send out commands to the microcontroller in the event of maintenance. The power supply for the device will be a battery with a solar charger so as to maintain good durability. The possible water leakage for this option is obtained through the threshold method. The method classifies anything under a certain level of threshold flow rate as a possible water leakage.

The design of the SWLDM device comprised the development of water flow meter and display subsystem; a solar panel and power supply subsystem; a GSM/GPRS subsystem; a keypad interface subsystem; a database and web-site subsystem; and the final integration of all these sub-systems into the SWLDM device as shown in Figure 1.


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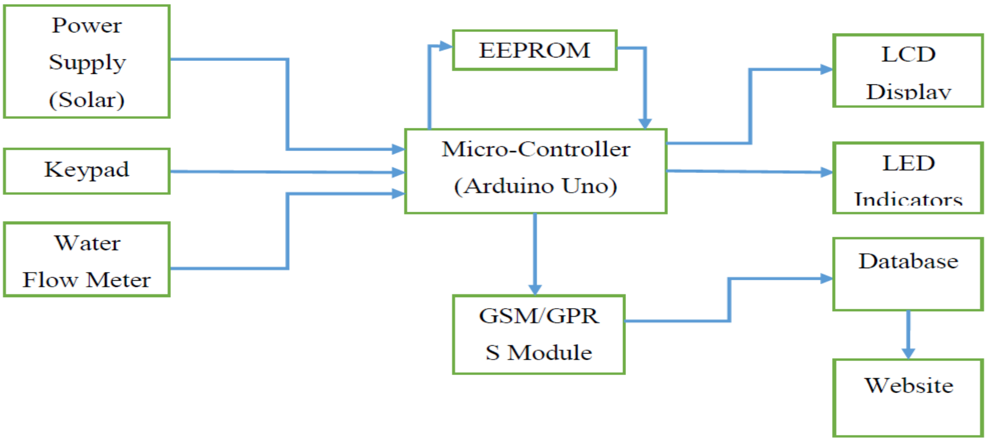


*Figure 1: Various Sub-systems of the SWLDM Device*

The main advantages of the proposed design are the use of one sensor (flow meter) to determine the flow rate, water consumption and possible water leakages in the system. It also has an LCD display for cases where the customer does not have a cell phone and it does not require the consumer to have Wi-Fi or Ethernet access. The GSM/GPRS Module will only be switched on during transmission of data. It also does not contribute to the national energy consumption since it uses solar power. In addition the use of the on-board Arduino EEPROM ensures there is no need for external storage and the keypad is used to send commands for maintenance and trouble shooting.

Each pulse output by the liquid flow meter is equivalent to 2.25 $ml$ water flow. Assuming a sample rate (t) of 1 second per sample we can calculate a general formula for the water flow rate (Q) as follows [9]:

$$Q = \frac{L}{t} \quad (1)$$

Where the total number of litres is given by:

$$L = 2.25 \times 10^{-3} \times pulse \quad (2)$$

The pulse frequency is given by:

$$pulse_{frequency} = \frac{1}{t} = \frac{1}{1} = 1\,Hz \quad (3)$$

Therefore:

$$Q = 2.25 \times 10^{-3} \times pulse_{frequency}\ [l/s] \quad (4)$$

The general flow rate formula in L/Hour is given by:

$$Q = 60 \times 60 \times 2.25 \times 10^{-3} \times pulse_{frequency}\ [l/h]$$

$$Q = 8.1 \times pulse_{frequency}\ [l/h] \quad (5)$$

The code uses the equation (5) to determine the water flow rate and the amount of water consumed. The code also detects if there are any water leakages by monitoring the flow rate results from the meter. In the event of a power failure or device update the number of litres consumed will be stored in the 1KB EEPROM of the microcontroller. The data collected is displayed on the LCD. The LED indicator is used to indicate possible water leakages, thus the LED will only turn on if and only if a possible case of water leakage is detected.

The data acquired from the flow meter by the microcontroller is sent to the website via a GSM module. The microcontroller uses serial communication to communicate with the GSM module. The GSM module establishes an internet connection with the server through the Transmission Control Protocol/Internet Protocol (TCP/IP) protocol. When the connection is established between the server and the GSM module, data is sent to the server database which can be extracted and displayed on a web page.


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## 5. Developments

In order to determine the expected flow meter readings we need to know the output escape velocity and flow rate of the tank. To determine the efficiency of the water flow meter and if there is a possible water leakage the experiments shown on Figure 2 and Figure 3 was setup.

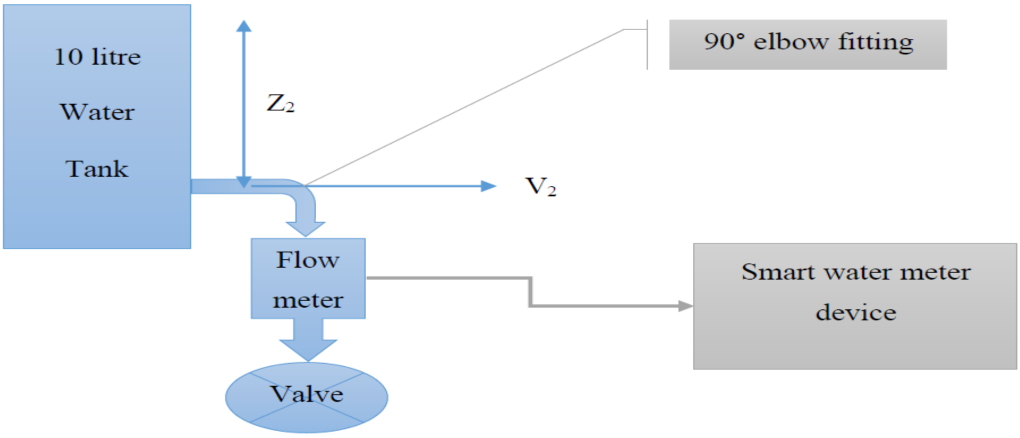


*Figure 2: Flow Diagram of Water Leakage Detection Experiment*

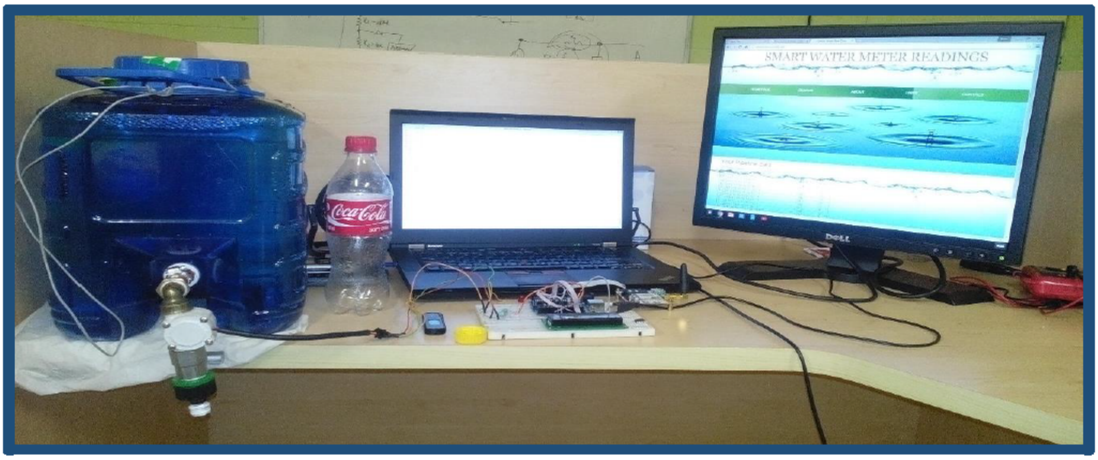


*Figure 3: Water Flow Leakage Detection Experimental Setup*

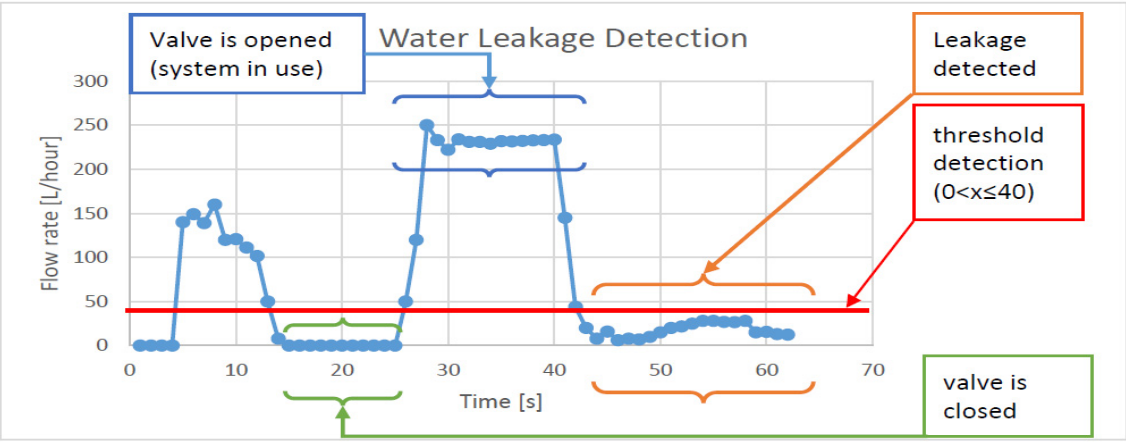


*Figure 4: Water Leakage Detection Graph*

Each fitting has plumbers tape to prevent water leakages around the joints and all electrical components are shielded from any possible water spills. The valve is opened (max open)




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and water is poured into a 500ml bottle. The experiment is repeated 20 times for accuracy and readings on the LCD and Website server are recorded.

Using Torricelli's theorem [9] we have that:

$$\frac{P_1}{\gamma}+z_1+\frac{v_1^2}{2g}-h_{TL}=\frac{P_2}{\gamma}+z_2+\frac{v_2^2}{2g} \quad (6)$$

Assuming the system has 0% total losses ($h_{TL}$) and that $P_1=P_2\approx0$ due to atmospheric pressure since either ends are open, and that $v1\approx0$, then equation (6) simplifies into:

$$z_1=z_2+\frac{v_2^2}{2g} \quad (7)$$

$$v_2=\sqrt{2g(z_1-z_2)} \quad (8)$$

From the dimensions of a 10 litre water bottle we have that: $z_1$=15$cm$ distance from water level to the outlet level and $z_2$=12$cm$ distance from outlet level to the valve. Thus:

$$v_2=\sqrt{2\times9.81\times(0.15-(-0.12))}=2.2\,m/s\ \ (without\ losses) \quad (9)$$

From losses due to pipes, fittings, flow meter and connections we have that the output is:

$$v'_2=0.88\,m/s\ \ (with\ losses) \quad (10)$$

Calculating the flow rate in L/hour where the area of the ½ inch pipe (A) has an inner diameter = 0.011m:

$$Q=Av'_2=\frac{\pi(0.011^2)}{4}\times(1.1)(60\,sec\ \times60\,min)\left(1000\frac{L}{m^3}\right)=249\,L/hour \quad (11)$$

This value gives an idea of the expected values and a typical expected graph from the flow meter readings as shown in Figure 4. The graph shows that between (44 and 62) seconds, there is a possible water leakage (i.e. dripping tap, running toilet or pipe leakage). If the leakage detector code detects five consecutive values between ($0<x\leq40$) L/hour it will alert the user. If the flow rate is zero that means that the valve is closed and if there is a huge sudden overshoot that means that the valve is opened.

## 6. Results

Figure 5 shows the accuracy of the water flow meter when the flow rate is kept at a maximum constant of 230 L/hour. The graph shows an average deviation from the actual value of 0.5L and as a result, the water flow meter has an accuracy of 99.4% in measuring the correct value out of twelve iterations. The error percentage of 0.6% in this case might have been due human error when opening and closing the valves and losses in the flow meter itself.

Figure 6 shows the accuracy of the water flow meter when the flow rate is varied from minimum to maximum. The graph shows two important things namely: The water flow meter is less accurate at lower flow rates but more accurate at high flow rates; and that the minimum flow rate that the water flow meter can detect is an average of 20 L/hour.

Figure 7 shows both the possible water leakage graph and the water flow rate graph. The possible water leakage graph is a binary graph it only shows a pulse when the flow rate is between $0<x\leq40$ L/hour for more than 5 seconds (i.e. it sends out a peak only when there is a possible water leakage detected) where x is the threshold detection. The results obtained in Figure 7 compliment the theoretical results shown in Figure 4.

The minimum time delay that was used to allow the GSM to establish a TCP/IP connection with the website was 31.414 seconds. Figure 8 shows the website user interface. The website shows a pipeline data table that comprises of the following fields: ID [number of data points sent], Time Stamp [yyyy-mm-dd], Total Water Consumed [L], Water Bill [Rands] and Possible Water Leakage [binary format].



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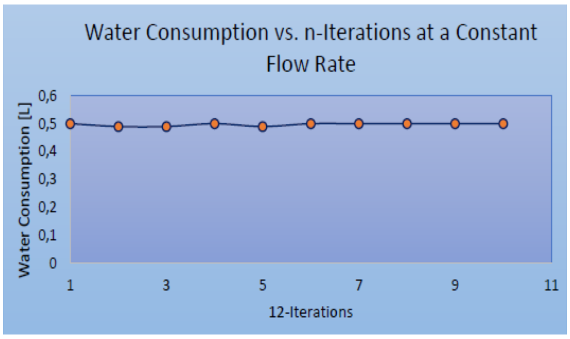


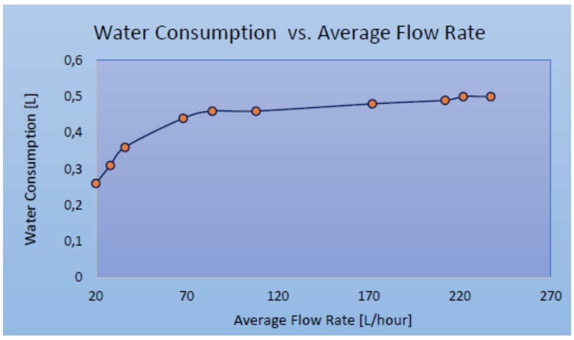


*Figure 5: Water consumption at constant flow rate of 230 L/hour*

*Figure 6: Water consumption vs average flow rate*

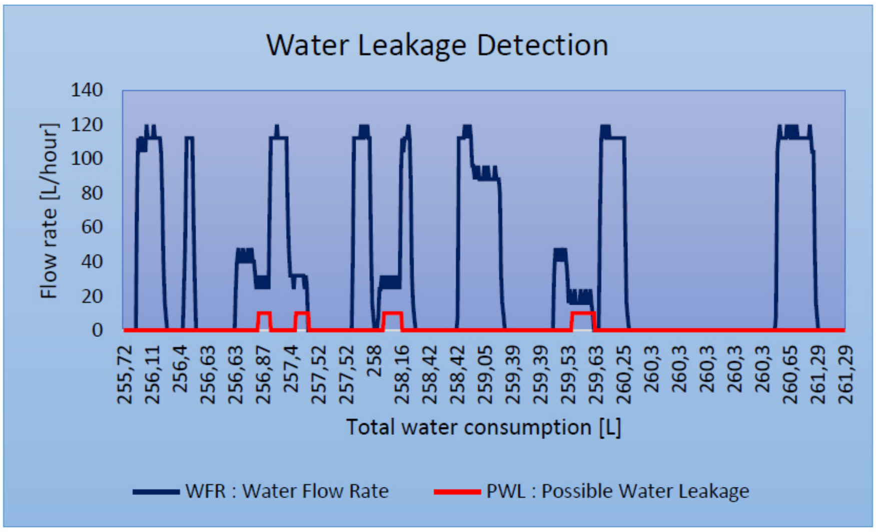


*Figure 7: Water Leakage Detection Graph*


*Figure 8: Website User Interface*



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## 7. Business Benefits

It is of great importance to note that Society's economic sectors, including but not limited to agriculture, Industry and Services, rely on water resources and related services. In view of this development, improved management of water resources contribute substantially to economic growth thereby increasing business productivity and development. In this particular project, possible water leakages which translate to revenue loss will be detected in the consumer's property and remedial actions will be immediately taken to minimise commercial losses.

The final aspect dwells on determining actual water consumption levels and sending the data to the nearest water municipality for billing purposes. This will assist in reducing operating expenditures (OPEX) for the water municipalities and data on actual water consumption will be available for the country to make informed decisions on water planning interventions.

The project is aimed at decreasing the water commercial losses in the country thus through the success of the project, commercial losses would be decreased. This will reflect positively on the economy. But for the success of the project capital input would be required. It can be argued that the capital input is outweighed by the fact that the country will be saving and conserving water; which plays a vital role in the eradication of poverty and a growing economy.

According to statistics obtained from the 'General household survey 2014' statistical release P0318 by Statistics SA [4], the percent of the South African population with access to basic water facilities in 2014 is shown in Table 2:

*Table 2: South African Households with Access to Basic Water Facilities*

| | |
|---|---|
| Number of households in RSA | 15 602 000 |
| Percentage of households with access to piped or tap water in their dwellings, off-site or on-site in RSA | 90% |
| Percentage of households with access to adequate sanitation (toilets) in RSA | 79.5% |

Therefore, the number of households with access to water and flushing toilets is:
$15\,602\,000 \times 90\% \times 79.5\% = 11\,163\,231$

Using the data provided by the Water and Sanitation Division at the city of Tshwane we have that in each household:

| | |
|---|---|
| Running Toilet | 16 000 litres/annum |
| Dripping tap | 24 000 litres/annum |
| Pipe leakage | 24 000 litres/annum |
| Total | 64 000 litres/annum |

Thus multiplying both end results we get that total water leakages are: $11\,163\,231 \times 64\,000 = 714\,446\,784\,000\ litres/annum$ . Since the NRW amounts to 1580 million cubic meters this means that the losses amounts to $\frac{714.446784}{1580} \times 100 = 45.21\%\ loss\ of\ the\ NRW$. In calculating the rate of water loss we have that for every hour the losses amount to $\frac{714.44678\ million\ m^3}{365 \times 24} = 81557.85 \frac{m^3}{hour}$

Thus if the consumer could attend and fix each leakage within an hour from detection by the device, only 81557.85 $m^3$ of water would be lost for each event of detection. Assuming that on average only five events are detected every year by the devices and the consumer attends to each of the events within an hour, we have that the losses would amount to 81557.85 $m^3 \times 5 =$ 407 789 $m^3$ of water. This means that the device would help save about: $\frac{714.44678 - 0.407789}{714.44678} \times 100 = 99.94\%$ of water losses due to the running toilets, dripping taps and pipe leakages per annum. From the calculations it can be seen that the efficiency of the device highly depends on the consumer's response to any possible water leakage on their property.



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## 8. Conclusions

In respect of the above discussions and presented water leakage detection results as per the threshold detection value of $(0<x\leq 40)$ L/hour , it can be clearly observed that the Smart Water Meter Device will address the challenges associated with water leakages which have resulted in loss of revenue for the past few years in South Africa [3].

In addition the SWMD will assist the end-consumer to optimally manage their water consumption by automatically and continuously informing the consumer about the water consumption levels in their households. The consumer can procure the services of a plumber earlier to investigate water loss instead of waiting for the water to seep to the surface as currently occurs. By detecting possible leakages and wastage earlier, it will enable the homeowner to save money.

The second objective of allowing municipalities to monitor in real-time the water consumption levels for a specific area, and automating the billing process, will result in increased efficiency in the municipality and better response times to water losses. It will also assist municipal water departments in managing the water supply and maintenance.

This is a low-cost practical solution suitable for many developing countries where proper management of this scarce resource is of paramount importance for social and economic development. Future work will involve creating an android app that will interface with the website so that the consumers will have their water pipeline activities displayed on their mobile android phones.

## Acknowledgment

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