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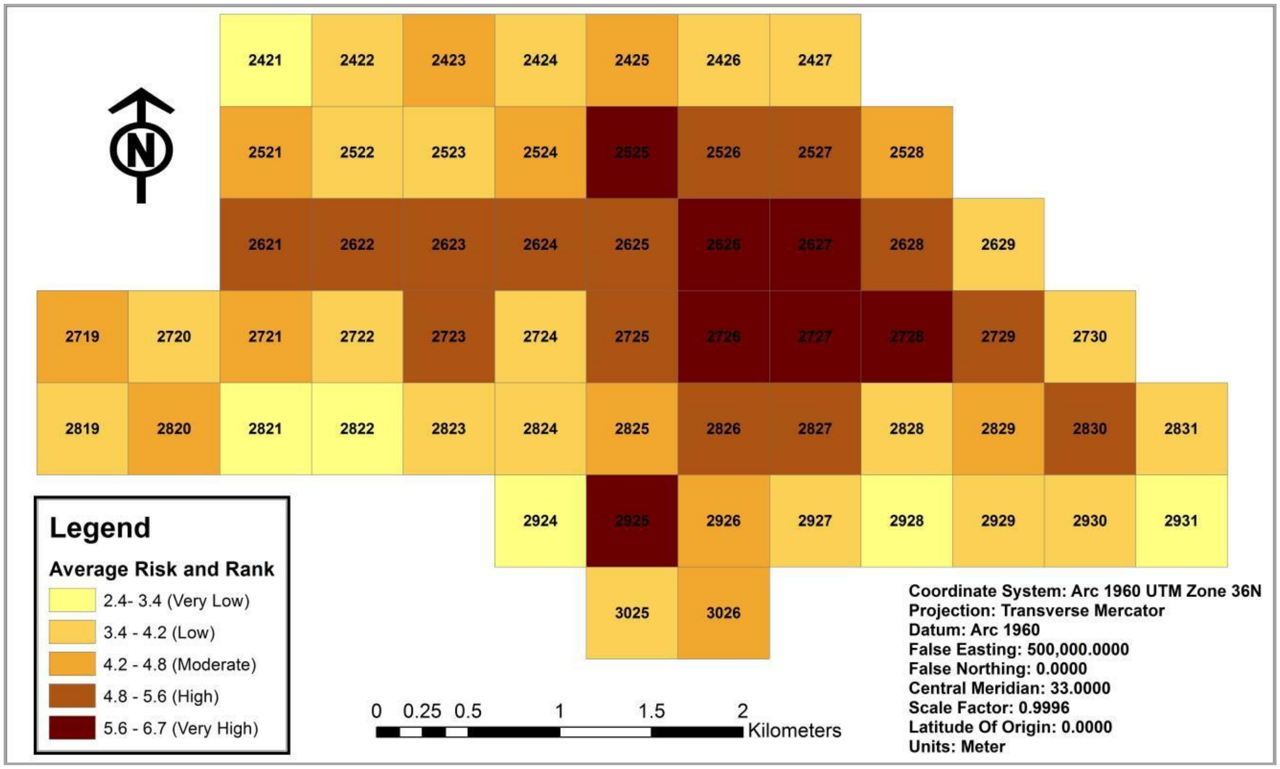
Asset Management: Integrating GIS as a Decision Support Tool in Meter Management in National Water and Sewerage Corporation



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Asset Management: Integrating GIS as a Decision Support Tool in Meter Management in National Water and Sewerage Corporation

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Master Thesis, 30 Credits, in Geographical Information Sciences

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ABSTRACT

National Water and Sewerage Corporation (NWSC) is a government parastatal established by the Government of Uganda to establish, operate and provide water and sewerage services in areas entrusted to it, on a sound, commercial and viable basis. As of December 2015, NWSC operates in 142 urban centres spread across the country with Kampala being the largest single area of operation. As of 30th March, 2016; Kampala has a customer base of 228,000 active connections accounting for approximately 70% of the total business of the entire corporation.

In order to determine the monthly volume of water used at each connection, the utility has metered all its customers using mainly volumetric mechanical meters of class B and C. The meters are read on a monthly basis in order to determine individual customer invoices for water consumed (also called water bills). Meters therefore form a major component of the NWSC asset base. Each year, NWSC connects approximately 11,000 new customer connections to its water supply grid.

Given the above scenario, the management of meters is critical to the corporation. The mechanical meters have a number of moving parts. The functioning of these parts can be negatively affected by age as well as throughput among other factors, and this leads to under or no registration of water consumed at the customer premise for the period in which the meter is defective. The effect on meter functioning therefore poses a major financial risk to the corporation due to would-be revenue lost by the utility. It is on this basis that this paper sought to demonstrate how GIS can be integrated in Meter risk Management within National Water and Sewerage Corporation using Kansanga Branch as a study area. Risk is determined as a product of the probability of failure and the criticality of a given meter.

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LIST OF ABBREVIATIONS

AC	Asbestos Cement
AM	Asset Management
AWWA	American Water Works Association
BSI	British Standards Institute
CIP	Capital Investment Projects
DN	Nominal Diameter
EAM	Enterprise Asset Management
ESRI	Environmental Systems Research Institute
GIS	Geographic Information System
IAM	Institute of Asset Management
KWSSA	Kampala Water and Sewerage Supply Area
LOS	Level of Service
NWSC	National Water and Sewerage Corporation
O&M	Operation and maintenance
PASS	Publicly Available Specification
PVC	Polyvinyl Chloride
SIMPLE	Sustainable Infrastructure Management Programme Learning Environment
SPSS	Statistical Package for Social Scientists
SQL	Structured Query Language
UBOS	Uganda Bureau of Statistics
UN	United Nations
UNDP	United Nations Development Programme
WHO	World Health Organisation

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1. INTRODUCTION

National Water and Sewerage Corporation (NWSC) is a fully government owned parastatal mandated to establish, operate and provide potable piped water and sewerage collection services in urban areas entrusted to it, on a sound and commercially viable basis. It was established by the Government of Uganda in 1972 with help from the World Bank; United Nations Development Programme (UNDP) and the World Health Organisation (WHO). The NWSC Statute of 1995, Section 5(1) defines its mandate as "to operate and provide water and sewerage services in areas entrusted to it, on a sound, commercial and viable basis". As of December 2015, NWSC operates in 142 urban centres spread across the country.

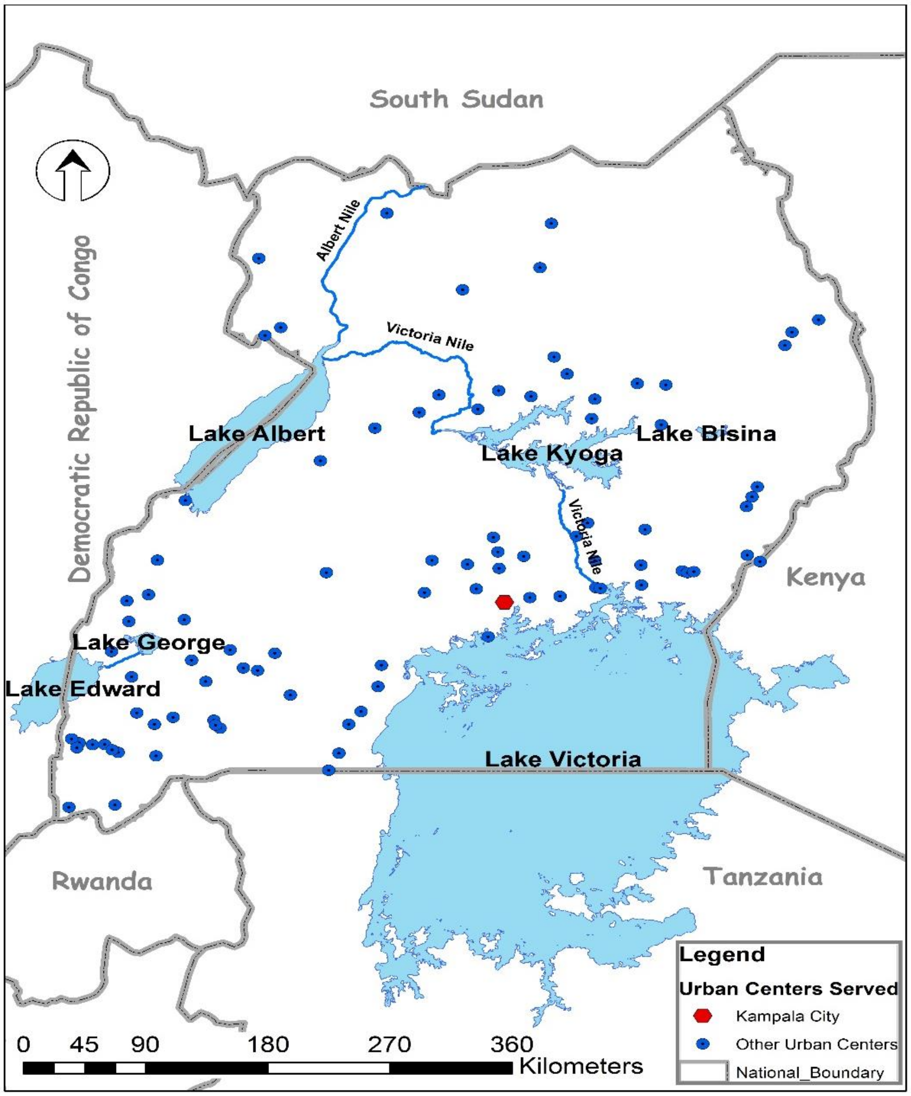


Figure 1: ***Map of Uganda showing urban centers where NWSC operates***
Source: Gilbert Akol ECHELAI, (2016) NWSC

Kampala Water represents the NWSC staff and management team mandated with providing water and sewerage services to the Kampala Metropolitan city. It represents the largest single town of operation by NWSC and with currently an approximate number of 228,000 connections, accounting for over 65% of the utility's total annual business.

Many African cities are experiencing rapid population and urban growth driven by both high natural growth rates of the urban population and the ongoing immigrations from the rural areas (UN-HABITAT 2010). It is estimated that more than half of global population growth between now and 2050 is expected to occur in Africa, growing at a pace of 2.55 percent annually between 2010 and 2015 (UN, 2015). Uganda's population growth rate between 2002 and 2014 stood at 3.03% (UBOS, 2014).

Kampala is no exception and its growth has absorbed nearby villages to form the now metropolitan Kampala that stretches to the nearby districts of Wakiso and Mukono. The total built up area in the city has grown from 73 km² in1989 to 325 km² in 2010 at an average growth rate of 10, 14 and 14.4% per annum during 1989-1995, 1995-2003 and 2003-2010 study periods respectively (Abebe, 2013). This growth rate has translated into the need for increased water and sewerage services on the part of NWSC and this need has been met by increased investment in the provision of water and sewerage services.

As the number of water meters installed continues to rise due to the rapid growth rate of Kampala (estimated at 5.6%), the need to have an optimal meter management framework is crucial if NWSC is to continuously maintain its desired level of service, maximize its returns on the investment made by acquiring and installing these meters, as well as minimize the risks that may arise as a result of meter malfunction (consequences of meter failure). To date, a number of meters fail each month, necessitating some form of proactive ways of determining the failure rates and thus planning for their procurement, repair and or replacement.

1.1 Purpose of the study

The purpose of this study is to demonstrate how GIS can be integrated as a decision support tool in meter management at NWSC, Kampala. It is important that the utility devises an effective mechanism for managing the water meters in Kampala and uses this approach to manage similar meters in other urban centers where it operates. A key aspect in managing meters is to understand the business risk that each meter poses to the utility and attributing that risk to location in order to develop an effective management framework. This is made more pertinent given the fact that in most cases where a meter is reported as defective by the Meter Readers, such meter is either not registering or under registering the consumption volumes of the customer due to age, wear and tear of its moving parts or blockages caused by water impurities. The corporation therefore needs to understand geographic distribution of the business risks that currently installed meters pose to the utility in order to effectively deploy staff for their monitoring, repair and or replacement so as to minimize potential losses due to under or no registration of consumption.

Some studies have been undertaken to demonstrate how GIS has been integrated into asset management (Schultz 2012 and Michael et al, 2011). The role of GIS in Asset Management in Otay Water district is described (Schultz, 2012). This study uses an existing model for horizontal assets and includes vertical assets (pumps) and then assigns criticality and probability of failure scores which are later transformed into risk factors for each of the 79 pumps. This model helps in demonstrating the risk factor for each of the pumps.

Michael S.A.et al (2011), discuss the role of GIS in network maintenance in Tarkwa, south western Ghana. In their study, GIS is used to create a geodatabase to support improved operations as well as determine costs of network asset replacement.

In order to ensure sustainable delivery of the desired customer service levels by utilities in a cost effective manner, it is important that utilities replace reactive maintenance with planned maintenance. Utilities that seek to implement effective asset management must first know where these assets are located. The location of these assets determines the prevailing conditions under which these assets operate (customers whom they serve, the accessibility of assets, proximity to related assets, climate, soil conditions, traffic levels, etc) and these conditions determine how the utility will strategise to effectively manage these assets.

In this study, meter criticality index and probability of meter failure index are computed and applied to estimate the risk associated to each of the meters within the branch. Criticality relates to the impact of meter failure. It can best be answered by the utility answering the question: If a specific water meter failed to register consumption, what is the quantifiable loss that would accrue to the utility? In this regard, Meter criticality is estimated as a function of average monthly consumption.

On the other hand, a Meter Failure Index is generated to represent probability of failure using the meter age. The Meter failure index is computed by dividing the age of a given water meter by the design life of a mechanical water meter.

1.2 The Key Research Questions

i) How can the probability of meter failure be estimated and geovisualised? This question seeks to understand the spatial distribution of the probability of meter failure considering age as the determining factor

ii) How can Meter criticality be estimated and geovisualised? In answering this question, the magnitude of impact of meter failure will be spatially presented across the branch using the average monthly consumption volume of each meter within Kansanga.

iii) How can the risk of meter failure be estimated and geovisualised to inform the Meter Management process? Risk is estimated as a product of criticality and probability of failure. Spatial distribution of meter risk is generated by multiplying the criticality and the probability of failure generated for each meter across the area of study.

iv) How useful is the generated risk model to the utility? How can the utility utilize the risk model in order to strategically position itself to effectively manage the water meters across the supply area?

2. BACKGROUND

2.1 Water Meters

A water meter can be described as any tool that has the capacity to measure the volume of water that passes through it. In order to effectively function, a water utility needs a reliable water source from which it can abstract water, a means of ensuring that the water abstracted meets recommended standards, a means of transmitting and sometimes storing that water, a means through which that water reaches a customer premise and finally, a means through which it can determine consumption by each of its customers.

In this regard, a water utility has to develop infrastructure to allow for abstraction, transmission, storage and distribution of the water. The utility needs a water treatment plant, water transmission lines, water reservoirs, water distribution lines, water service lines and finally, a water meter. The above infrastructure forms the core assets of a water utility. In some countries, different piped water pricing models have been employed that may not necessarily require a water meter at the customer premise. This is the case where water is provided at a flat rate, irrespective of the volume of water consumed by the household.

Mutikanga et al. (2011), argue that where a meter is used to determine consumption, it then becomes a very important asset to both the customer and the water utility as it forms an independent tool that determines how much the customer should pay to the utility for water services rendered. They add that when metering is inefficient and coupled with low tariffs, the financial sustainability of utilities is at stake.

Other scholars have described the importance of water meters to a utility. Van Zyl (2011) argues that water meters are used to measure how much raw water is taken from a resource such as a large dam, how much of this water leaves the water treatment plant, how much is purchased from bulk suppliers or sold to other municipalities, how the water is distributed within the water distribution system, and finally, how much of the water is delivered to individual consumers. This knowledge helps the utility to understand how best to manage its transmission, storage and distribution system in order to effectively deliver water to the customers. He adds that by combining the network and customer meters, a utility is able to estimate and manage the water supply system, including revenue and losses.

AWWA (1999) summarises the importance of water meters as "…accurate water measurement is the means by which water utilities produce revenues to cover expenses, charge each customer equitably, prevent waste of water and minimize the load of waste water facilities". Again from that statement, one can clearly see the importance of meters to a utility. Not only are they a source of revenue determination, they help prevent water waste as consumers realise the need to use water more meaningfully.

In Uganda, and particularly within the Kampala Water and Sewerage Supply Area (KWSSA), this is very important because the utility can only meet approximately 75% of its demand. In this situation, if the customers who have adequate pressure and flow in their pipes on a 24-hour basis use water rationally, they will be saving the water for other customers who are on the fringes of the water distribution system. However, if they use it wastefully, the customers located at the fringes of the water distribution system will not be able to get any water.

Again, it can be seen that as more water is used, more waste water is generated and hence more load on waste water facilities. Meters therefore, through the effect of making users consciously mind their water usage, help reduce the waste water load generated for waste water facilities. AWWA (2002a) assert that no tool available to water utilities has played a greater part in water conservation than the water meter. This statement underlines the magnitude of the role that water meters have played in the water industry.

Water meters can generally be classified into three categories: Electromagnetic Meters, Mechanical Meters and Ultrasonic Meters. This classification is based on how the meters function. Despite this classification, Van Zyl (2011) explains that all water meters consist of four basic components: A sensor to detect the flow of water passing through the meter; A transducer or measurement transducer which transmits the signals detected by the sensor to other parts of the meter; A counter that keeps track of the flow that has passed through the meter; and finally, an indicator that communicates the readings to the meter reader.

The mechanical meters have moving parts that detect the flow, such as a piston or impeller. They can further be classified into volumetric, inferential and combination meters. The volumetric meters directly measure the volume of water flow passing through them using a rotating disc, while the inferential meters infer the volumetric flow rate from the velocity of the water. The combination meters on the other hand made up of two meters of different diameters that are combined to measure a particularly wide range of flow. One of the meters will have a smaller diameter and will measure minimum flows while the meter with the larger diameter measures larger flows. These meters have a changeover device that directs flow to the specific meter depending on the volume of flow. When the flow is high, the changeover device directs flow to the larger meter and when it is low, it directs flow to be measured by the smaller meter. Overall, mechanical meters are the most common type of water meters used.

Electromagnetic and ultrasonic meters on the other hand have no moving parts, but detect the flow through the meter using electromagnetic principles or ultrasound waves. Van Zyl (2011) adds that in order for an electromagnetic flow meter to measure the volume of water, a magnetic field is created across the pipe. Given that water is an electrical conductor, when it moves through the magnetic field, a voltage is induced that is detected by two electrodes that are placed at right angles within the body of the meter. The voltage is directly proportional to the flow velocity, which allows the flow rate to be calculated and hence the volume of water consumed.

Ultrasonic meters utilize the properties and behaviour of sound waves when passing through moving water. There are generally two types of ultrasonic meters that use different measurement mechanisms: Doppler and transit meters. The functioning of the transit time ultrasonic flow meters are based on the phenomenon that sound waves slow down when moving through the water against the flow, and speed up when they move with the flow while the Doppler meters are based on the Doppler effect which is the change in the frequency of a sound wave when it is reflected back from a moving object.

The performance of water meters is therefore very important to the financial viability of any utility and as such, a number of studies have been conducted to ascertain meter performance with various findings. In general, National Water and Sewerage Corporation uses mechanical meters due to their low costs of acquisition. Specifically, the corporation uses the velocity or inferential meters (Single jet and Multi-Jet meters) and volumetric or displacement meters. Studies have found out that mechanical meters become more and more inaccurate during their operating life due to ‘wear and tear’ of the measuring components (Arregui et al., 2006b). Although this is true, there are also several other factors that may cause the water meter performance to become compromised and hence to be termed as defective in its operation. Mutikanga, et al (2011) carried out a study on meter performance in Kampala and found out that among other things, the volumetric positive displacement meters are not suitable for the Kampala Water distribution network as high failure rates were observed compared to the velocity meters.

2.2 Geographical information Systems

GIS is an acronym that stands for Geographical Information Systems. Rolf et al (2001) define a geographic Information system as a computer based system that allows studying natural and man-made phenomena with an explicit bearing in space. They further explain that a GIS therefore allows entering data, manipulating the data and producing interpretable output that may teach us lessons about phenomena.

Vanier (2004) credits GIS with the ability to link database records and related attribute information to a specific location and by so doing creating a “smart map”. This is achieved through its “database of spatially distributed features and procedures that collect, store retrieve, analyse, and display geographic data”. Relatedly, Wade and Sommer (2006) define a GIS as an integrated collection of computer software and data used to view and manage information connected with specific locations, analyse spatial relationships, and model spatial processes.

From the above definitions therefore, one can conclude that GIS is a tool that is specific to geographic data. Geographic or spatial data is data that has a defined geographical location and extent. Consequently, a GIS can then be defined as a combination of software, hardware and human methods or skills that allow for capture, storage, analysis of geographic data and generation of spatial output information that supports effective decision making. Given the nature of output generated by a GIS, one can add that it supports an all-inclusive decision-making process. The inclusion of other stakeholders (non-professionals in a particular field) emanates from the ability of a map to be easily interpreted by many who may not necessarily be experts in a particular field. This is particularly important in situations where consensus needs to be arrived at by a diverse team of professionals.

Across the East African region, there is a growing interest by water utilities on how they can utilise GIS to support performance improvement within the utilities. Areas of application have ranged from mapping of water and sewerage networks to support deployment of staff for both commercial and technical activities like meter reading, revenue collections, meter repair, leakage repair, and asset management, among others. However, GIS has not been applied in the context of analysis of risk geovisualisation for water meters since emphasis has been on meter performance as opposed to risk.

2.3 Asset management

The British Standards Institution (BSI) and the Institute of Asset Management (IAM) in their publication of the Publicly Available Specification (PAS55-1, 2008), define asset management (AM) as "systematic and coordinated activities and practices through which an organization optimally and sustainably manages its assets and asset systems, their associated performance, risks and expenditures over their life-cycle for the purpose of achieving its organizational strategic plan". It further defines an organizational strategic plan as "overall long-term plan for the organization that is derived from and embodies its vision, mission, values, business policies, stakeholder requirements, objectives and the management of its risks".

The Association of metropolitan Sewerage Agencies (AMSA), (2002) Defines Asset Management as "an integrated optimisation process of managing infrastructure assets to minimise the total cost of owning and operating them, while continuously delivering service levels customers desire, at an acceptable level of risk". The objective of Asset management in this case is to deliver services at acceptable levels of risk while optimizing costs.

Sustainable Infrastructure Management Programme Learning Environment (SIMPLE) website defines asset management as a paradigm and body of management practices that is applied to the entire portfolio of assets at all levels of the organisation, seeking to minimise the total cost of acquiring, operating, maintaining and renewing assets within an environment of limited resources while continuously delivering the service levels customers desire and regulators require, at an acceptable level of business risk to the organisation.

There are a number of definitions of Asset management. However, all these definitions point to some basic aspects regarding the management of assets. Echelai (2013), summarises "…what is common in all these definitions is that asset management takes into consideration capital investment and operations costs; maintenance of adequate service levels; minimisation of risks to acceptable levels throughout the life-cycle of the assets”.

Every utility needs its customers to trust the means through which it determines how much they pay for the services rendered by the utility. It is against this background that a water meter is instrumental in determining the utility revenues as well as customer confidence and trust in the water bills delivered on a monthly basis. The confidence and trust that the customers attach to the bills delivered translates into willingness to pay for services invoiced.

This refers to decisions ranging from their acquisition to disposal and the attendant decisions on which meter gets replaced and or bought from an informed perspective. The Institute of Asset Management (IAM, 2014) rightly points out that Asset Management gives any interested organization the knowledge and tools to use chosen assets to achieve its purpose. Moreover these techniques and processes allow such an organization to demonstrate that it is managing its assets optimally– “often of great interest to many stakeholders, whether owners, customers, regulators, neighbors or the general public”. Meters rightly fall in this category, with customers, regulators and the utility as interested stakeholders.

The world over, utilities are faced with the challenges of how best to answer the critical asset management questions (what is the current state of my assets? What is my required sustained level of service (LOS)? Which of my assets are critical for sustained level of service and performance? What are my best minimum lifecycle cost for Capital improvement Plan (CIP) and Operations and Maintenance (O&M) strategies? Finally, what is my best long-term financing strategy?). The website further explains that in attempting to answer these questions, a utility will derive associated techniques or outputs which actually define the actions and strategies of the utility with regard to asset management.

One of the associated techniques to understanding the current state of assets of a utility is that called the Delphi approach. It is a systematic and interactive method of obtaining forecasts about assets from a panel of independent experts when there is no or inadequate information and is based on the assumption that two or more heads are better than one (Nerantzidis, 2012). This technique is preferred as a problem solving or policymaking tool when the knowledge about a problem or a phenomenon is incomplete and is used with the aim of obtaining the most reliable group opinion (Kittell - Limerick, 2005).

Table 1: ***The Five Core Asset Management questions.*** *Source: SIMPLE Website (http://simple.werf.org/Books/Contents/Getting-Started-(2)/What-is-Asset-Management)*

Core Question	**Associated Technique/Output**
1. What is the current state of my assets? ▪ What do I own? ▪ Where is it? ▪ What condition is it in? ▪ What is its remaining useful life? ▪ What is its economic value?	▪ Asset registry/inventory ▪ Data standards / asset hierarchy ▪ System maps ▪ Delphi approach to locating other sources of data ▪ Process diagrams ▪ "Handover" procedures ▪ Condition analysis ▪ Condition rating ▪ Valuation techniques ▪ Optimized renewal / replacement cost tables
2. What is my required sustained Level of Service? ▪ What is the demand for my services from my stakeholders? ▪ What do regulators require? ▪ What is my actual performance?	▪ Customer demand analysis ▪ Regulatory requirements analysis ▪ Level of service statements; LOS "roll-up" hierarchy ▪ "Balanced scorecard" ▪ Asset functionality statements ▪ AM Charter
3. Which of my assets are critical for sustained performance? ▪ How do my assets fail? ▪ How can they fail? ▪ What is the likelihood of failure? ▪ What does it cost to repair? ▪ What are the consequences of failure?	▪ Failure analysis ("root cause" analysis; failure mode, effects and criticality analysis; reliability centered analysis) ▪ Risk / consequence analysis ▪ Asset list by criticality code ▪ Failure codes ▪ Probability of failure ▪ Business risk exposure ▪ Asset functionality statements ▪ Asset "decay curves" ▪ Asset unit-level management plans and guidelines ▪ Asset knowledge
4. What are my best minimum lifecycle cost CIP and O&M strategies? ▪ What alternative management options are there? ▪ Which are most feasible for my organization?	▪ Optimized renewal decision making ▪ Life-cycle costing ▪ CIP development and validation ▪ Condition-based monitoring plans and deployment ▪ Failure response plans ▪ Capital "cost compression" strategies ▪ Operating "cost compression" strategies

Core Question	**Associated Technique/Output**
5. Given the above, what is my best long-term funding strategy?	▪ Over-arching financial impact analysis ▪ Optimized financial strategy ▪ Total Asset Management Plan ▪ Telling the story with confidence

What is clear is that in order to effectively replace water meters, the utility has to have a clear understanding of what meters it has, their condition, remaining useful life, their economic value, what the customers require of those meters, the risks associated with not replacing such meters and the cost implications to the utility among a host of other questions. Although this is very useful information, the application or implementation of asset management in any utility will be based on the information that can be accessed by the utility, the capacity or competence of its staff to make use of that information and the prevailing legal and regulatory framework which sometimes demands that certain aspects of asset management or replacement have to be undertaken within a certain time. It will also largely depend on the awareness of customers and their ability to exercise their rights. Where the customer base is highly literate and aware of their rights, they can easily demand better service and hence lead to implementation of certain activities aimed at improving or sustaining levels of service by the utility.

2.4 Risk

The nature of risk is such that it can be understood by different people from different perspectives and all those perspectives will be right. It is also true that risk is present in every aspect of life and in whatever we do. HM Treasury, (2004) puts it rightly: “Whatever the purpose of the organization maybe, the delivery of its objectives is surrounded by uncertainty which both poses threats to success and offers opportunity for increasing success”. Given this nature of risk it is therefore not surprising that there are different definitions. California Department of Transportation (Caltrans) (2012), define risk as uncertainty that matters; it can affect project objectives positively or negatively. It further explains that the “uncertainty may be about a future event that may or may not happen and the unknown magnitude of the impact on project objectives if it does happen”. They conclude that “risk is characterized by its probability of occurrence and its uncertain impact on project objectives”. Although this definition looks at risk from a project perspective, it is applied in the context of projects. Risk however, is not limited to projects, but is inherent in every facet of any activity performed either as an individual or by an organisation. HM Treasury, (2004) defines risk in terms of actions or events whose occurrence is uncertain but their outcome can be either a positive opportunity or a negative threat. It adds that "risk has to be assessed in respect of the combination of its likelihood of something happening and the impact which arises if it does actually happen". The likelihood of risk is what Schultz (2004) defines as the probability of failure of an asset, while impact of risk is the asset criticality. This definition in general agrees with that of Caltrans (2012). HM Treasury (2004) goes onto explain the importance of organisations understanding risk: "The resources available for managing risk are finite and so the aim is to achieve an optimum response to risk, prioritized in accordance with an evaluation of the risks". In this regard, the risk associated to meter failure is examined in line with the criticality of a meter as well as the condition of the meter (probability that it can fail). In the study, an engineering definition of risk is adopted (Damodaran, 2008). He explains that from an engineering perspective, "risk is defined as a product of the probability of an event occurring, that is viewed as undesirable, and an assessment of the expected harm from the event occurring".

Generally speaking, not all meters have the same likelihood of failing and if such a failure were to happen, not all meters have the same level of criticality in terms of the revenue that will be lost by the utility due to the meter being unable to accurately register consumption. This is because not all meters are of the same age and neither is it that all customers consume the same amount of water each month. Given that meters are installed at various locations within the supply area, any interventions aimed at managing risks have to consider where they are located.

2.5 Integration of Geographical Information Systems and Asset Management

Michael S.A.et al (2011), discuss the role of GIS in network maintenance in Tarkwa, south western Ghana. In their study, they investigate a section of the water supply network of Tarkwa municipality with the objective of creating a geo-database that supports improved operations performance and as well as determine the costs of asset replacement. They use digital vector maps that were obtained or digitised after scanning of analogue maps to create a geodatabase. The results of their analysis indicated that more than a half of the network was over aged given the year of installations of the network. The study also developed three scenarios that can support the design of long- term expansion and replacement action plans while providing detailed spatially referenced information on pipelines and the associated costs of replacement as they reach their designed lifespan.

Although the study developed three scenarios: replacing all pipes; replacing Asbestos Cement (AC) and Polyvinyl Chloride (PVC) pipes that are more than 25 years; and finally replacing AC and PVC pipes that are more than their design lifespans, all these scenarios are too general and simplistic to be used for replacing pipes. All these scenarios make the assumption that pipes should be replaced based on their age. The first scenario assumes that all pipes are aged. This is simply not true since all pipes in any utility could not have been installed at the same time. This is mainly because there are always network expansions, intensifications and replacements which are ongoing and all these activities are performed using new pipes. The second scenario of assuming that all pipes (AC and PVC) beyond 25 years should be replaced is also misleading. First, AC and PVC pipes do not age at the same rate. This is simply due to the differences in their materials which make them to have varying lifespans. When considering their last scenario where pipes are to be replaced based on the design life span, it is also not cognizant of the loads and repair history of each of the pipes. Sometimes a pipe may be new but the fact that it is subject to abnormal pressure (beyond its design capacity) or is in a high traffic area (runs across the road), means that such a pipe will not serve until its design life. Making such a pipe to serve until its design life will create a situation where the costs of repair and maintenance outstrip the cost of investing in a new pipe and thus it will become uneconomical to the utility to use such an approach.

Although there is a suggestion to adopt a gradual approach in replacing the pipes, all the above approaches to determining when to replace a pipe assume that all pipes have the same level of risk. This is never the case. Some pipes are generally more risky than the others. Also, by replacing all pipes or those beyond a certain age, the assumption is that money is not a limiting factor. In most times, utilities operate in a financially constrained environment that dictates that priorities in investment have to be made. I would therefore suggest that for each of the scenarios, operational data needs to be taken into consideration. What is the repair history about a particular pipe saying? What are its current operating conditions? What is the risk attributed to a certain pipe if it failed? What are the costs of replacing a certain pipe? It is certainly not the same for all pipes.

Schultz (2012) analysed the role of GIS in asset management in Otay Water District, in the state of California, United States of America. The major factor that he considered in Asset Management was asset risk. In his study, asset risk is determined by asset criticality and asset condition. Relatedly, asset condition relates to the probability that such an asset is likely to fail while asset criticality is the consequence to the utility that arises out of the failure of such an asset (water lost, number of people affected, revenue lost etc.). The study focused on the role that GIS can play in asset management by considering horizontal infrastructure assets (pipes) and vertical infrastructure assets (pumps). To these assets, asset criticality and asset failure probability scores are assigned. The multiplication of the criticality score and the failure probability score constituted an overall risk factor for each of the assets under consideration. He adds that risk is based on condition (probability of failure) and criticality (consequence of failure). Since he was considering pumps in Otay Water utility, the risk posed by failure of a pump was related to where the pump was sending the water (the customers and the water hydrants). He cited two studies; Hyer (2010) and (2011) for Florida Toho Water Authority found in Florida and Austin Water Utility in Texas.

The final outcome of the two studies was the development of a scoring criteria and guides that can be adapted for other water utilities with simple revisions. The resulting model scores were then plotted on a point symbology map to be used by decision makers where the size of point denotes the magnitude of risk. The map generated was then subjected to verification by the staff involved in the day to day operations of the pumps. A sensitivity analysis of his model revealed that manipulating the model parameters (criticality scores and probability scores) "to increase overall scoring accuracy of some pumps can have a negative impact on the scoring" of other pumps. He recommends that there is a need to carry out further studies "to plan and implement schemes that allow vertical assets at utilities to inherit asset management scores based on their positions within the larger horizontal networks".

The study demonstrates how GIS can be integrated into the decision making process for effective asset management. Although this study provides a framework for decision support in regard to the management of the pumps in Otay, it largely relied on expert opinion when scoring criticality and probability. The expectation is that the researcher should utilise historical data on the performance of the pumps by analysing the repair and performance history in order to come up with more accurate scores. This historical data would have in a way taken care of the performance history of the assets without so much relying on expert opinion which can be subjective in nature. The asset performance parameters like hours of operation, design life, operating environment, throughput in the case of meters, etc all influence the performance of such assets and thus contribute to risk. The results from such analysis that involves the use of performance historical data would then have been validated through expert opinions by engaging those managing these pumps. Although the use of historical performance data does not discount the findings of the study conducted by Schulz, his findings can be further improved by integrating the historical data of pump performance.

3. METHODOLOGY

3.1 The Study Area

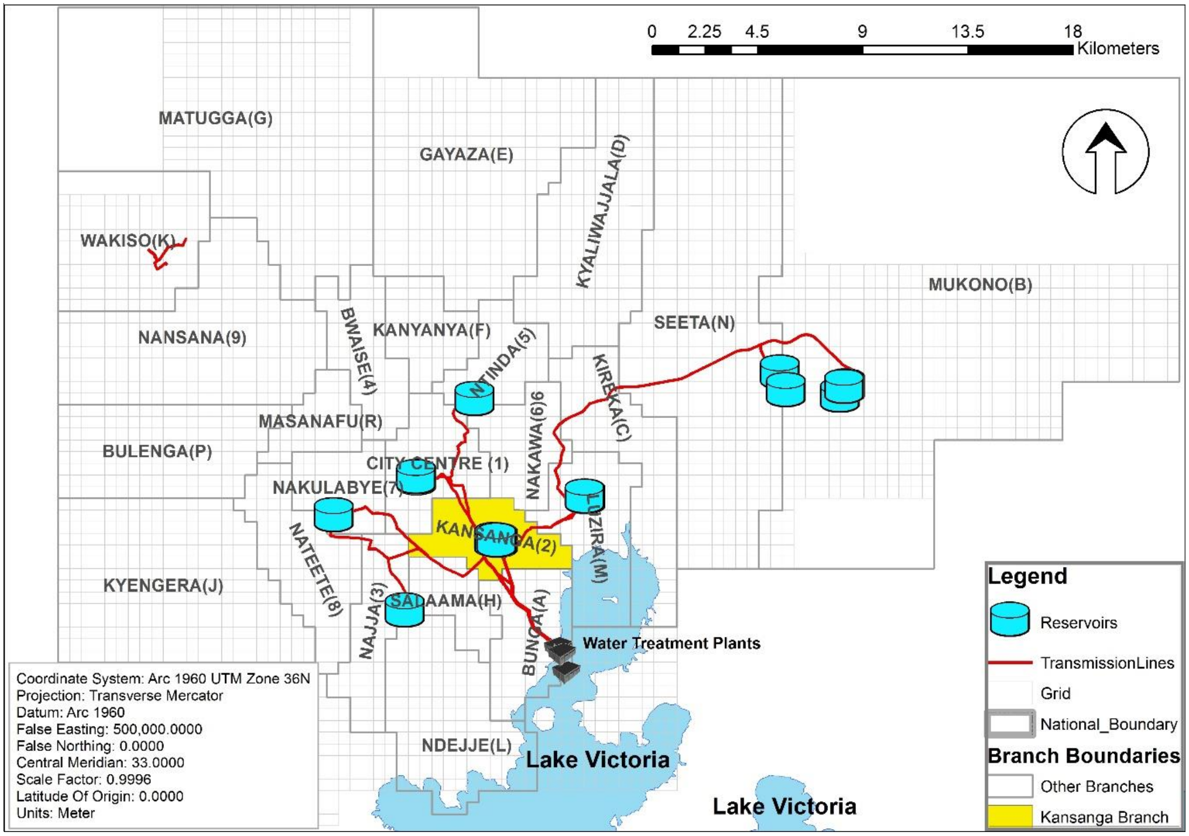
The study area is Kansanga Branch which is shown in Fig 2 below. It is one of the 24 branches that make up Kampala Water supply and Sewerage Services Area (KWSSA). It is located to the south of the city and has a total of 11,136 active customers as of 10th February, 2016. These meters range from nominal diameter (DN) 15 millimeters (mm) to DN80 mm. They account for an average monthly total consumption volume of 248,432 cubic meters of water, representing total monthly average revenue of approximately 918,987,534 Uganda shillings (I USD= 3,450 UGX). This translates into USD 266,373 of average monthly revenue collections.

The branch is generally hilly and houses the corporation's largest primary water reservoirs located in Muyenga Hill. There are five reservoirs in Muyenga each with a storage capacity of 4000 cubic meters of water and they sit at an altitude of 1300 meters above sea level. It is from these reservoirs at Muyenga that water gets transmitted to other secondary reservoirs in Seeta (2), Mukono 2), Gunhill (1), Naguru (1), Namasuba (1), Mutungo (1) and finally Rubaga (1). It is from these secondary reservoirs that water is finally distributed to the customers. The entire branch has nearly 24 hours supply with limited incidences of low pressure and no water complaints registered by the call center.

The types of meters installed within the branch vary according to size, make and class. These meters have been installed overtime with some having since been replaced due to age and malfunctioning, while others are newly installed. In this regard, these varied meters operate at varied efficiency levels in determining the volume of water consumed by the respective customers and therefore present different levels of risk for failure and eventual replacement.

Kansanga branch is chosen as the study area owing to the fact that it has no technically challenged areas in terms of service provision. The entire branch has the capacity to receive water on a 24 hours a day supply, unless there are specific interventions being carried out like cleaning of reservoirs, servicing of water production plant, power outages at the water production plant or damage of particular distribution lines by road construction activities. This means that the functioning of meters can be tested without considering some of the effects of low pressure and no-water situations that abound on the outskirts of the supply area.

Figure 2: ***Branch Administrative boundaries of Kampala showing Kansanga Branch***



Source: Gilbert Akol ECHELAI, NWSC, (2016).

3.2 Data Collection and Preparation

Various data sets were compiled in order to enable this study as follows.

3.2.1 GIS Datasets:

All the GIS datasets were obtained from the GIS unit of the Corporation. These included the following:

i) Branch Administrative Boundaries. The GIS unit also maintains a polygon shapefile of the Kampala Water Supply and sewerage services area administrative units called branches. The branch administrative boundaries are generated by allocating blocks to a specific administrative branch. Each branch therefore has a given set of blocks. The composition of blocks that define a branch is reviewed periodically to ascertain the need for creation of new branches and or expansion of the existing ones. This dataset was used to define the spatial location of Kansanga branch within Kampala supply area, as well as select all the specific block grids within the branch.

ii) Spatial locations of water meters. The GIS unit maintains a point shapefile within its geodatabase that is continuously updated with coordinates defining the location of all meters that get connected. This is done at the time of connecting a successful applicant to the water grid. In storing the information, the GIS only keeps the property reference that is attached to the customer property. It is this property reference which was used to link the point files to the table containing meter details in the billing system in order to access the details of the meter. Specific meters located within Kansanga branch were selected by location using ArcGIS software with the meter shapefile as the target layer and the branch grid shapefile as the source layer.

iii) Block grid. This is a grid that covers the entire supply area and is made of individual uniquely numbered and geo-referenced blocks measuring 500 meters by 500 meters (0.25Km^2). It is generated and maintained by the GIS unit. They are the basis of spatial identification of customer properties. Each property that gets connected to the water grid gets assigned a sequential counting number within the block, starting from one. A unique property number is then generated by concatenating the block number and the number indicating the sequence of connection within the block e.g. if a successful applicant was the first to get connected to the water utility grid within a given block say 3412, their connection number becomes one. His property number then becomes 3412/1. This number is the basis of identification of the location of each meter connected and therefore the customer premise. Subsequent applicants who get connected within the same block will be allocated subsequent sequential numbers after one with the block number remaining constant. All documentation and communication from the utility to the customer uses this number for spatial identification of the customer.

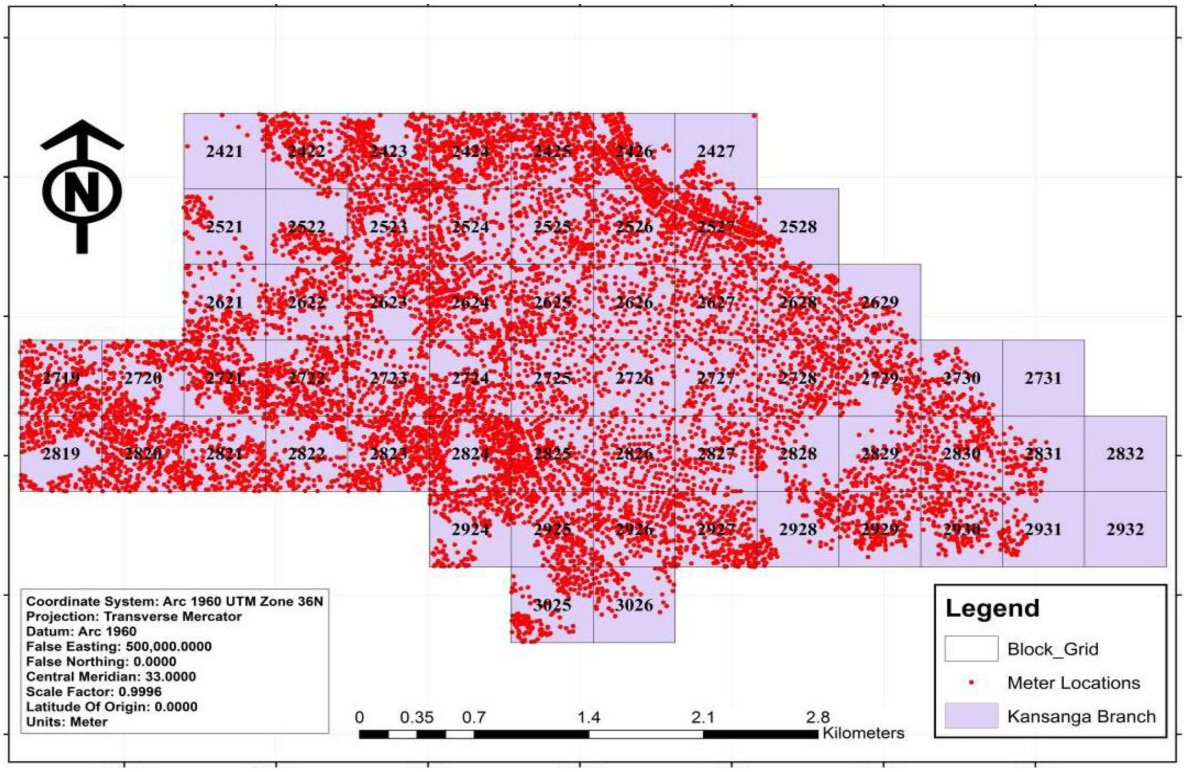


Figure 3: ***Map of Kansanga Branch showing block grid and customer meter points***
Source: Gilbert Akol ECHELAI, NWSC, (2016).

3.2.2 Meter Performance Data

Data regarding meter performance was obtained from the utility database. The billing database is based on Microsoft Structured Query Language (SQL) database. Data relating to date of meter installation, meter readings, as well as property references was exported by the billing officer to MS Excel Worksheets. The Worksheets were imported into an MS Access database that was designed for the manipulation of the data during the study. The following was obtained through manipulation:

i) The age of the water meter was calculated using MS Excel prior to importation of the MS Excel sheets into the MS Access database, by determining the date difference from the time the meter was installed (stored in the meter database) and the date the data was extracted for analysis. While determining the meter age, only the years (for installation and the date of extraction of the data) were considered. In order to facilitate spatial analysis at each block, the table of meter age and property references to which these meters are attached, also contained the block number within which each meter is installed.

ii) Average Consumption registered by a Water Meter. This is the average volume of water that has passed through the meter from the beginning to the end of each month. This was obtained by considering actual consumptions that were registered on a monthly basis for a period of one year during which the meter was functioning. Data regarding consumption was imported into an MS Access table where a crosstab query was applied to determine the average monthly consumption volumes for each of the meters in Kansanga branch based historical meter reading data for twelve (12) months. At each time of meter reading, the previous reading is considered as a base from which consumption is determined given the current reading of the meter. This data was easily obtained from the billing database. The block within which such a meter is installed was also registered as part of the generated table of average consumptions per meter. This block is stored within the billing database and allows for the number of meters within each block to be ascertained.

iii) Meter failures registered within the period of analysis. In order to facilitate model validation, data of meter failure was obtained from the utility billing database. Meter Readers visit each individual meter once every month with the purpose of obtaining the readings of such meters and these readings form the basis for determination of consumption by each customer. During such visits, the Meter Readers are also tasked to report on the meter functionality (whether the meter is working or not working) and this information gets collected on a monthly basis. It is this information that is used by the other teams to disconnect such meters from the customer premises and take them to the Meter Laboratory for testing to determine the next course of action which could be servicing or replacement of such meters depending on the diagnosis.

3.3 Data Analysis

Data was analysed to determine the probability of meter failure using the Meter Failure Index and the criticality of meters using the criticality index. In determining criticality and probability of failure, the method as applied by Schultz (2012) was adopted, with only the parameters being differently applied as illustrated in sections 3.31, 3.3.2 and 3.3.3. Statistical Package for Social Sciences (SPSS) software, Microsoft Access, Microsoft Excel and ArcGIS 10.2 were the tools used for data preparation and analysis. A number of meters were eliminated from the analysis as detailed below and in the end, only 9,915 meters were considered. Data on actual meter failure was collected in order to validate the model. Actual meter failure per block was correlated with the average age of all meters within each block.

3.3.1 Probability of Meter Failure

A number of studies have shown that as meters age, their components wear out and they typically become defective and hence under-register (Davis, 2005; Arregui et al., 2003; Arregui et al., 2011; Mutikanga et al., 2010). It can therefore be deduced that as meters age, their probability of failure increases. In this study, the probability of meter failure is estimated by a Meter Failure Index. This index is computed by applying a formula adopted by Schultz (2012). Schultz (2012) computed the probability of pump failure by dividing the age of the pump by the design life of a pump. In order to apply a similar principle, the design life of a water meter was assumed to be ten (10) years. Earlier studies by Van Zyl (2011) recommend that domestic water meters should be checked and considered for replacement before the age of 10 years, and bulk meters before 5 years. After a period of ten years from the date of meter installation, it is assumed that such meter begins to function in a defective manner that does not reflect the actual water consumption at the premise where it is installed.

This recommendation is the basis for determining the meter failure index in this study. Subsequent studies by Couvelis and Van Zyl (2015), found that indeed meters under-register as they age. In their study, a number of factors were analysed in determining the meter under registration. Specifically, meter under registration due to age was found at 2.6%. Mutikanga, et al (2011) noted that the average age of the meters within the Kampala Water Supply and Distribution System was about 10 years, with some meters being more than 20 years old. In this study, the Meter Failure Index was computed by dividing the age of each meter by the age at which such meter is assumed to start failing or being defective (10 years). The individual meter age was computed by subtracting the year of meter installation from the current year. Descriptive statistics for meter age show that the oldest meter is 18 years while some of the meters were installed within 2015. The mean age of the water meters was 4.32 years, with a standard deviation of 3.44 and a median of 4.0 years.

Table 2: ***SPSS generated descriptive statistics of Meter age***

Descriptives			
		Statistic	**Std. Error**
Age	Mean	4.320	.035
	Median	4.0	
	Variance	11.823	
	Standard Deviation	3.438	
	Minimum	0	
	Maximum	18	
	Range	18	
	Skewness	.762	.025
	Kurtosis	.032	.049

The range of the meter failure indices was then divided into ten equal class intervals and scores of between 1 and 10 assigned to each of the ranges, with the lowest index class interval assigned a score of 1 and the highest index class interval assigned a score of 10. As seen in the table below:

Table 3***: Scoring of Meter Failure Index***

No	**Failure Index Scoring Range**	**Score assigned**
1	0-0.18	1
2	0.19 – 0.36	2
3	0.37 – 0.54	3
4	0.55 – 0.72	4
5	0.73 – 0.90	5
6	0.91 – 1.08	6
7	1. 09 – 1.26	7
8	1.27 – 1.44	8
9	1.45– 1.62	9
10	1.63 – 1.8	10

The scores assigned to each meter failure index were averaged within each block using the crosstab query in MS Access with the field for probability scores used as an average value, while the block field was chosen as a row header. The resulting table was generated using a

Make Table query. This table of average scores within each block was then linked to ArcGIS block shapefile and symbolized using a colour ramp to represent the average score for each block, with five class intervals of Very Low; Low; Moderate; High and Very High to represent the rank associated to each block. This rank is the proxy for probability of meter failure in such a given block. In determining the five class intervals used for the ranking in ArcGIS, Natural Breaks method (also called Jenks Method) was used. This is because of its ability to identify natural breaks that are inherent in the data (ESRI, 2006).

Table 4: ***Ranking the probability of meter failure scores within each block***

No	Failure Score range	Failure Probability Ranking
1	1.8– 2.4	Very low
2	2.4 – 2.7	Low
3	2.7– 3.0	Moderate
4	3.0 – 3.3	High
5	3.3–3.7	Very High

The resulting map from the above analysis is shown in Fig.4, section 4.1 below.

3.3.2 Meter Criticality

The concept of criticality is premised on the fact that assets have differing value to a utility and hence the impact of their failure will be felt differently for each asset by the utility. Criticality therefore measures the consequence of failure which is based on an assessment of how the failure of an asset will impact on the ability of the utility to meet service delivery goals. It is very useful in informing the utility how to plan routine monitoring of the water meters as well as planning for their replacement (stocking) in the event of the need for replacement of such assets. Assets that are considered to be more critical require more frequent monitoring than those that are less critical in nature.

In this case, the average monthly consumption registered by a meter was used to determine the criticality index of each meter. There are a number of other variables could have been considered to determine criticality, however, average monthly consumption represented the best proxy to criticality in this study. Variables like the customer consumption category (different customer categories pay different tariff rates) or meter size (Different meters are bought at different prices depending on the size and class of meter), could have been considered but data considering these variables was not consistently being managed by the utility. Relatedly, average monthly consumption volumes was regarded as more significant when determining criticality since it directly translates into monthly revenues for the utility and hence more significant to the survival of the utility. A larger average monthly consumption means that potential revenue loss due to failure of such a meter to register consumption translates into a greater loss of revenue for the utility.

Although the consumption data obtained covered one year, there were instances when consumptions were estimated for some meters. This is especially so when the meter readers fail to access the water meter because the premises were either locked at the time of meter reading or when the meter is already found to be defective (specifically, when the meter is not registering despite flow of water) at the time of meter reading. There are also instances when Meter Readers are deliberately denied access to the water meter by people left at home by the family heads. This is mainly due to ignorance by the people left at home like housemaids and or visitors who do not understand how the utility operates. The end result is that the consumption for such a meter is estimated since it is costly for the meter readers to revisit these premises.

When computing the average monthly consumption, the specific months where consumption was estimated (no actual reading was obtained by the Meter Reader due to inability to access the meter), were deleted from the computation. Additionally, when the analysis was computed using a crosstab query in MS Access, some of the meters registered negative averages. A total of 40 meters registered negative consumptions. The highest average monthly consumption computed was 29,261.25 cubic meters of water while the lowest average was 0. In order to avoid outliers in the analysis, 64 large consumers (mainly industrial water users with a consumption average greater than 200 cubic units per month) were eliminated. These are treated as large consumers by the utility and are currently proactively monitored by the branch on a weekly basis while those analysed are only visited once in a month for purposes of meter reading. Additionally, the installation dates of 1,117 meters could not be found in the billing system. This left a total of only 9,915 meters for the analysis.

Descriptive analysis of the average monthly consumption data of the 9,915 meters showed a minimum of 0 and a maximum of 199 cubic meters of water. The minimum of 0 units can be attributed to houses that were not inhabited during the period of analysis. This is mainly associated to houses whose construction has not been completed due to financial constraints. The connection is needed at the start since water is used for construction. The mean average consumption was 20.935 cubic meters as seen in the table below:

Table 5: ***SPSS generated descriptive statistics of Average monthly consumptions per meter***

Descriptives			
		Statistic	Std.Error
AvgOfConsumption	Mean	20.935	.230
	Median	14.000	
	Variance	525.5	
	Std.Deviation	22.924	
	Minimum	.000	
	Maximum	199.	
	Range	199.	
	InterquartileRange	19.00	
	Skewness	2.939	.025
	Kurtosis	12.0	.049

Average consumptions were classified into ten equal class intervals and each interval given a criticality score of between 1 and 10 in ascending order with the lowest average consumption getting a score of 1 and the highest getting a score of 10. Equal class intervals as a method for classification was chosen because it easily emphasizes the amount of an attribute value relative to other values (ESRI, 2006). In this case, the idea is to emphasise the different average consumptions registered by each meter, relative to other meters, since average consumption is used to denote criticality. Relatedly, ten class intervals were chosen in order to accommodate the large data range of 199 so as not to oversimplify the classification for each of the meters, while allowing for future reclassification into five easily interpretable Likert classes for each of the blocks when averaged.

Table 6: Scoring criticality based on average monthly consumption

No	Consumption Interval	Score
1	0 – 19.99	1
2	20 – 39.99	2
3	40 – 59.99	3
4	60 – 79.99	4
5	80 – 99.99	5
6	100 – 119.99	6
7	120 – 139.99	7
8	140 – 159.99	8
9	160 – 179.99	9
10	180 -200	10

Using the table of the individual meter consumption averages, each meter was assigned a criticality score based on its average as per the above table. In order to generate a map that shows the spatial criticality of water meters within each block across Kansanga branch, the scores (1-10) of each of the meters, were first summed up and averaged for each individual blockmap using a crosstab query in Microsoft Access database with the average consumption field chosen as the value field, branch name as the column header and block as Row header. The block averages were chosen primarily because the block represents the smallest spatial unit of operation within the utility. It is the basis for allocation of work like meter reading, field supervision as well as performance analysis.

The shapefile of all blocks in Kansanga was then joined to the table of average criticality for each of the blocks using the Block field. In order to analyse criticality (as well as probability of failure and risk in general), a Likert scale was used. Harry (2012) explains that ‘Likert scale items are created by calculating a composite score (sum or mean) from four or more type Likert-type items; therefore, the composite score for Likert scales should be analyzed at the interval measurement scale”. This means that the categories have a rank order, but the intervals between values cannot be presumed equal (Blaikie, 2003). In ArcMap, the average criticality scores for each of the blocks were then classified into five Likert-like rating intervals (Very low; Low, Moderate, High and Very high) using the Jenks (Natural breaks) classification.

Table 7*: Criticality ranking of water meters within each block*

No	Criticality score Interval	Criticality Ranking
1	1.1 – 1.3	Very low
2	1.3 – 1.5	Low
3	1.5– 1.7	Moderate
4	1.7 – 2.0	High
5	2.0 – 2.3	Very High

Jenks method of generating the five classes was chosen because it generates the classes based on natural groupings inherent in the data (De smith et al, 2015). Schultz (2012) adds that "the class breaks are identified that best group similar values and that maximize the differences between classes and thus minimizes the average deviation from class means, while maximizing the deviation of the means from other groups". In the case of this data, there are meters that had a monthly average consumption of 0m^3 while others had as high as 200m^3. This calls for a suitable method of identifying the class intervals and hence the choice of the natural breaks method. The blocks were then symbolized by a graduated colour ramp using the average criticality field for each block. The resulting map is illustrated in Figure 5, section 4.2

3.3.3 Meter Risk Determination

Risk is computed from an engineering perspective that explains risk as a product of the probability of an event occurring, that is viewed as undesirable, and an assessment of the expected harm from the event occurring (Damodaran 2008; Harlow 2005). This means that risk is a product of probability of occurrence (Meter age) and the damage (Criticality) associated to the failure of the meter in question. The risk associated with any asset can be defined as the product of the probability of failure of such an asset and the likely impact or damage created by such a failure. In order to determine the meter risk, the meter failure index of each meter as computed in 3.3.1 was multiplied by the criticality of such a meter (3.3.2). The result was a risk index for all the meters in Kansanga branch. The resulting individual meter risk indices were then averaged per block in order to generate the average risk per block, using the Crosstab query in MS Access. Descriptive analysis of Meter risk for the blocks using SPSS returned the following:

Table 8: ***SPSS Descriptive statistics of Average risk per block***

Descriptives			
		Statistic	**Std.Error**
AvgOfRisk	Mean	4.499	.116
	Median	4.388	
	Variance	.789	
	Std. Deviation	.888	
	Minimum	2.429	
	Maximum	6.661	
	Range	4.232	
	Interquartile Range	1.403	
	Skewness	.254	.311
	Kurtosis	-.170	.613

There are a total of 59 blocks that make up Kansanga Branch. The highest average risk score is 6.7 while the lowest is 2.4. The mean average risk score is 4.5 and the median is 4.4. The results were saved using a Make Table query in MS Access and linked to the ArcGIS shapefile of blocks found within Kansanga using the Block number. While symbolizing the map in ArcMap, 5 classes of risk were created using the Jenks/Natural breaks method. These classes were then given the 5 Likert rankings of Very Low, Low, Moderate, High and Very High to denote the different levels of risk. The five levels of ranking were chosen in order to easily communicate the extent to which risk is attributed to a specific block relative to others. The lower the average risk class interval, the lower the rank associated and the higher the average risk class interval, the higher the rank associated to it. The resulting table is as shown below:

Table 9: ***Risk Ranking of Blocks within Kansanga***

No	Average risk score per block	Risk Ranking
1	2.4 -3.5	Very low
2	3.5 -4.2	Low
3	4.2– 4.8	Moderate
4	4.8 – 5.6	High
5	5.6 – 6.7	Very High

It is the above table generated in ArcMap that was symbolized using a graduated colour ramp to generate the map seen in Figure 6.

3.3.4 Model Validation

Validation is a set of methods for judging a model's accuracy in making relevant predictions (David et al, 2012). Mayhew (1984) adds that in most cases, formal models, including computational models, are evaluated in terms of their clarity, parsimony, generality, and testability. In this study, the focus is only on the testability of the model, also called model validity. Knepell and Arangno, (1993) explain that there are six types of validation: conceptual, internal, external, cross-model, data, and security. In this study, the focus is on external or operational validity. Carley (1996) explains that external or operational validity is concerned with the linkage between the simulated and the real. External validity refers to the adequacy and accuracy of the computational model in matching real world data. In carrying out external validation, verification as a method was used. Carley (1996) defines verification as a set of techniques for determining the validity of a computational model's predictions relative to a set of real data. In order for a model to be verified, the model's predictions are compared graphically or statistically with the real data (Kleijnen, 1995b). In this study, the assumption is that as a meter ages, its probability of failure increases.

In order to validate the assumption used in the study, real data collected about meter failure in Kansanga branch was used. Data for the period of one year from October, 2014 to March, 2016 was extracted from the meter readings database. The defective meters identified were then joined to the table containing the 9915 meters of Kansanga in order to select only those related to the data being analysed. Out of the 9915 meters analysed, a total of 686 were reported to have been defective within this period.

These data was subjected to exploratory descriptive analysis using SPSS. The results of the descriptive statistics were then compared to those of the descriptive statistics for all meters in the branch where the assumption had been used.

Relatedly, the same data regarding the number of meters that failed within Kansanga was cross-tabulated in MS Access to generate the number of meter failures per block. The resulting number of failures within a given block was then correlated with the average probability of failure within each block generated in 3.2 above. It must be noted that the data that was correlated was only for the blocks where the meters were found to have failed (defective meters found). Although Kansanga has a total of 62 blocks, only 59 have meters installed in them and of the 59, meter failures were only registered in 57 blocks over the period of one year. A count of 0 in terms of the number of meter failures was allocated to the two blocks that did not register any meter failures. The other blocks that are yet to register new connection applicants were not considered in the analysis. It is the data for the 57 blocks which was correlated with the corresponding data about average probability of meter failure within each of them.

4. RESULTS AND DISCUSSION

Analysis of Meter Risk within Kansanga branch was carried out considering a total of 9915 meters. Their probability of failure was estimated using the meter age while their criticality was estimated using their monthly average volume of water dispensed through the respective meters. Risk was then computed as a product of the probability of meter failure and the criticality of such failure. The model was validated using a total of 686 meters that actually failed during a period of one year within the study area. Below is a detailed discussion of the results.

4.1 Probability of Meter Failure

The meter failure index (representing probability of Meter failure) was also subjected to descriptive statistical analysis using SPSS. The resulting table shows a median score of 4 years and a mean score of 4.32 years. Given that the median is lower than the mean, the data suggests positive skewness. However, in this case, the mean is very close to the median and this means that the data is slightly positively skewed compared to that of the average monthly meter consumptions (criticality) registered. This means that there are more meters that are less than 4 years old in the system, as compared to those that are more than 4 years old

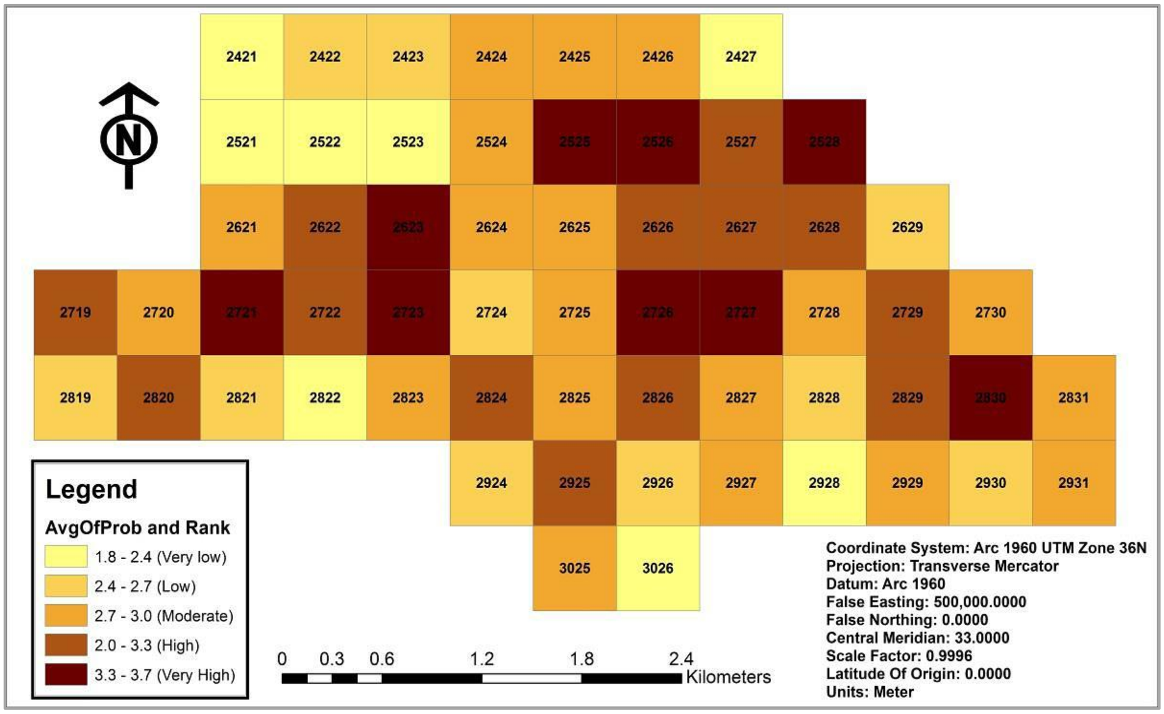


Figure 4: ***Average probability of meter failure and rank across Kansanga branch***
Source: Gilbert Akol ECHELAI, NWSC, (2016)

Figure 4 above indeed shows that some blocks have older meters (darker colors and higher average probability of failure indices) as compared to others (lighter colours and lower associated probabilities of failure indices).

4.2 Meter Criticality

The summary of descriptive statistics on the average monthly consumption volumes registered per meter shows that the median (14) is smaller than the mean (20.94).This shows that the data is positively skewed with more observations having average monthly consumptions that are lower than the mean consumption (Pallant 2013; Rogerson 2001). This is supported by the positive value of skewness (2.94) as seen in Table 2 above. This means that more customers register average consumptions of less than 20 cubic units per month, than those who register above 20 cubic units. This is also in line with the fact that the domestic consumers account for a majority of the 9,915 meters analysed in Kansanga branch. The data on customer profiles is as summarised in Table10 below.

Table 10: ***Summary of customer categories***

No	Probability Interval	No of Meters	Percentage
1	Domestic	8179	82.49%
2	Commercial/Industrial	1273	12.84%
3	Government Institutions and Foreign missions	217	2.19%
5	Public Stand pipes	246	2.48
Total		9915	100%

Overall, domestic consumers use less water on average as compared to the commercial/Industrial, Government and Public Standpipes consumption categories. A further look at figure 4 indeed reveals that certain blocks enjoy higher average monthly consumptions than others and hence represent higher average criticality to the utility than others. These blocks therefore represent locations where meters that register higher average monthly consumptions are located as seen below

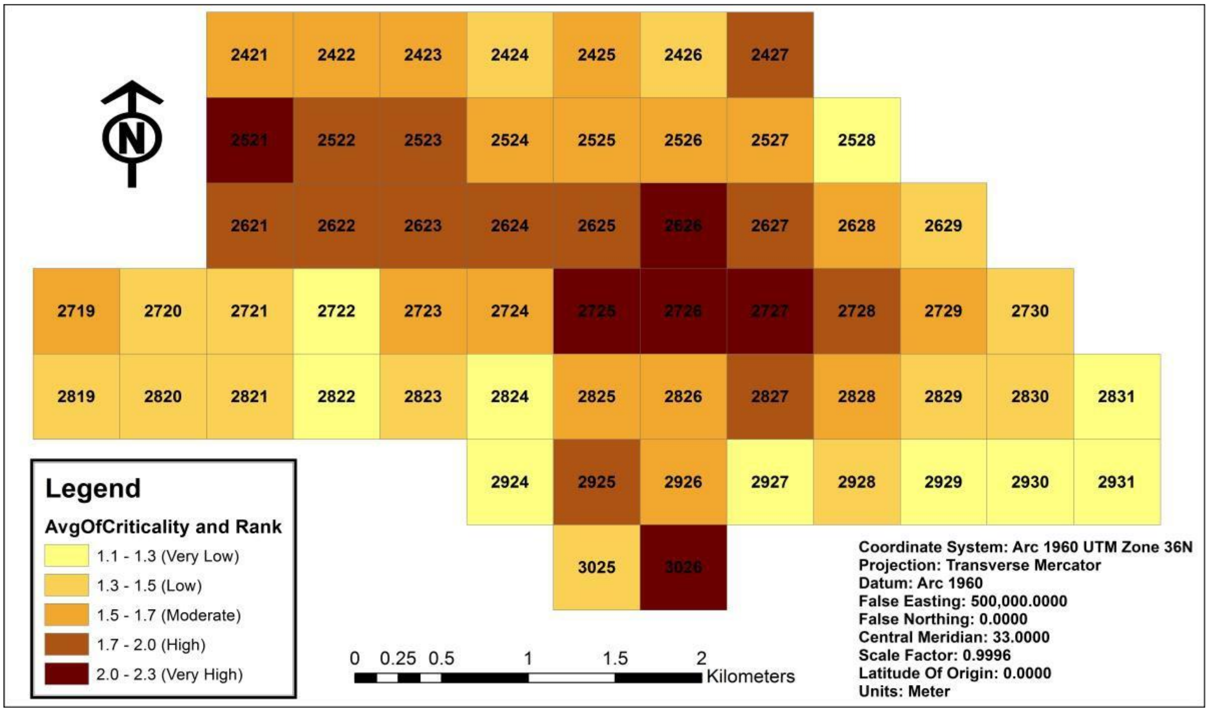


Figure 5*: Average criticality score and ranking per block across Kansanga Branch*

Source: Gilbert Akol ECHELAI, NWSC (2016).

4.3 Meter Risk

A spatial distribution of meter risk across Kansanga can be seen in Fig.6 below. The map shows that the darker the colors the higher the risk of the meters located within such a block. Conversely, the lighter the colours, the lower the risk associated to such blocks. Given that the median value is lower than the mean value, one can conclude that the data is slightly positively skewed with more blocks having risk levels that are lower than the mean value and less blocks having risk levels higher than the mean value. Criticality was denoted by average monthly water consumption volumes while probability was derived from the meter age. Analysis of the Risk model for the water meters in Kansanga showed that indeed certain water meters pose a higher level of risk to the utility than others. Using the Lickert scale (Very High, High, Moderate, Low and very low) to denote levels of risk, it was possible to geovisualise the blocks that had high levels of risk compared to others. This is illustrated in the map below:

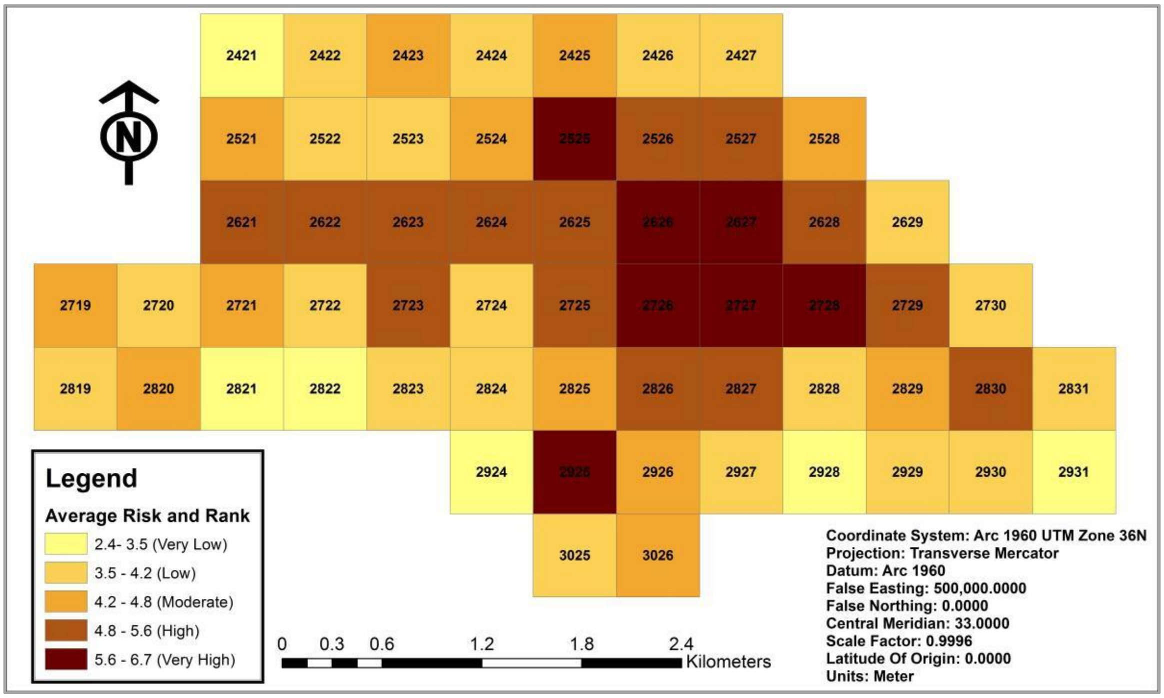


Figure 6: ***Ranking Average Meter risk across the blocks of Kansanga***

Source: Gilbert Akol ECHELAI, NWSC (2016)

4.4 Model Validation

In this study Meter Risk is estimated as a product of the probability of failure and the criticality of such a failure. In validating the model probability of meter failure was validated using actual meter failures that were registered by the utility for the meters located within the area of study.

Figure 4 above shows the spatial distribution of the probability of meter failure across Kansanga based on the assumption that as a meter ages, its probability of failure rises. The maps shows that the darker the color within a given block, the higher the probability of meter failure in that block, and conversely; the lighter the color, the lower the probability of meter failure. In this regard, the model points out that the blocks with the highest probability of meter failure are 2525, 2526, 2528, 2623, 2723, 2721, 2726, 2727 and 2830 as seen in Figure.5 above. In order to validate this assumption, the meter failures registered from October, 2014 to March, 2016 were extracted from the meter readings database. There were a total of 686 meters that were registered as defective during this period. The count of failures within each block was generated using a crosstab query. The resulting number of meter failures within each block was then added as a column to the table that was earlier generated showing the average probability of meter failure within each block.

Blocks 2421 and 2521 did not register any meter failure and were therefore given a countof0interms of the number of meter failures. A correlation analysis between the number of meter failures within each block and the average probability of failure generated for each block was done using SPSS. The results are as follows:

Table 11: ***SPSS generated correlation between Average Meter Failure Index within each block and the actual number of Defective Meters registered in each block in Kansanga***

Correlations			
		CountOfDefective	ProbabilityScore
CountOfDefectivemeters	PearsonCorrelation	1	.247
	Sig.(2-tailed)		.059
	N	59	59
Average Probability Score for each block	Pearson Correlation	.247	1
	Sig.(2-tailed)	.059	
	N	59	59

From the above table, it can be seen that there is a positive correlation (0.247) between the number of defective meters registered per block and the Average Meter Failure Index generated for each block. This means that where the Meter Failure Index is high, there is a higher likelihood of meters failing within that block. Given the P Value of 0.059, it is greater than both 0.01 and 0.05. This means that the correlation coefficient (r) of 0.247 is insignificant at both 0.01 and 0.05 levels of confidence.

The conclusion here is that meter age alone cannot adequately explain the number of defective meters reported in each of the blocks. Although the correlation is positive, there are also other contributing factors to meter failure within each block. The model was further subjected to validation using the individual meter data, without aggregating it per block. In this case, the individual meter age of the defective meters was compared to the meter age of the entire dataset. The age of each of the defective meters was calculated by subtracting the year of installation from year that the specific meters were reported as defective. This dataset on the age of defective meters was then compared with the age of the meters that comprise the entire dataset within the branch. Using SPSS, a descriptive analysis of the actual meters that were reported as defective revealed the following:

Table 12: ***SPSS generated descriptive statistics for Defective Meters registered in Kansanga***

Descriptives			
		Statistic	**Std.Error**
Age	Mean	6.24	.128
	95% Confidence Interval for Mean	5.98	
		6.49	
	5% Trimmed Mean	6.12	
	Median	6	
	Variance	11.279	
	Std.Deviation	3.358	
	Minimum	1	
	Maximum	17	
	Range	16	
	InterquartileRange	6	
	Skewness	.359	.093
	Kurtosis	-.046	.187

Comparing these descriptive statistics with the statistics earlier generated from the Meter Failure Index, provides an indication of the validity of the model for probability of meter failure. From the above table, it can be seen that the oldest meter to register as defective was 17 years of age while the latest was 1 year. The mean age of defective meters was 6.24 and the median 6.0 and therefore, one can see that the median is slightly lower than the mean. This means that the data is positively skewed.

Positive skewness means that there are more defective meters with an age that is less than the mean age of 6.24. Comparing the mean and median age of the defective meters (6.24) and (6.0) respectively, to the mean and median of the 9,915 meters analysed within the branch (4.32 and 4.0 respectively), one can notice that both the mean and median of the defective meters is way higher than that of the overall meters analysed. This means that on average the meters that fail are older as compared to the others. This is in line with the assumption that as meters age, their chances of failure increase, as assumed in this study.

Analysis of the correlation between the average age of the defective meters within each block and the average meter failure index per block for all meters (9,915) across Kansanga revealed the following table:

Table 13: ***SPSS generated correlation between the average meter failure index and the actual average age of failure within each block***

Correlations

		AvgOfProb	AvgOfAge
AvgOfProb	PearsonCorrelation	1	.372**
	Sig.(2-tailed)		.004
	N	57	57
AvgOfAge	PearsonCorrelation	.372**	1
	Sig.(2-tailed)	.004	
	N	57	57

**.Correlation is significant at the 0.01 level (2-tailed).

In order to determine significance of the resulting correlation coefficient, a comparison was made between the P values and the stated levels of significance. One can notice that there is a positive correlation (0.372) between the two parameters with a 95% level of confidence. This means that as the age of the meter rises, the meter failure index too increases and this is in line with the model assumptions.

The descriptive statistics of meters that actually failed was compared to the statistics of all meters within the branch. The data for defective meters was slightly positively skewed. Comparing the mean and median of the defective meters, they were higher than those of all the meters within the branch (6.24 and 6.0 against 4.32 and 4.0 respectively). Relatedly, the correlation between the estimated average probability of failure within a given block and the average age of the meters that were actually registered as defective (failed) was positive (0.372) and significant at both 0.05 and 0.01 levels of significance.

All the above arguments point to the fact that indeed there is positive relationship between the meter failure and the age of the meters. As the age of meters increases, their likelihood of failing also rises. However given that the data for defective meters was slightly positively skewed with the median being slightly lower (6.0) than the mean (6.4), one notices that more meters that failed were less than 6.4 years of age. Relatedly, a correlation coefficient of 0.247 between the total number of actual defective meters within a given block against the average estimated probability of meter failure within a given block was; positive but not significant at either 0.05 or 0.01 levels of significance.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Meters form one of the most critical assets of any utility as they are the basis for determining the volume of water consumed by any individual customer. However, these meters are subject to failure or under registration due to a variety of reasons ranging from age (wear and tear) and quality of water among other reasons. Whenever such a failure occurs, the utility revenues are at risk. This means that the utility must be able to institute management measures that allow for early detection of such failures in order to reduce the time between actual failure and detection of such a failure. This is very important since these meters are not equipped with any technology to report such failure except when visited physically.

This study has demonstrated the role that GIS can play when integrated in meter management. This is through the power inherent in GIS of giving a location meaning to any form of analysis. In the study, risk was estimated as a product of the probability of meter failure index and meter criticality index.

5.1.1 Estimation and Geovisualisation of the probability of Meter Failure

A Meter Failure Index was generated to represent the probability of Meter Failure. The age of individual meters was divided by the estimated design life of the mechanical meters (10 years) in order to derive the meter failure index for each meter. This index generated was classified into ten equal classes and each class given a score ranging from 1 to 10, with the lowest class assigned a score of 1 and the highest class assigned a score of ten. The scores assigned to meters within a given block were then averaged and the data linked to the GIS shapefile of blocks located in Kansanga. Using a 5 Class Likert Scale (Very low, Low, Moderate, High and Very High), the resulting data was visualized in ArcMap. A gradual colour ramp was used to represent the five different ranks with the darker colours showing blocks where meters were more likely to fail on average, and the lighter colours showing there they were least likely to fail, considering their age. Although the data shows a positive correlation between the age of a meter and its likelihood to fail, there is a need to consider more variables (water quality, meter class, how meter is installed, etc) that also contribute to meter failure. This could affect the nature of map generated.

5.1.2 Estimation and Geovisualisation of the Meter Criticality

In order to estimate criticality, the average water consumption for all the meters over a period of one year were obtained from the utility billing database. Average consumption was used to represent the criticality of each meter. The range of all average consumptions was divided into ten equal class intervals and scores of between 1 and 10 assigned to each each meter. The resulting scores for all meters within a given block were then averaged to generate criticality index for each of the block blocks. The data of averages for all the blocks was then linked to ArcGIS and geovisualised on a 5 class Likert Scale, with the lighter colours representing blocks with low average consumptions and hence low criticality while the blocks with darker colours represented higher average consumptions and thus higher criticality rank levels. Generally speaking, the more water that is dispensed by a water meter, the more critical such a meter is to the utility since the volume of water translates into revenue. However, there are other factors that were not considered that could also contribute to criticality: the tariff applicable to a particular customer meter, the cost of purchase and maintenance, etc.

5.1.3 Estimation and Geovisualisation of Meter Risk

In order to estimate Meter risk, the Meter Criticality Index was multiplied by the Meter criticality Index for each of the meters. The resulting data was averaged per bock map (considering all meters within a given block) and data linked to ArcGIS shapefiles defining all blocks in the branch. A gradual colour ramp was used to visualize the data against a 5 class Likert Scale and each class assigned a rank of either Very Low, Low, Moderate, High or Very High to denote the rank of risk associated to each block. Low risk scores were assigned lighter colours and high risk scores darker colours. In order to improve this map, the estimation of the meter failure index and the criticality index need to be improved.

5.2 Suggested Improvements to the model

5.2.1 Probability of Meter Failure

The probability of meter failure was estimated using a probability of Meter Failure Index. The darker the color of a given block, the higher the average age of meters within that block and consequently, the higher the probability of meter failure within that block. Several analyses were carried out to validate this assumption as described in 4.4 above.

The conclusion is that meter age alone cannot adequately explain meter failure. There are other contributing factors to meter failure. It could be the meter make (manufacturer), the quality of water, the way the meter is installed, etc. These factors need to be studied and incorporated in model estimation so as to improve the prediction ability of the model. Relatedly, there was little data available for validation. Although some of the meters in Kansanga were as old as 18 years, the data for actual meter failures registered that was accessed was for only one year! More data on meter failure needs to be collected and analysed for better correlation purposes.

5.2.2 Meter Criticality

Meter Criticality was approximated using the monthly average volume of water consumed or dispensed by the water meter. This was spatially presented as in Figure 5 where the darker colors show higher average consumption volumes per block and the lighter colors show lower monthly average consumptions registered for the given block. Indeed the more volume of water consumed, the more revenue that the utility is expected to generate as the water bill is a product of the volume consumed and the tariff applicable. The more water a meter dispenses, the more critical such a meter becomes to the utility as its contribution to the utility revenues rises. However, given different meters have different costs of procurement, it would also be better if the cost of purchase and maintenance of the individual meters were considered in determining criticality. This is because the higher the cost of purchase and maintenance of any given meter, the more critical it would be to the utility since its failure means that the utility has to spend more money to maintain and or replace such meter.

5.2.3 Meter Risk

Risk is generated as a product of the probability of failure and the criticality of failure. The spatial representation of risk is presented in Figure 6 above where the darker colors show that on average which blocks have a higher level of risk as compared to those with lighter colors. However, given that risk is a product of probability of failure and criticality of failure, the reliability of the model rests on how accurately probability of failure and the criticality of failure have been estimated. Improvements in the estimation of probability of failure and the criticality of failure as suggested above will improve the estimation of risk.

5.3 Recommendations to National Water and Sewerage Corporation

National Water and Sewerage Corporation relies on the accuracy of its water meters to determine the amount to invoice its customers. The water meter therefore is vital for the financial sustainability of the utility. This study is beneficial to the utility in a number of ways

The estimation of the probability of meter failure gives an indication of the age of meters across the supply area. The analysis has shown that indeed there is a positive correlation between the age of water meters and the probability of failure. Although this particular assumption requires further studies to improve, it shows that the utility needs to consider implementing an effective meter management policy that takes into consideration the age of water meters, their repair and or replacement. This will help inform the budgeting process for management. Older meters that are more likely to fail can easily be identified.

Meter Criticality is a significant aspect of meter management. Meters that dispense higher volumes of water are more critical than those that dispense less volumes of water. This is largely due to the fact that if such meters failed, then the customer will most likely consume free water as the meter either under registers consumption or does not register at all. The visualization of criticality based on average monthly consumption helps the utility to plan and effectively deploy its field monitoring teams. Blocks that have higher average monthly consumptions can therefore be prioritised for more frequent monitoring e.g. bi-weekly monitoring instead of waiting until the end of the month when the Meter readers make their monthly visits to read the water meters. When a utility reduces the response time to a defective meter, it reduces the potential losses that could arise out of under registration or no registration at all. This is especially so because most customers are not vigilant enough to understand that their water meter has failed or is under registering. Where such a bill gets estimated, it is a source of customer dissatisfaction since he is not sure of the estimated bill generated by the utility.

Meter risk combines criticality and the probability of failure. In this regard, some meters may be very old, but dispense less water and hence may not pose a major risk to the utility. On the other hand, some meters may be new, but are susceptible to failure in some way. Estimating risk helps the utility to understand how to plan for and manage both criticality and probability of failure and hence optimise staff deployments and interventions to address inherent risks associated with water meters.

The integration of GIS has helped visualize the data. The deployment of staff is based on geographically defined boundaries whose lowest unit is the block. GIS has been able to spatially allocate the extent of probability, criticality as well as risk to these blocks. This is very useful to the managers when planning how to allocate not only staff but resources as well like transport (how many blocks is someone responsible for in terms of servicing, repair etc.), number of water meters budgeted for replacement per block, volume of staff allocated to address meter management, meter repair planning, etc. Without the use of GIS, it would be very difficult to apportion these resources equitably across the different blocks, and subsequently branches within Kampala Water.

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