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Application of Geospatial Technology in Curbing Non Revenue Water: A Case Study of Murang'a Municipality

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Abstract: ***Non Revenue Water is water that has been produced but cannot be accounted for through billing process. This has been contributed by frequent bursts, meter inaccuracy as well as high pressure within the water reticulation system. Murang'a Water and Sanitation Company laid numerous spatially related strategies to reduce NRW level from 49% to 20%, but due to lack of a spatially indexed tool which would assist in planning, budgeting and procurement of appropriate items, the implementation exercise was ineffective, resulting to abandonment of the strategies before achieving the expected results. This project aims at utilizing GIS technology in the implementation of the spatially related strategies to curb high NRW level. The methodology adopted involved data collection whereby GPS points for water facilities, pressure data, elevation data, NRW data and cadastral data were obtained. The data was harmonized through creation of a geodatabase. Pressure data and elevation data were interpolated using Inverse distance weighted method. Geoidal Undulation was applied to ellipsoidal height collected using GPS to obtain orthometric height before interpolation was done. Data were then integrated in a GIS platform and numerous analyses performed including identification of pipes networks prone to bursts and leakages, identification of class A and B meters that required immediate replacement, buffering from road reserve sharing boundary with consumers' parcels of land through which topological analyses identified connections served by long service lines exceeding 5m from the distribution main, suitable regions for installing Pressure Reducing Valves as well as Air Reducing Valves. Susceptibility and vulnerability to bursts and leakages model was generated using pressure data and elevation data to identify regions within the zone requiring special attention. In addition, network dataset was developed that has capacity of generating optimal routes for quick response to bursts and leakages. Solutions to the effective implementation of these strategies were arrived at, through effective handling of spatial data related to water reticulation systems using GIS technology.***

Keywords: Spatial strategies, Non Revenue Water, GIS, Pressure Reducing Valves, Air Releasing Valves, District Metered Area.

1. Introduction

The world faces a huge challenge in providing improved water supply and sanitation services especially in urban areas in the developing world, where population growth rates have been highest. The World Bank estimates that in developing countries, leakage is about 45 million cubic meters per day (m^3/day) [1]. Nevertheless, studies have shown that efforts toward conservation and Non Revenue Water reduction can provide water at about one-half to one-third of the cost of water production [2]. NRW is water that has been produced but cannot be billed [3].

NRW includes physical losses (pipe leaks) and commercial losses (illegal connections, unmetered public use, meter error, unbilled metered water, and water for which payment is not collected)[4]. NRW levels are high in many developing countries and they can be expensive to reduce [5]. High levels of NRW are detrimental to the financial viability of water utilities as well as water [6], [7]. Metering of water use at the level of production at key points in the distribution network and for consumers is essential to estimate levels of NRW [8]. It is therefore necessary to be very careful of type and specification of the meter suitable based on the water quality to be measured.

Over the past three years, Murang'a Water and Sanitation Company Limited had continued to put more effort on curbing NRW to allowable level of less than 20% from 49% [9]. The process had been ineffective due to lack of spatial information related to water reticulation system within the area [10]. Thus, the general objective of this project was to develop an appropriate spatial database that would assist in planning, budgeting and full implementation of spatially related strategies and policies whose mission is to reduce NRW.

The specific objectives focus in identifying pipe networks frequently reported of having bursts and leakages; Identifying categories and classes of meters installed and those requiring replacement for been class A or B which are of low quality; Determining pressure distribution within the pilot project zone to assist in the installation of PRVs [11]; Determining the consumers' connections served with long service lines exceeding 5m from the distribution main to facilitate relocation exercise; Generating optimal routes for effective and efficient reading of sub-zonal master meters as well as attending bursts and leakages minimizing time, money, labour, distance; Determining the vulnerability of the region within the zone to bursts and leakages as well as suitable locations for installing air releasing valves to avoid throttling effect.

Since it was impossible to work on the whole supply area at once, called for subdividing it into manageable pieces whereby Station Road zone within Murang'a Municipality was selected as the pilot project [12]. GIS being a powerful tool made the process of decision making based on spatial locations of water facilities very easy [13]. GIS assisted in mapping all infrastructure components i.e. incoming/ outgoing DMA meters, primary and secondary distribution network, consumer meters, service connections, valves etc. The analysis of faulty and under/over-registering meter causes (dirt, sub-standard specifications, sub-standard quality, and age), locations of leakages (pins on hardcopy maps or GPS coordinates) were important ingredients considered while conducting this research [14].

2. Problem statement

In Murang'a Water and Sanitation Company, spatial information of pipes networks, pressure distribution, faulty meters, low quality meters as well as dilapidated network required urgent consideration [15]. Numerous strategies for reducing NRW from 49% to 20% have been developed, but due to lack of a spatially indexed tool which would assist in planning, budgeting and procurement of appropriate items made the implementation exercise ineffective. This resulted to abandonment of the strategies before achieving the expected results [12]. One of the strategies stipulated was to identify pressure distribution within the water reticulation systems. The exercise was conducted, but the obtained pressure data lacked spatial index that would show spatial distribution of pressure within the network [9]. This required a compilation of pressure distribution map that would provide a room for overlaying other data, so that identification of pipes network recording high pressure would be very easy and assists in identifying suitable locations for installing PRVs [11].

Within MUWASCO's area of jurisdiction, most consumers' meters were found located in the consumers' homes compounds leading to long service lines from the distribution main. They were more prone to interference by human activities resulting to physical losses [12]. From the bursts record, it was realized that they contributed the highest percentage of bursts reported and called for a need of relocating them to at most 5m from the distribution main. Another strategy that was laid was the replacement of low quality meters with high quality ones. MUWASCO had used a mixture of different classes of water meters of different categories [10]. Water meter installed included class A, B and C and from meter calibration tests results, Class A and B were of low quality compared to class C type and thus was an urgent need to replace class A and B meters with class C as recommended by WASREB [12]. Lack of actual number of meters required to be replaced caused a problem in budgeting and procurement process of Class C meters.

Moreover, there was a need for identifying locations within the pipe networks where other water facilities especially Pressure Reducing Valves and Air Releasing Valves could be installed [15], [16]. Due to lack of clear knowledge of the existing water facilities, pressure distribution as well as the topography (terrain) variations, the exercise was abandoned [12]. For effective response to bursts, leakages, relocation exercise as well as monitoring the area, there was a need to generate optimal routes for immediate and quick response to bursts [13]. In addition, there was a need to identify regions within the area of jurisdiction susceptible and high vulnerable to bursts and leakages caused by driving factors such as pressure and elevation change so that appropriate measure would be taken [17], [18].

3. Study area

MUWASCO is located in Murang'a Municipality, Murang'a County. It has 6,414 active consumers' connections where it supplies water. Its area of jurisdiction is approximately 142 km^2 but currently served area is 44 km^2. MUWASCO area of jurisdiction lies between longitudes 37° 4′ 30″ E and 37° 15′ 0″ E and latitudes 0° 46′ 0″ S and 0° 44′ 30″ S. The area is zoned into fives zones namely Njoguini, Karuri, Mumbi, Maragi, Kongoini. In particular, the zone of interest is Mumbi which contains the Station Road pilot project zone of interest. Figure 1 shows Station road pilot project zone.

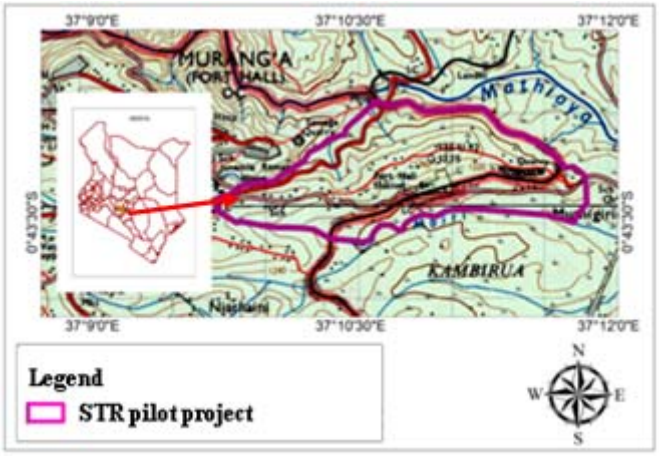

Figure 1: Station Road pilot project zone

4. Methodology

The project explores the viability of GIS technology in curbing NRW in Murang'a Municipality especially within the Station road zone that was selected as the pilot project area. Problem definition reviewed the general challenges experienced in MUWASCO in the implementation of spatially related problems pertaining curbing NRW in the Station Road pilot project zone.

After this, the research objectives were developed which guided on the relevant data to be collected pertaining water reticulation system as well as NRW. GPS data for water meters, gate valves, sluice valves, water lines (i.e. Primary, Secondary and Service mains), pressure data were collected using Hand held GPS and Pressure gauge. Moreover Cadastral data, roads shapefile, topographical maps as well as elevation data were obtained. All these data were harmonized to the same coordinate system i.e. UTM zone 37S. This was achieved by first geo-referencing topographical map using the UTM coordinates of four known points. Cadastral data was geo-referenced using the prominent landmarks and intersections of features such as

roads junctions as well as river junctions clearly visible on both topographical map as well as cadastral data. Then data digitization and editing was carried out to improve data integrity.

Then all data from various sources were integrated whereby attributes data were added to the spatial data. Observed pressure data collected using GPS and pressure gauge was interpolated using inverse distance weight interpolation method. This generated a continuous field that was used for further analyses as well as showing the spatial distribution of pressure within the zone. Due to inappropriate representation of the ground by the 30m resolution SRTM, ellipsoidal heights covering the region were collected. The ellipsoidal heights obtained were then reduced by application of geoidal undulations derived from EGM96 to obtain relatively more accurate orthometric heights. The obtained orthometric heights were then interpolated using inverse distance weighting (IDW) method to generate a digital elevation model of the region.

A selection by attribute spatial analyses was conducted to identify class A and B meters that required to be replaced for their inaccuracy. Moreover, a buffer of 5m from the road reserve that shares boundary with consumers' parcels of lands was generated. This aided in determining the consumers' connections served with long service lines exceeding 5m that were frequently interfered with by human activities. To be proactive in attending bursts, a network database was generated using distance as the impedance. This was used to generate optimal routes that facilitate quick attention to bursts and repairs where deemed necessary.

Susceptibility and a vulnerability to bursts and leakages model were developed. This was developed taking into consideration of pressure and elevation change as the driving factors. Pressure data was assigned a weight of 25% while the later was assigned a weight of 75%. This was because pressure data is dependent on the elevation change. In addition, a model to generate suitable regions within the water reticulation system, where Air Releasing Valves (ARVs) should be installed was also generated. This was achieved by consideration of pressure data, elevation data, slope data as well as Euclidian distance data. Pressure data was reclassified into three classes i.e. pressure data below 3 bars, pressure data between 3-4bars which is the recommended pressure as well as pressure data above 4bars. Elevation data was also reclassified using Triangular irregular network to determine the peak or crest points which are recommended for installing Air Releasing Valves (ARVs).

Slope was reclassified into two classes, whereby the slope between 0-7˚ was considered the most appropriate for installing ARVs while slope above 7˚ was considered unsuitable. Euclidian distance was reclassified with an aim of restricting the suitable regions from the weighted overlay model to be within the pipe network locations. In the weighted overlay model, elevation data was assigned a weight of 60%, pressure was assigned a weight of 20%, slope was assigned a weight of 10% and Euclidian distance a weight of 10%. This was because pressure and slope are dependent on the elevation change. Euclidian distance was just used to restrict regions to be within the pipe network. The results were represented in form of maps, tables, graphs, reports and pie charts. The overall approach of the project was as shown in Figure 2.

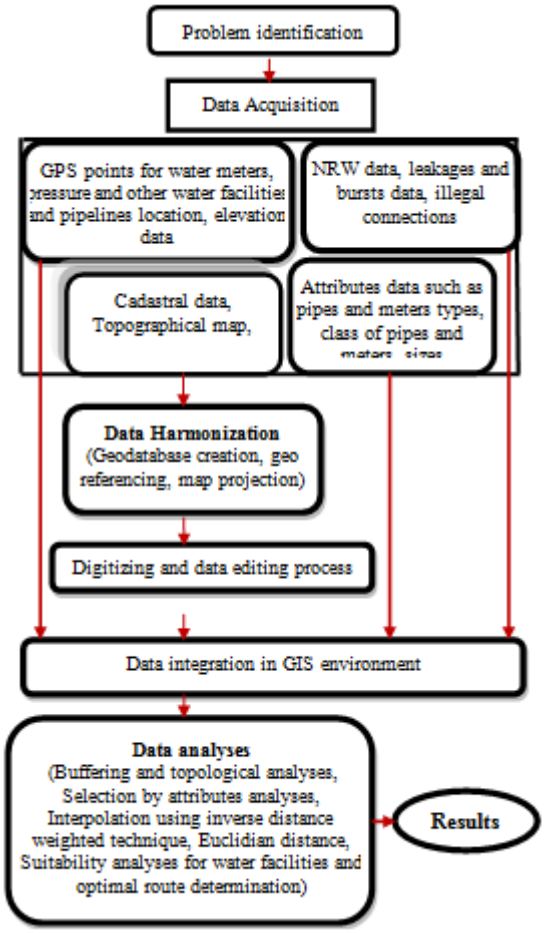

Figure 2: Overall Approach of the project

5. Results and Discussion

5.1 Station Road zone water reticulation system

A water reticulation systems map of Station road zone was generated as shown in Figure 3. It shows pipe networks, water meters, District Water Meters (DMA) as well cadastral data. Pipe networks were categorized into three i.e. primary distribution main, secondary distribution main and service main.

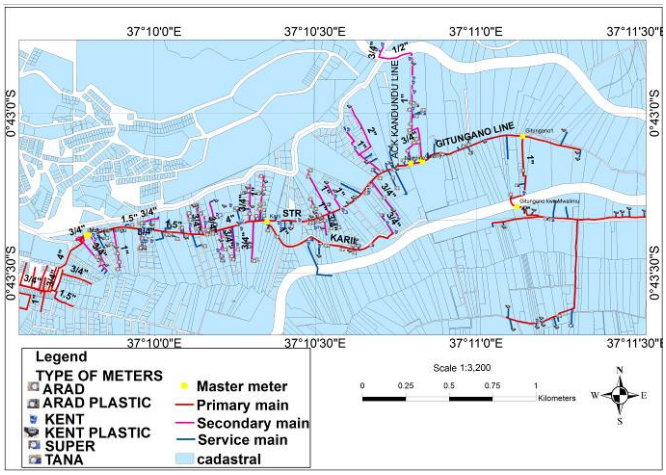

Figure 3: Station road water reticulation system

Water meters installed in this zone were of different Make as shown in Figure 4 including Arad, Arad plastic, Kent, Kent plastic, Super and Tana. Arad and Kent belong to class C which was recommended by Water Services Regulatory Board (WASREB) for its efficiency and accuracy, Arad plastic and Kent plastic belong to class B while Super and Tana are class A meters that are of low quality. All Class A and B meters required to be replaced with class C. It was identified that there were 21 class A meters, 80 class B meters and 187 class C meters. Thus, a map and a pie chart were generated, showing several classes of meters installed in the zone as shown in Figure 5 and Figure 6 respectively. Out of 288 connections, 101 connections required to be replaced with class C meters.

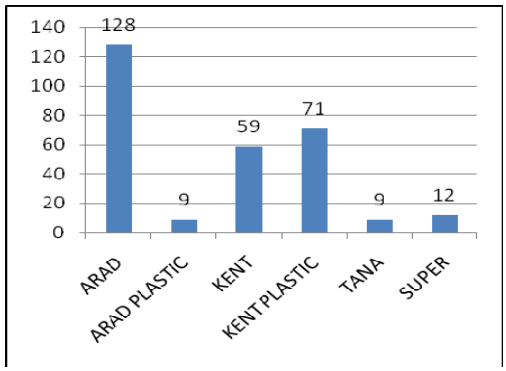

Figure 4: Categories of meters installed

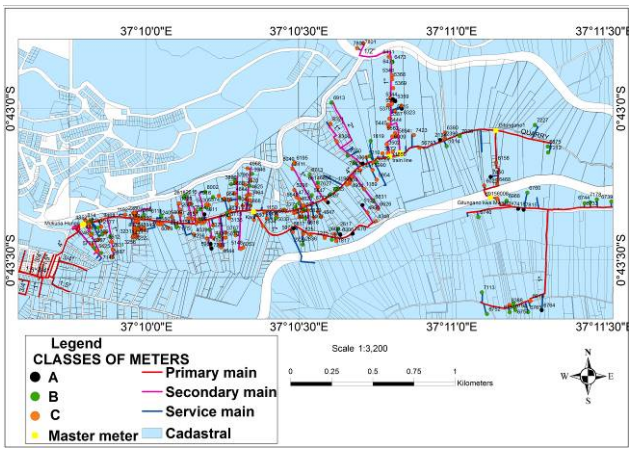

Figure 5: Classes of meters installed

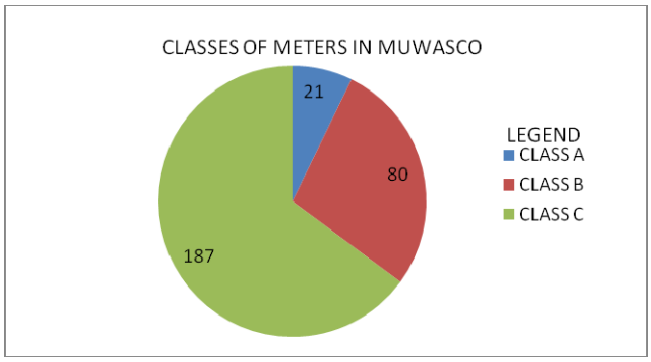

Figure6: Number of meters in each class

5.2 Pipe Network Prone to Bursts and Leakages

It was noted that there were three lines that were frequently reported of having bursts i.e. Karii line with 27 connections, Quarry (ACK Kandundu line) and another line serving five connections were prone to bursts based on the bursts record data obtained within a period of six months as shown in Figure 7.

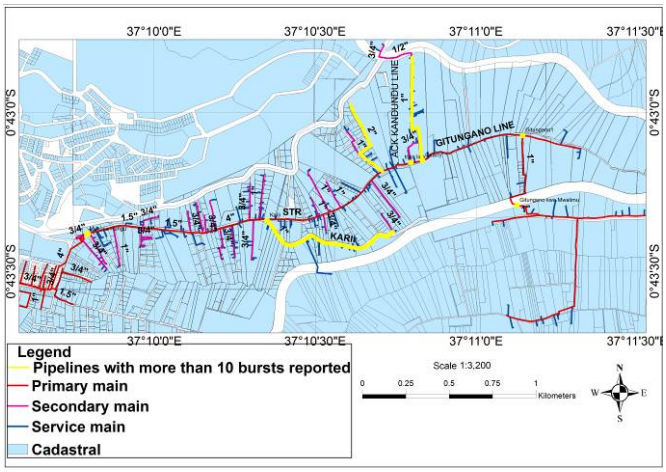

Figure 7:Pipe networks prone to bursts and leakages

The pipe networks symbolized with a yellow colour, had more than ten bursts and leakages recorded within a span of six months.These lines were unstable and thus frequently reported of contributing to high NRW level.

5.3 Connections served with long service lines

Comparison of bursts recorded based on the category of pipes network, (i.e. primary main, secondary main and service main) was undertaken as shown in Figure 8. It was noted that, service lines had the greatest number of bursts i.e. 128 compared to 98 bursts for the secondary main and 32 bursts for primary main. Taking into consideration the amount of water that was lost through long service lines, there was a need to relocate consumers' connections to at most 5m from the distribution main thus minimizing interference by human activities.

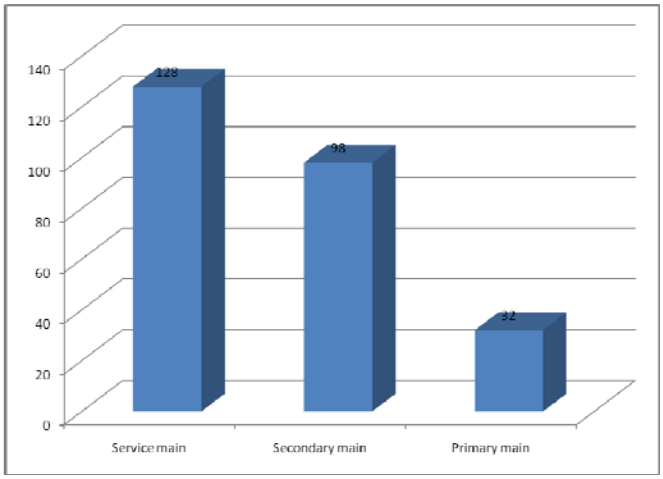

Figure8: Bursts recorded based on the category pipe network

To overcome the problem of very long service lines, GIS technology generated a 5m buffer zone based on road reserve polygon, sharing boundary with consumers' parcels or plots. Using topological analyses, all consumers' water connections beyond five meters from distribution mains were identified as shown in Figure 9. The map would assist greatly in identification of locations of all connections served with long service lines for purpose of relocation. Out of 288 connections, 180 of them were identified located beyond 5m from the distribution main and required to be relocated.

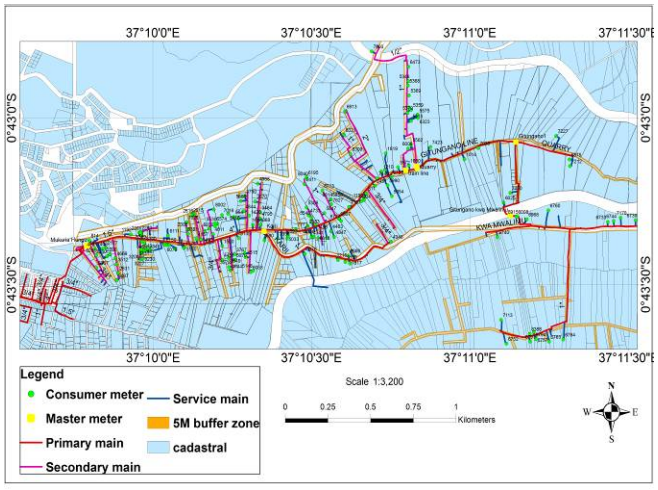

Figure 9: Connections to be relocated

5.4 Optimal routes

For effective and quick response to bursts as communicated by customers or Customer Relation Officer (CRO) to the plumber, it was very important for the plumber to use the optimal route possible to attend the issue before losing a lot of water contributing to high NRW level. This was made possible by creation of network database that aided in generation of optimal routes using distance as the impedance. The demonstration of the same is shown in Figure 10.

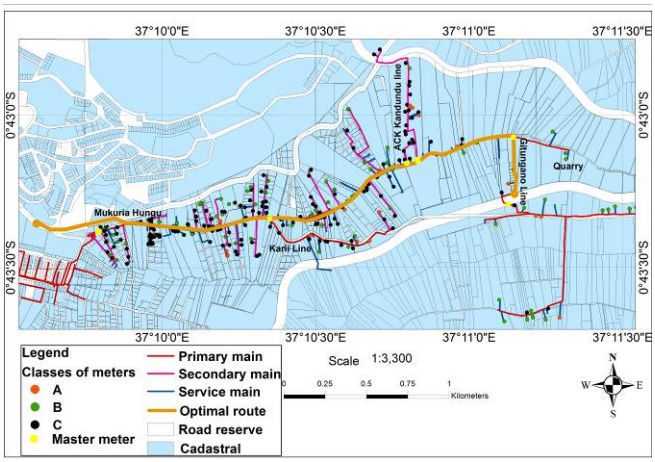

Figure 10: Optimal route generated

This means that, once an issue has been reported to have occurred somewhere, by just assigning the stop locations in the network dataset i.e. one at the location of the plumber or any staff attending the issue and another one at the location of the incidence or issue to be attended, optimal route are generated automatically.

5.5 Pressure distribution within the zone

Pressure distribution map as shown in Figure 11 was generated through inverse distance weight interpolation method using pressure data. In addition, pipes network layer displaying the number of bursts recorded within a period of six months was overlaid on pressure distribution map.

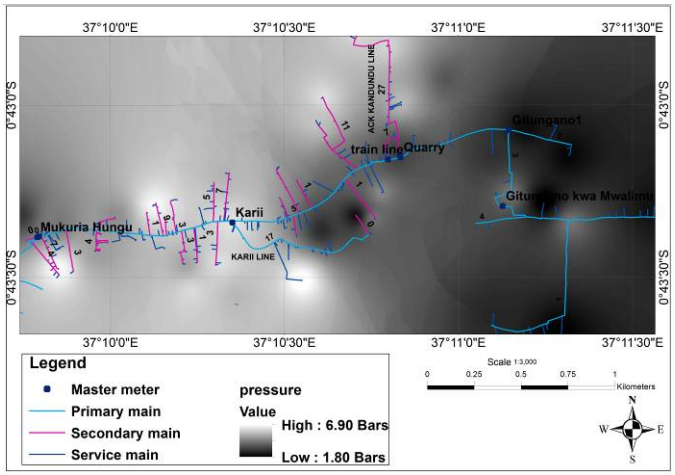

Figure 11: Pressure distribution within the zone

It was noted that regions where pressure was high, the number of bursts recorded were also high. Overlay analyses showed that Karii line recording 17 bursts, experienced pressure exceeding 4bars. Quarry (ACK Kandundu) line with 27 bursts recorded, also experienced pressure exceeding 4 bars. Also, it was clear that the part of the pipes network between Mukuria Hungu and Karii Junction experienced high pressure. Moreover, highest numbers of bursts were recorded in the same regions. From Figure 12, PRVs required to be installed in the pipe network where pressure was above 4bars. The region with pressure between 3-4bars had been operating under recommended pressure, thus no pressure reducing valves require to be installed. Moreover,

where pressure was less than 3bars, pressure reducing valve should not be installed, since pressure is too low.

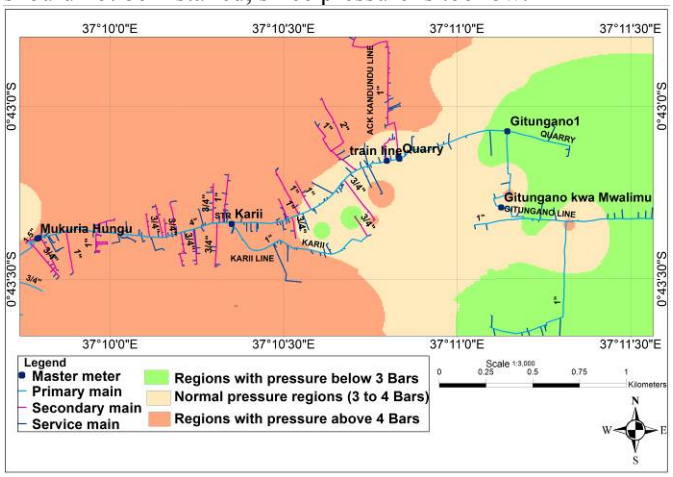

Figure 12: Variation of pressure in the region

The regions shown with light green color experienced pressure below 3bars thus not suitable for installing PRVs. The region shown by reddish-brown color experience pressure beyond 4bars and PRV required to be installed in this region. The region in between the two was operating under recommended pressure between 3-4bars, thus no need of installing PRVs in this region.

5.6 Vulnerability of region to bursts and leakages

High pressure and rapid change of elevation were major contributing factor to increased number of bursts and leakages occurring in a given zone. For a good water reticulation system, pressure should be about 3-4bars. Thus, to generate a burst and leakages vulnerability map, pressure distribution data as shown in Figure 11 and digital elevation data as shown in Figure 13 were used as the main driving factors. To combine the two data, the weight overlay model was used as shown in Figure 14. Pressure being a dependent factor on change of elevation was given 25% weight whereas, elevation data bearing in mind contribute greatly to change in pressure of water confined in a pipe was given a weight of 75%.

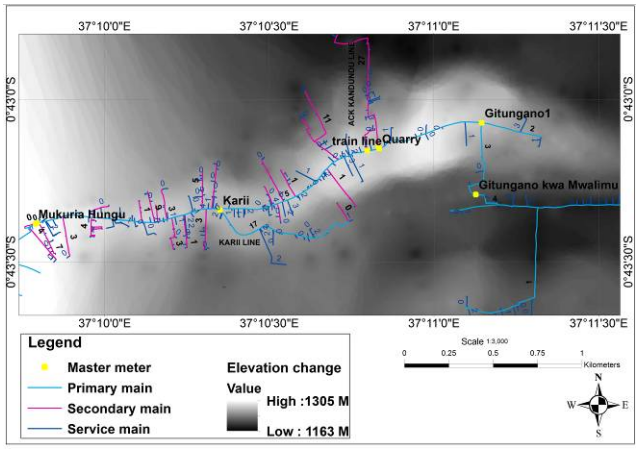

Figure 13: Elevation data

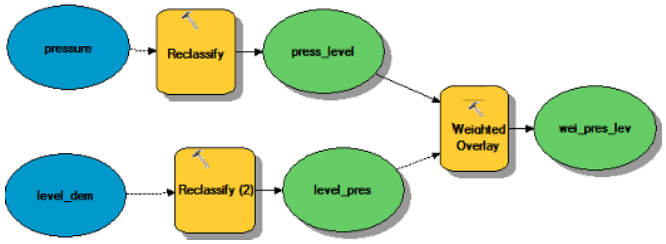

Figure 14: Weighted overlay model used

The results of the weighted overlay model in Figure 14 was a bursts and leakages vulnerability map that showed regions with different degree of susceptibility to bursts and leakages as shown in Figure 15.

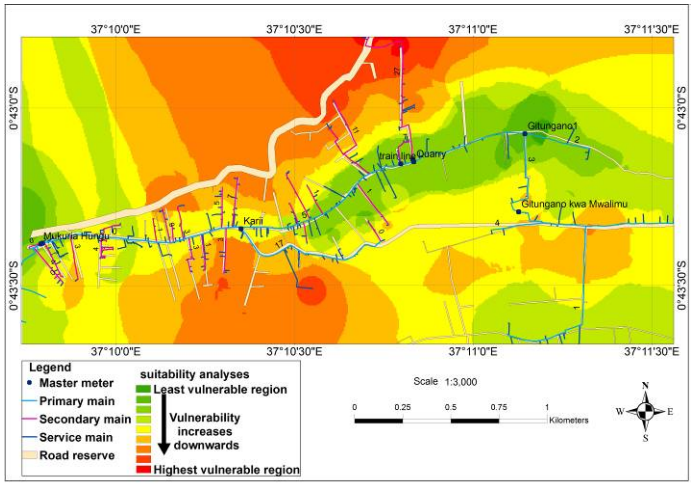

Figure 15: Vulnerability of regions to bursts and leakages

From Figure 15, it was clear that regions that experienced high pressure were located where elevation was low. By overlaying the pipe network data to the vulnerability map, it was clear that Karii line and ACK kandundu line were more vulnerable to bursts and leakages. Lower regions in terms of elevation height were more vulnerable to bursts and leakages as shown by red colour. Degree of vulnerability (susceptibility) to bursts decreased with increase of elevation, thus where the terrain was less gentle, the regions were less susceptible to bursts. Thus precaution should be taken when purchasing pipes for extension especially in regions more susceptible to bursts as shown by red colour. Thus, regions shown by colour scheme changing from yellow to red colour should be highly emphasized.

5.7 Suitable locations for installing Air releasing valves

Air Releasing Valves require to be installed at high regions in the systems. They automatically vent small pockets of air as they accumulate at high points in a system while the system is operating and pressurized. Air Release Valves (ARVs) must be installed to prevent this 'throttling' effect that caters for pressure surges and fluctuation in the network. Air releasing valves should be installed in regions where pressure is greater than 3bars equivalent to 0.3MPa. To determine suitable locations for installing air valves, elevation data depicting the ground condition, slope data, pressure data as well as Euclidian distance of the pipe network were used. Euclidian data was used to restrict the suitable locations generated to be within the pipe network.

Triangular irregular network was generated that aided in identification of highest ground points as well as generation of digital elevation model of the area. Weight overlay model was used to combine digital elevation data depicting high points (crests) and sags, pressure data, slope data in Figure 16 and Euclidian distance data. Elevation data was assigned a weight of 60% compared to pressure data with 20%, slope data with a weight of 10% and Euclidian data with a weight of 10%. The reason behind this was that pressure and slope are dependent on elevation change i.e. pressure change with variation in vertical distance ignoring the friction loss, slope is also influenced with change of vertical distance. The result of weight overlay model in Figure 17 was a map that generated regions along the pipe network where air valves would be installed as shown in Figure 18.

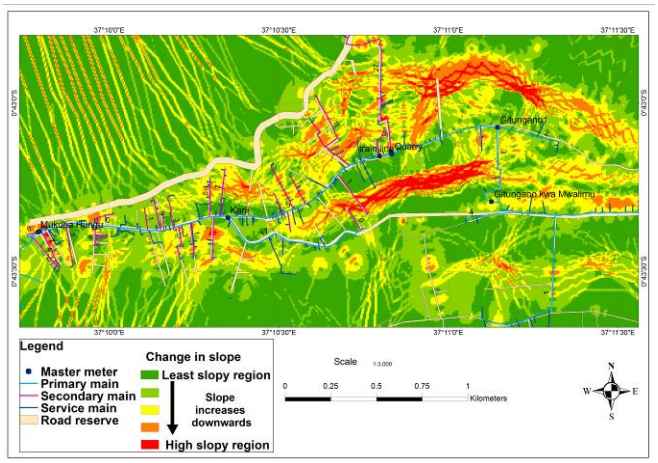

Figure 16: Slope data

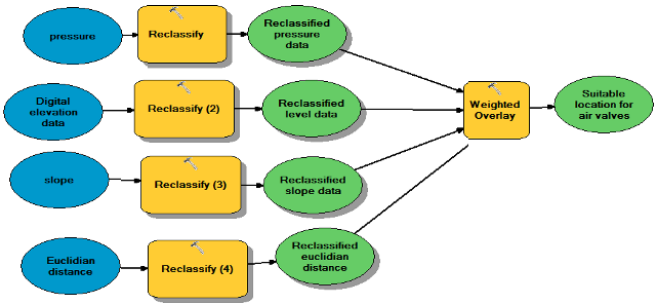

Figure 17: Weighted overlay model used

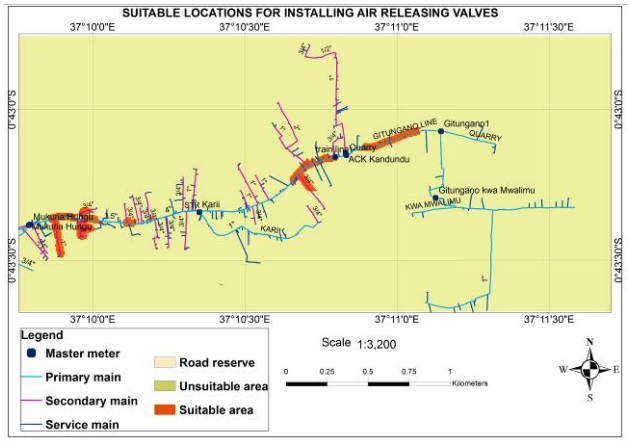

Figure 18: Suitable regions for ARVs

From Figure 18, suitable regions for installing air releasing valves were generated shown by reddish- brown colour. They satisfied the conditions that they were at high points as depicted by the digital elevation model, as well as in regions where pressure was greater than 3bars. Also, the regions were flat or gently sloping with a maximum slope of 7˚ and were restricted along the pipe network using reclassified Euclidian distance.

6. Conclusion

Most of the gaps experienced (i.e. lack of spatial indexing) in the existing billing system i.e. MAJISOFT database used in MUWASCO were achieved using GIS technology. The generated map of water reticulation system shows sections of pipe network frequent reported of having bursts and was identified that Karii line and Quarry line (ACK Kandundu line) were more prone to bursts recording 17 and 27 bursts respectively. Moreover, the map showing classes of meters used in MUWASCO i.e. Class A, B and C was generated. This would be of great assistance when it comes to replacement of Class A and B meters that are of low qualities with class C which is recommended by WASREB for its accuracy and efficiency. In addition, the map was generated showing connections served with long services lines exceeding 5m from distribution mains. It was identified that out of 288 connections in the zone, 180 connections required to be relocated. Relocation of these connections would minimize the number of bursts caused by human activities that contributed to high NRW level in the region.

In addition, Pressure distribution map was generated by interpolation method from pressure distribution points collected using GPS. A further suitability analyses was performed through reclassification of pressure data that generated regions appropriate for installing PRVs. For quick response to bursts and leakages, a network database was generated using distance as the impedance. This dataset has the capacity to generate optimal routes between the specified starting point and destination locations within the zone. The optimal routes would be of great importance for quick and fast attention to bursts as well as visiting water facilities reported having problems. Weighted overlay model developed using pressure data and elevation data, generated a map showing vulnerability and susceptibility of the regions to bursts and leakages. It was identified that, regions reported having highest number of bursts were within areas experiencing high pressure as well as in regions where elevation changed greatly downhill.

7. Recommendation

The spatial database generated and spatial analyses done were static. Updating of this database requires to be done frequently. Thus, the spatial database generated would be more effective and efficient if the data collection, analyses would be made in real time across all departments and sections in the Water Company. This would make the system to be frequently updated and on real time basis as well as ensuring that all staffs can access GIS data related to their fields of specialization on real time basis. Moreover, in developing bursts and leakages vulnerability map, it would

be better to consider other factors such as soil data and social-economic data, so as to come up with more robust results.

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