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GIS-Integrated Approach for Non-Revenue Water Reduction in Sumbawanga Urban District, Tanzania

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Abstract

This study sought to determine daily water consumption in the three zones of Sumbawanga Urban district. The study applied the geographical information system (GIS) to map and quantify non-revenue water (NRW), and tested the use of geospatial database management strategy to reduce NRW. The study used water distribution networks of zone A (Majengo ward), zone B (Katandala and Mazwi wards), and zone C (Chanji and Kizwite wards) that are served by the Sumbawanga Urban Water Supply Authority (SUWASA). The study collected water flow and water loss data by recording and mapping the existing water networks using a GPS device. The methodology for determining the quantity of NRW abstracted from the International Water Association (IWA), and maps made through QGIS, were used to show the degree of water loss by zones. A geo-database that assists in maintenance, budgeting, planning and procurement of water assets to reduce NRW was developed using postgress and postGIS, and connected to QGIS for visualization. Experimental results and computations indicate that around 8787.6m^3, 10718.3m^3, 14637.1m^3 of water are consumed monthly in zones A, B and C, respectively. Furthermore, the results show that averages of 15.15%, 40.2%, and 24.52% of water are lost as NRW in zones A, B, and C, respectively. The NRW in all the three zones were greater than the maximum NRW of 20% recommended by Energy and Water Utilities Regulatory Authority (EWURA), and key performance indicators suggested by the SUWASA. This study inform planners and decision-makers that management strategies should employ GIS to establish optimal routes for effective and quick response to bursts before losing a lot of water, instead of using traditional auditing systems that results into high NRW levels.

Keywords: *water consumption, non-revenue water, geospatial database management*

1. Introduction

Water, a resource that is irregularly distributed in space and time, and one that suffers overutilization pressure due to human activities, is essential for socioeconomic and human survival (AbdelBaki et al., 2019). This resource exits in different qualities, hence requiring specific treatment to suit intended uses and means of abstraction. Despite its importance, it is alarming to see the volume of non-revenue water (NRW) lost each year globally. Each year, more than 32bnm^3 of treated water is lost through bursts and leakage in distribution networks. Apart from that, a total of 16bnm^3 of water delivered to customers are not paid for due to

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physical (real) and apparent losses (Neji et al., 2015). In some developing countries, this loss represents 50–60% of the water readily available for supply, while the global average of treated water loss is estimated at 35% (Gikuhi, 2011). Many developed countries use different methods to control water loss, including GIS and remote sensing technology (Khan & Adnan, 2010; Motiee & Ghasemnejad, 2019).

In Africa—and particularly in sub-Sahara Africa (SSA)—many water utilities are struggling to provide drinkable water to their consumers due to sporadic urban population growth and an increase in service areas. This state is also contributed to by insufficiency of water sources, intermittent supply, and the quality of tap water at the consumer's end. Since the more water is lost, the more it has to be produced to meet customers' needs, more expenses are incurred that might unsettle water suppliers' financial stability (Mutikanga et al., 2011). Therefore, water loss is one of the major challenges faced by water suppliers in developing countries. The effect of water loss is more felt by bodies responsible for meeting consumer demands in rapidly growing urban areas because lost water yields no revenue, making it harder to keep water tariffs at reasonable and affordable levels (Neji et al., 2015). This situation is common in many SSA cities where the existence of NRW is contributed by various reasons related to the levels of technological development. In contrast, some developed countries have managed to keep the level of NRW low. These include Singapore, with 5% loss; and the Netherlands, with 6% loss (Dominic, 2014). In developing countries, including those in SSA, efforts to keep water loss at 20% or below as per the regulators have not succeeded yet (Motiee & Ghasemnejad, 2019).

According to Vitianingsih et al. (2018), a lot of water is lost before reaching customers due to various reasons, including poor infrastructure and the lack of relevant technologies. Many studies—including Motiee & Ghasemnejad (2019), and Neji et al. (2015)—show that the most important aspect in the whole NRW issue is not the quantity of water supplied and freshwater resource available on earth, but the management of infrastructures and resources available. Many water supply authorities use a react-to-crisis management approach in dealing with infrastructure problems to control NRW. The approach covers the maintenance and replacement of leaking or bursts in aged pipes, aged faulty meters, and bypasses or double connection problems. However, this approach is associated with additional costs of emergency crews and property damage (Vitianingsih et al., 2018). In our case study, the storage and records of maintenance and replacement of pipes and other assets in the Sumbawanga Urban Water Supply and Sanitation Authority (SUWASA) is done manually on paper, which puts information in danger of getting lost after the work in question has been done. Nevertheless, the authority does not have a documentation of its water network and associated assets for new staff members to locate old pipes and other underground assets during the process of maintenance or replacement. This gives room for trial and error, or forces the authority to find older and/or retired staff who are familiar with existing water network for help. These people have to be paid to solve such problems, which in turn increases expenses and creates the risk of failing to solve problems when such staff are not around.

Although numerous strategies for reducing NRW from 40%–38% since 2013 have been developed (SUWASA, 2016), the lack of a spatially indexed tool to facilitate planning, budgeting, and procurement of appropriate items makes their implementation ineffective. As a result, strategies have been abandoned before achieving results. Thus, NRW reduction targets can be reached when effective asset management systems are used to ensure that overall infrastructural costs and NRW are reduced proactively instead of waiting for asset failures (Vitianingsih et al., 2018; Shamsi, 2005). GIS presents an important option for reducing NRW and improving both the quantity and quality of water, hence reducing water scarcity (Farley et al., 2010). WIN (2001) reported that the use of GIS technology in asset management in water supply can cut operational and maintenance costs for water supply authorities by 15%–40%. The technology helps to analyse and communicate spatial information associated with physical assets; and helps facilitate the availability of timely information for timely action, preventative maintenance, development of new water systems, and collection of water system attributes for populating a GIS database. Shamsi (2005) claimed that, except for the computer itself, no technology has revolutionized the water industry as GIS. Therefore, it is important to recognize water challenges in Tanzania; and the opportunity that GIS technology presents in addressing them. This paper seeks to determine the quantity of NRW in Sumbawanga Urban district, and the application of geospatial technology through geodatabase development to reduce the problem.

2. Materials and Methods

2.1 Study Area

Sumbawanga Urban district is one of the four districts in Rukwa region of Tanzania. It is found at 7°58'00"S and 31°37'00"E; and at an elevation of 1833m above mean sea level. This study was carried out at zone A (Majengo ward), zone B (Katandala and Mazwi wards) and zone C (Kizwite and Chanji wards): all within Sumbawanga Urban (Figure 1). These zones were chosen because they normally face serious water shortages, and NRW is high compared to many places in Tanzania.

2.2 Data Collection Methods

Since the SUWASA water network did not exist as a hard or soft copy, transect walks and guided field walks with a GPS device were done to map the water network (i.e., primary, secondary and service mains) of the three zones. Components of the network such as water network locations, meters, gate valves, and sluice valves with their attribute information—e.g., the number of water users and amount of consumption—were collected by the use of a GPS device. During data collection, the GPS software was configured with spatial datum of Arc 1960, UTM zone 36 S. Water flow data were collected using a FLUXUS F410 H_2O Ultrasonic flow meter. Furthermore, the difference between water supply and customer bill data was measured using a FLUXUS F410 H2O ultrasonic flow meter for each zone.

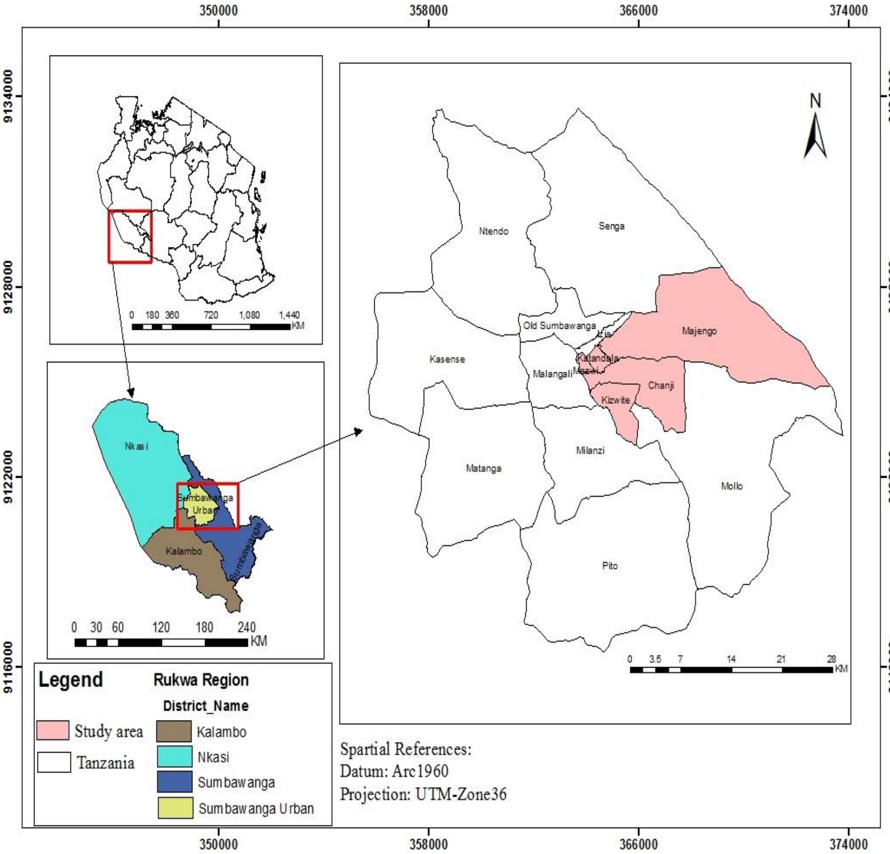

Figure 1: Location of the Study Area

Source: GIS Lab, Department of Geography-UDSM, 2019

2.3 Data Analysis

Prior to data analysis, data processing was made by cleaning and removing apparent errors. Frequency tables were created to identify what was missing, detect entry errors, and check for inconsistencies and outliers. The GPS data was downloaded into a computer using a map source/easy GPS software. Water level, counter of water flow, and water pressure were obtained using ultrasonic flow meter. The data logger, DL09, was downloaded and arranged in excel spreadsheet in a CSV format. The data were then imported into a QGIS software for visualization and further GIS analysis. Raw data of pressure around the reticulation water system, water level and water flow, which were observed by the data logger DL09, were imported into a computer using the Acua31A software, before being cleaned to remove unsolicited information; and then arranged and saved in a notepad system. Thereafter, the notepad file was exported into Excel software where data was saved in a CSV format, which is accepted by Quantum GIS, for further analysis.

Data analysis involved the measurement of NRM in cubic meters (m^3). A mathematical expression was used to determine the quantity of NRW for the three study zones. The NRW was calculated by considering the difference between input water volume and average billed water for the period of six months from January to June 2019. The NRW was further determined by subtracting the total volume of revenue water from the inlet pipe flows (total water input) measured for 24 hours using an ultrasonic flow meter as indicated in the formula below:

NRW = Total volume input – Revenue water

$NRW\%$ = (Total volume water input– Revenue water) × 100/(Total volume of water input)

To ensure that the problem of water revenue loss is reduced and controlled, a geospatial database postgresSQL and postGIS software, through pgAdmin III, were developed. The database were used to store important water information like pipeline segments, utility stations, connection points, line casing, customers, meters, repair materials, bulk water meters, illegal connections, damages, maintenances, and water pressure to link the water services, water users, and water authority. To create the database, the standard processes as illustrated in Figure 2 were adopted.

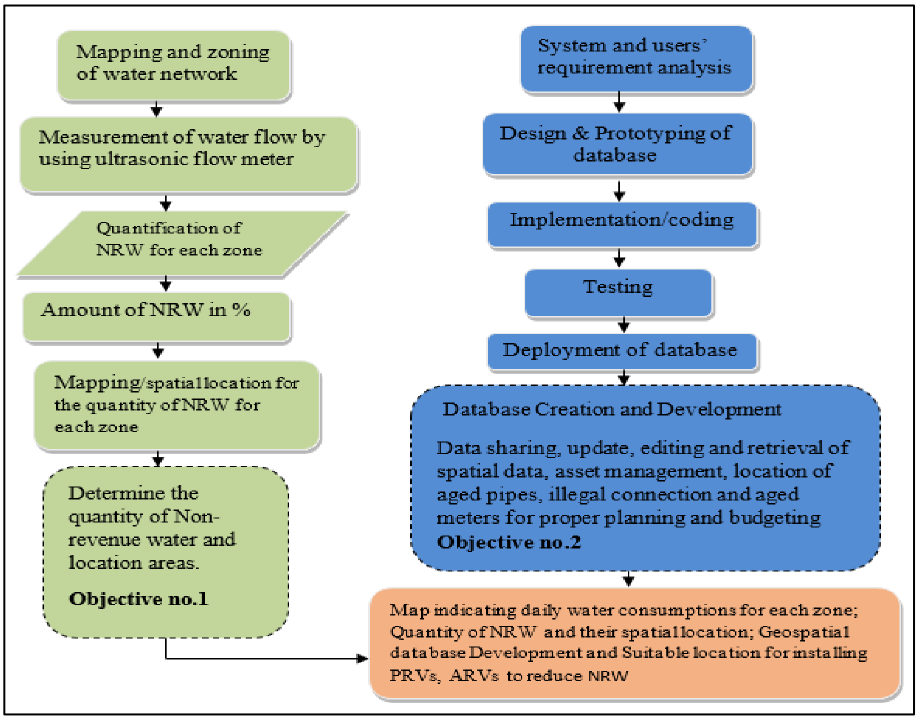

Figure 2: Schematic Presentation of Data Analysis

Source: Field data, 2019

System and user requirement analysis: The process explored the system and user requirements of the database. This involved studying data collection methods and tools, data types, volume and formats, relationships, data flow, report types and reporting frequencies. From this stage, tables and their respective attributes were identified and used to create the database.

System design (conceptual modelling): The database was designed in such a way that it facilitates data collection, storage, access, retrieval, transfer, information dissemination, spatial (geo)visualization, and reporting. The system adopted a relational data model, which usually uses a SQL query language. In such a database, data and their relationships were organized in a table. During the designing of the database, information products that could be created and managed using the QGIS were identified, followed by the definition of key aspects of each data theme. Thereafter, specification of scale ranges and the spatial representations of each data theme at each scale was done, followed by the identification of the tabular database structure and behaviour for descriptive attributes. Afterwards, spatial behaviour, spatial relationships, and integrity rules for datasets were established. In addition, the set of geodatabase elements for each data theme was defined.

System implementation/full coding: This process involved the realization of technical specifications and algorithms for operationalizing the envisaged system. The following technologies were used in the development of the database: postgreSQL for the creation of back-end/data storage; QGIS for data visualization, mapping and analysis; and postGIS for linking the back-end and interface/user environment.

System testing: Before its deployment, the database was tested and evaluated to ascertain its capacity to perform the intended operations. For system testing and evaluation purposes, a sample of data was used. This procedure brought all the pieces (modules) of the database into a special testing environment to check for errors, bugs, logics, and ascertain if the business flow was captured end-to-end.

Deployment of the system: After completion of the database development and testing processes, the database was installed for use. This involved the installation of supporting software, plug-ins, and uploading of the database. The geo-database was named SUWASA; its schema (core tables) was named co_customer, with columns named id, customer_number, account_nunber, organization_name/surname, first_name, and customer type. Finally, database, schemas, tables and columns were created using a scrip method that was executed using SQL.

3. Results and Discussion

3.1 Daily Water Input and Consumptions

This is the amount of water flowing into a system area in a limited time interval as shown by Figure 3. The flow measurement results indicated by Figure 3 gives the total volume of 292.92, 357.28 and 487.90 (m^3/day) for zones A, B and C, respectively. This shows that zone C had the largest volume of water flowing into its system than the other zones, followed by zone B; with zone A being the last. The volume of water imported into zone C reflects the size of the area, which is larger than the other two; and hosts more water users. Figure 3 shows the water inputs of these zones.

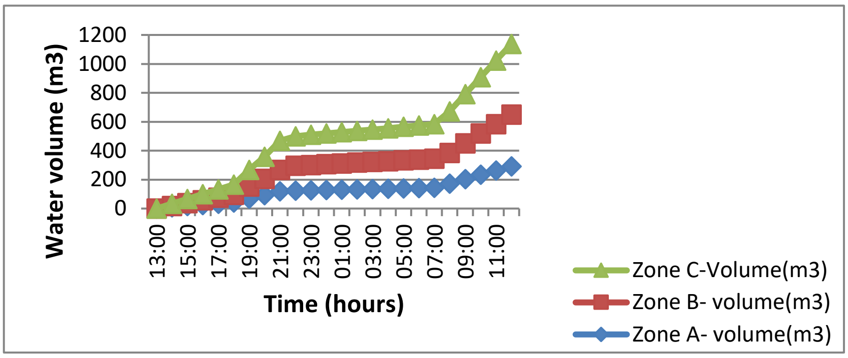

Figure 3: System input Volume at Different Time Intervals
Source: Field data, 2019

Water consumption from 13:00hrs to 18:00hrs indicate a gradual increase of 42.64m^3, 52.00m^3 and 71.02m^3 in water consumption by zones A, B and C, respectively (Fig. 4).

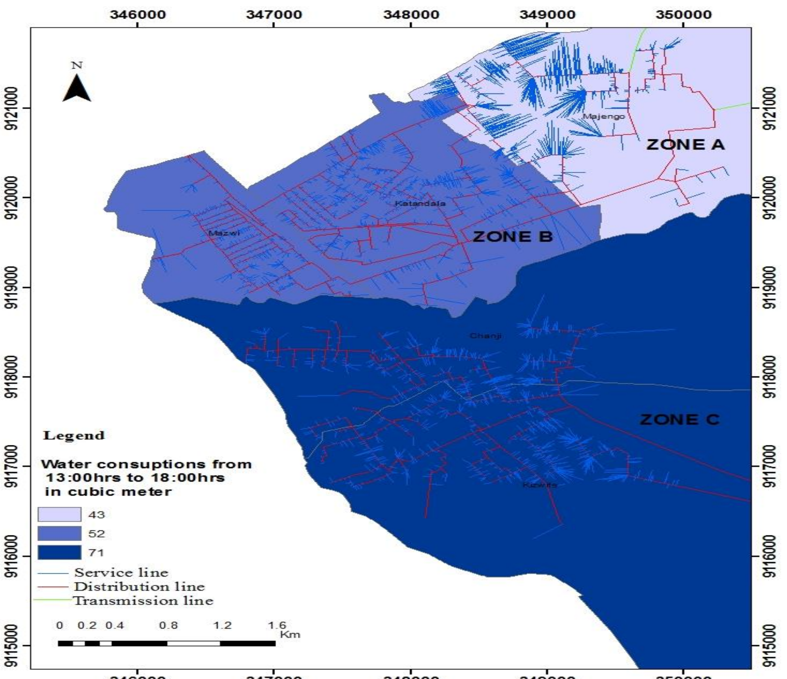

Figure 4: System Inlet Water Consumption from 13:00hrs to 18:00hrs
Source: Field data, 2019

Results on water consumption from 18:00hrs to 21:00hrs during week days indicated a total of 78.15m³, 95.33m³ and 130.17m³ of water being consumed at zones A, B and C, respectively (Figure 5). This increase in water consumption is twice as much as that measured between 1300hrs and 1800hrs. This difference is attributed to the fact that during these hours, all home occupants are usually back for the day because Sumbawanga urban residents get home early due to limited road congestions. Therefore, many activities that need water (cooking, bathing, and washing) take place during these hours, hence high water consumption. Overall, zone C has higher water consumption than the other two during both peak and off-peak water usage periods. Nonetheless, a large increase in water consumption during early hours of any night (Figure 5) is not new, especially in urban areas. This observation is confirmed by Harawa et al. (2016) and Gupta et al. (2018), who noted that the use of water increases a lot during this time when all people are in their homes.

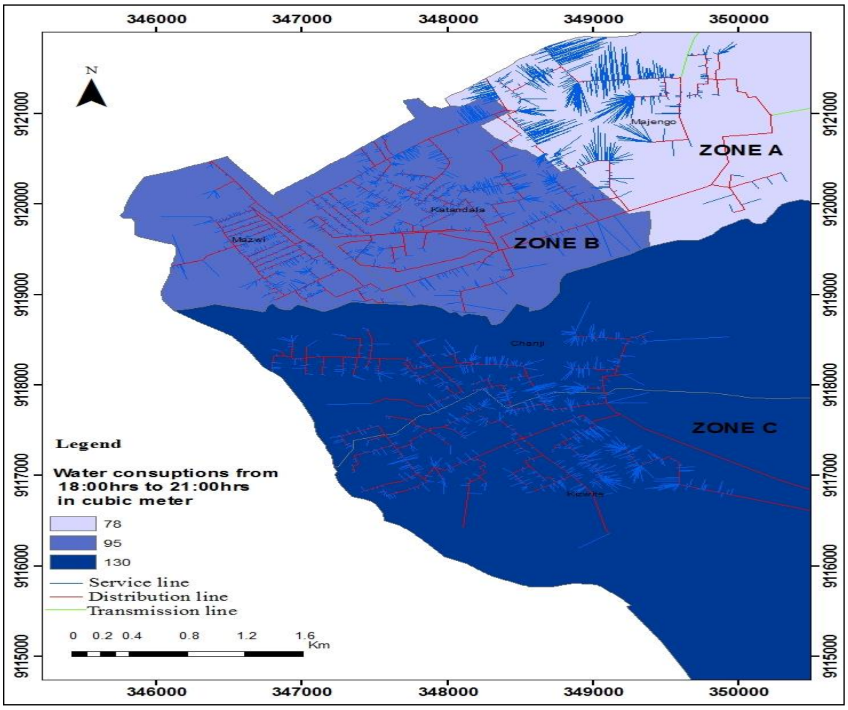

Figure 5: System Inlet Water Consumption from 18:00hrs to 21:00hrs
Source: Field data, 2019

As shown on the Figure 6, a small quantity of water amounting to 22.60m³ and 37.65m³ is consumed between 21:00hrs and 7:00hrs in zones A and C, respectively. This result can be explained by considering the number of customers likely to use water during night hours, which is usually very small, hence the sharp drop in water consumption.

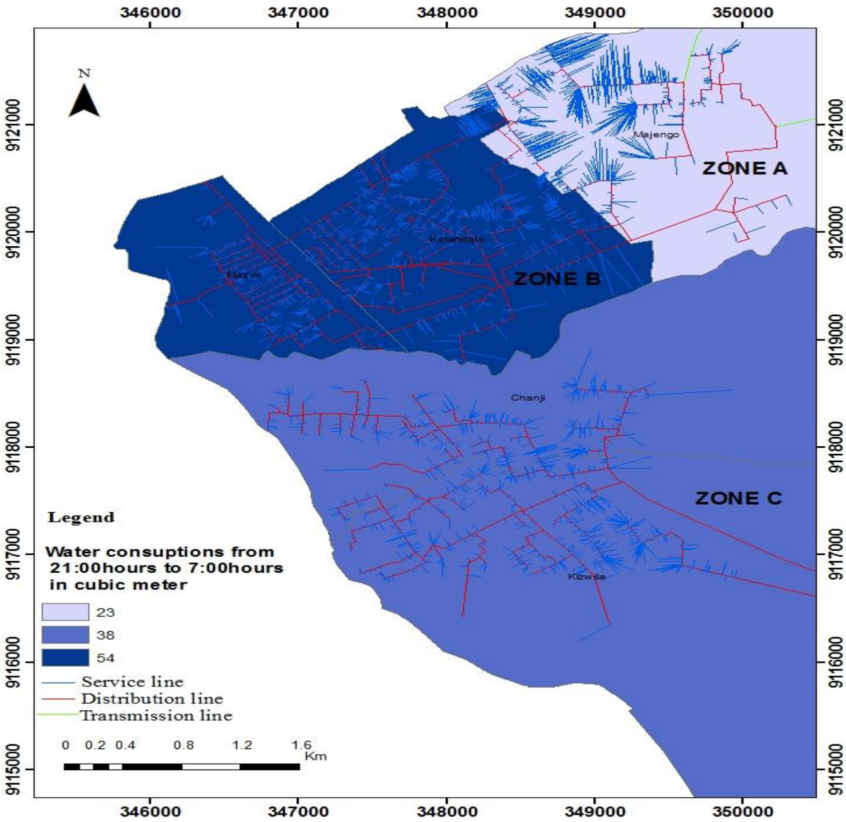

Figure 6: System Inlet Water Consumption from 21:00hrs to 7:00hrs
Source: Field data, 2019

This study was also interested in looking at the use of water during weekends between 7:00hrs to 12:00hrs. As indicated in Figure 7, zone C consumed a larger amount of water (249m^3) than the others, followed by zone B (166m^3), and zone A (155m^3). Generally, water consumption is greater during weekends since results show that weekend consumption is three-and-a-half times more than weekday consumption, which averaged at more than 50m^3. As it has already been explained, larger consumption of water during weekends is caused by bigger numbers of consumers at home during weekends. This finding is in line with earlier studies done by Harawa et al. (2016), and Kanakoudis and Tsitsifli (2019).

From the foregoing, it is clear that water supply authorities need accurate information to effectively regulate the amounts of water in relation to consumption differences between times of the day, and days of the week. This is as well supported by Gupta and Kulat (2018), who argue that spatio-temporal information on water use is important in ensuring proper water distribution and prioritization.

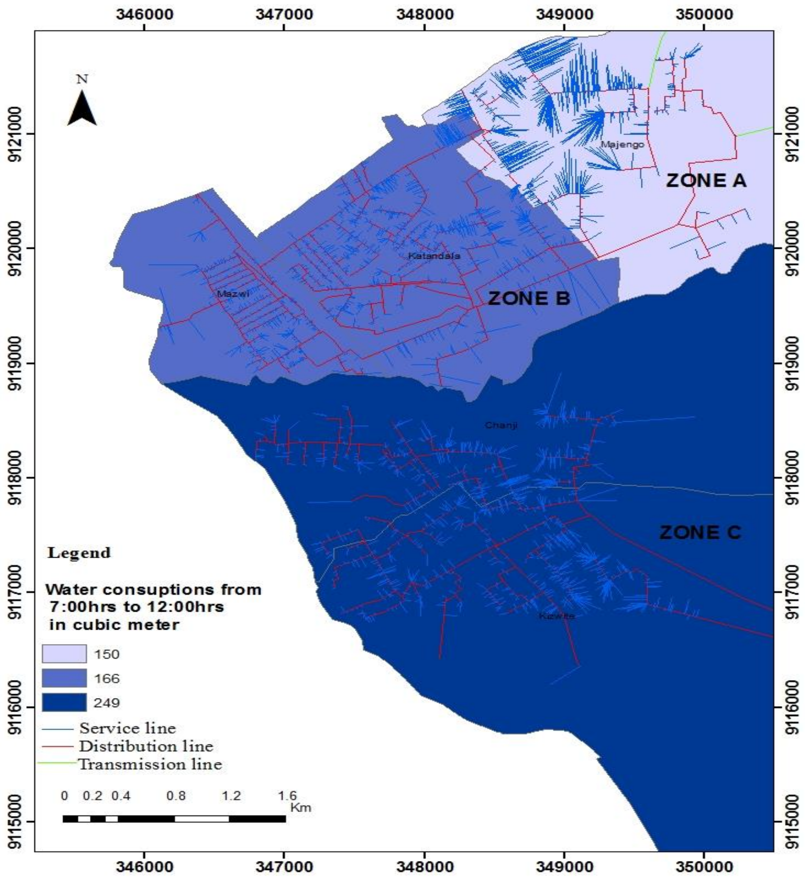

Figure 7: System Inlet Water Consumption from 7:00hrs to 12:00hrs
Source: Field data, 2019

3.2 Billed Authorized Consumption and Amount of Non-Revenue Water

Billed authorized consumption comprised both meter billed consumptions and non-meter billed consumptions. Table 1 provides the total billed authorized consumptions (revenue water) from January to June, 2019 for the 354,571,725 service connections in zones A, B and C, respectively. The billing efficiency was 100% as there was no unbilled customers in all zones. The monthly average revenue water of 7456.32m^3, 6409.5m^3, and 11048.08m^3 for these months was subtracted from the total volume input of 8787.65m^3, 10718.3m^3, and 14637.1m^3 for zones A, B and C, respectively. This resulted in the following values of NRW: 1331.33m^3 for zone A, 4308.8m^3 for zone B, and 3589.02m^3 for zone C. These values are equivalent to NRW of 15.15%, 40.2%, and 24.52% for zones A, B and C, respectively. From the results, zone B has more NRW, followed by zones C and A. It was found that water was lost due to leakages and commercial issues in the water distribution networks.

Table 1: Non-revenue Water in Zone A, B and C

ZONE A	Jan 2019	Feb 2019	Mar 2019	Apr 2019	May 2019	Jun 2019	Average 6months
Number of accounts	354	354	354	354	354	354	354
Billing Efficiency (%)	100	100	100	100	100	100	100
Input volume (m^3/month)	8787.65	8787.65	8787.65	8787.65	8787.65	8787.65	8787.65
Revenue (m^3/month)	7508.18	7474.78	7442.26	7529.26	7424.69	7361.41	7456.32
NRW (m^3/month)	1279.47	1312.87	1345.39	1258.39	1362.65	1426.24	1331.33
NRW (%)	14.56	14.94	15.31	14.32	15.51	16.23	15.15
Zone B							
Number of accounts	571	571	571	571	571	571	571
Billing Efficiency (%)	100	100	100	100	100	100	100
Input volume(m^3/month)	10718.3	10718.3	10718.3	10718.3	10718.3	10718.3	10718.3
Revenue (m^3/month)	6591.8	6656.1	6431	6345.2	6323.8	6109.4	6409.5
NRW (m^3/month)	4126.5	4062.2	4287.3	4373.1	4394.5	4608.9	4308.8
NRW (%)	38.5	37.9	40	40.8	41	43	40.2
Zone C							
Number of accounts	725	725	725	725	725	725	725
Billing Efficiency (%)	100	100	100	100	100	100	100
Input volume(m^3/month)	14637.1	14637.1	14637.1	14637.1	14637.1	14637.1	14637.1
Revenue (m^3/month)	11651.13	12178.07	11563.31	11051.01	10714.36	9133.55	11048.08
NRW (m^3/month)	2985.97	2459.03	3073.79	3586.09	3922.74	5503.55	3589.02
NRW (%)	20.4	16.8	21	24.5	26.8	37.6	24.52

Source: Field data, 2019

The results in Table 1 indicate that zone B produces 40% of NRW, followed by zone C (25%), and zone A (15%). Thus, zones A and C produce less NRW than the 38.9% average for Sumbawanga Urban (SUWASA, 2016); while zone B (40.6%) beats the district's average. According to the field observations, aged pipes, poor pipe materials, water pressure in the reticulation system (especially for undulating terrain), meter reading errors, double connections, and illegal connections are among the main reasons for this loss of water and the increase in NRW. Overall, the percentages of NRW lost by the three zones are higher than the 14.59% recorded by Alone (2015) in Kawe area, Kinondoni district, in Dar es Salaam. This signifies that the area loses a lot of NRW and special interventions are required, especially in zone B (Katandala and Mazwi wards) where there is 40% of NRW, which is above the 20% limit set by the EWURA (AUWSA Annual Reports 2015/2016–2016/2017). The water lost by the zone is also above the target of 23% set by the World Bank (Singh et al., 2014; Tynan & Kingdom, 2002; Kanakoudis & Tsitsifli, 2019). According EWURA (2018), the national NRW average is about 38%; which is much higher than the national limit of 20%. This means interventions are needed not only for the studied zones, but also for the whole nation. Kayaga and Smout (2007) have reported a similar problem in Uganda with a NRW of 42.5%. In other regions, the levels are as follows: Bucharest, Romania (46.0%); Mwanza, Tanzania (50%); Adana, Turkey (69.0%); Diyarbakir, Turkey (51.0%), Guayaquil, Ecuador (73.0%); Hyderabad, India (50.0%); New Delhi, India (53.0%); Jakarta, Indonesia (51.0%); Manila West (53.0%), Kayseri, Turkey (45.0%); and Sofia, Bulgaria (62.0%) (Upendo et al., 2021; SWAN, 2011).

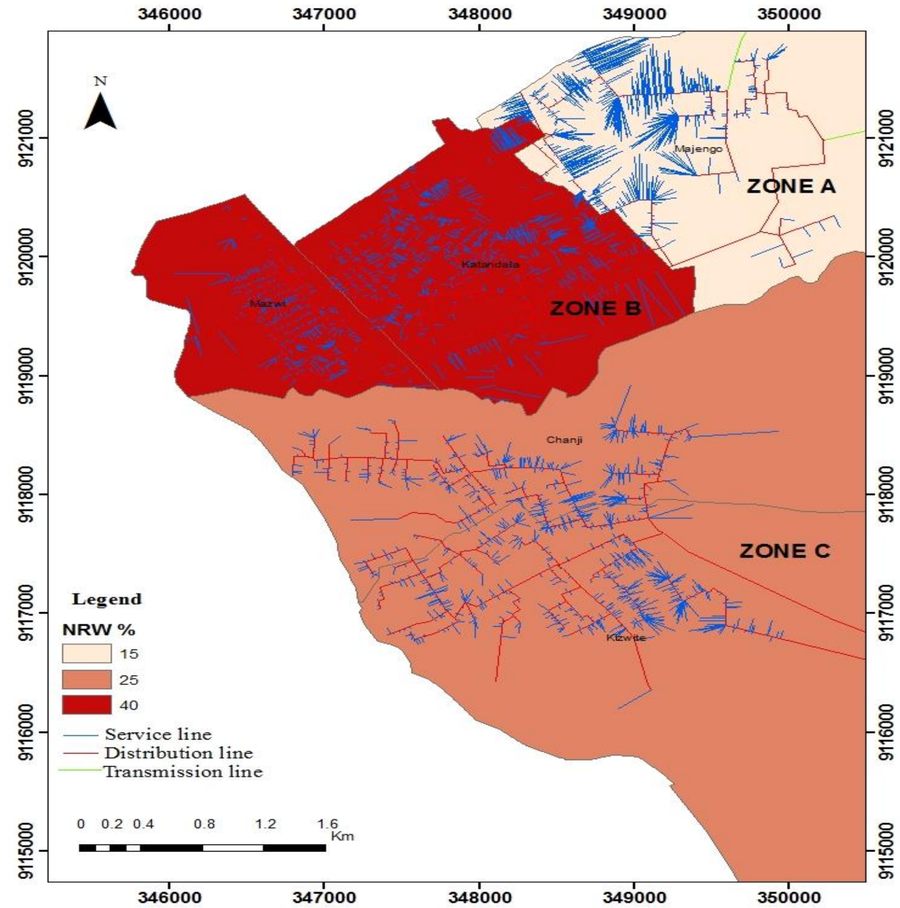

Figure 8: Average Percentage of Non-Revenue Water for Six Months

Source: Field data, 2019

3.3 Developed Geospatial Database

The main theme of the database was to assist the SUWASA in water use planning, budgeting and procurement of appropriate assets; and reducing non-revenue water. Table 2 consists of 'rows' or 'records', and 'columns' or 'fields'. Rows have been identified by a unique 'key', which is a single column or a group of columns. The columns were then linked to other tables with similar columns. Postgress was used to store information such as the locations of illegal connections, faulty meters, leakage/burst points, high pressure distribution points contributing to NRW, and all information relating to customers. PostGIS was used for the development of a spatial database and linking the back-end and interface/user environment, while QGIS was used for mapping all information relating to water network data, visualization and analysis.

Table 2: Database tables for storing attribute information

id [PK] serial	meter_numb character vai	control_no integer	installation_d date	meter_class character vai	m ch	plot_no character vai	district character vai	zone character vai	ward character vai	street character vai	date_of_first date	inspection_in integer
1	148886	97	1988-11-02	A		1267	sumbawanga	zone B	Mazwi	Sokoni	2011-03-06	10
2	147958	34	1989-12-03	B		2431	sumbawanga	zone B	mazwi	sokoni	1990-12-05	5
3	148886	4	1978-03-05	A		5689	sumbawanga	zone A	majengo	manase	1979-12-09	4
4	6151229	543	1990-01-04	A		1212	sumbawanga	zone B	katandala	madukani	2013-04-05	15
5	BM 1307K	786	1992-11-07	A		2316	sumbawanga	zone A	majengo	maugo	2000-07-08	6
6	BM 848k	908	2011-02-07	B		3215	sumbawanga	zone B	katandala	machinjioni	2001-05-12	8
7	BM1128K	764	1970-03-08	A		1217	sumbawanga	zone C	kizwite	shule	1999-06-08	5
8	BM160K	6712	1990-08-05	A		1054	sumbawanga	zone A	majengo	airport	1998-09-11	12
9	BM285K	58	1971-04-07	B		987	sumbawanga	zone C	kizwite	alizeti	2007-03-04	13
10	6152099	658	1979-01-06	B		176	sumbawanga	zone A	majengo	chelehani	2012-05-07	19
11	BM277K	123	1977-09-08	B		3421	sumbawanga	zone C	kizwite	kanisani	2004-04-09	20
12	BM1363	67	1980-04-09	A		2765	sumbawanga	zone C	chanji	golani	1998-06-08	13
13	BM-1610K	98	1967-05-09	B		2317	sumbawanga	zone A	majengo	arsenal	2013-05-08	9
14	BM 1630	104	2009-04-07	A		3217	sumbawanga	zone A	majengo	upendo	2012-09-03	23
15	bm-2628-k	453	2001-08-10	A		2187	sumbawanga	zone C	kizwite	makaburini	2014-04-05	7
16	147686	56	1972-06-09	B		1876	sumbawanga	zone C	chanji	moezi	2015-06-08	90
17	BM 2780K	341	1975-01-09	A		1987	sumbawanga	zone C	chanji	msikitini	2016-09-07	4
18	06-428941	412	1974-04-04	B		187	sumbawanga	zone B	katandala	kipondoda	2012-01-08	26
19	1309544637	679	1970-08-04	B		1987	sumbawanga	zone B	mazwi	sayuni	2015-07-09	5
20	06-427421	120	2000-01-08	A		278	sumbawanga	zone A	majengo	kisiwani	1980-05-08	12
21	BM 2483K	321	1998-04-06	B		5432	sumbawanga	zone C	chanji	kitochi	2003-06-08	14
22	BM 2032k	231	1978-01-10	A		4329	sumbawanga	zone C	chanji	chanji A	2013-07-09	12
23	649K	34	1977-06-12	B		4538	sumbawanga	zone C	kizwite	dew	2010-10-10	6
24	BM1486K	65	1967-03-12	A		4329	sumbawanga	zone C	kizwite	maji	2011-06-09	8
25	BM960K	87	1978-04-10	B		3276	sumbawanga	zone A	majengo	drop	2012-12-12	9
26	bm-1275-k	80	1971-05-09	B		2167	sumbawanga	zone B	katandala	mashine	2014-07-09	3
27	06-427410	675	1970-04-07	A		1875	sumbawanga	zone C	kizwite	rami	2010-05-07	2

Source: Field data, 2019

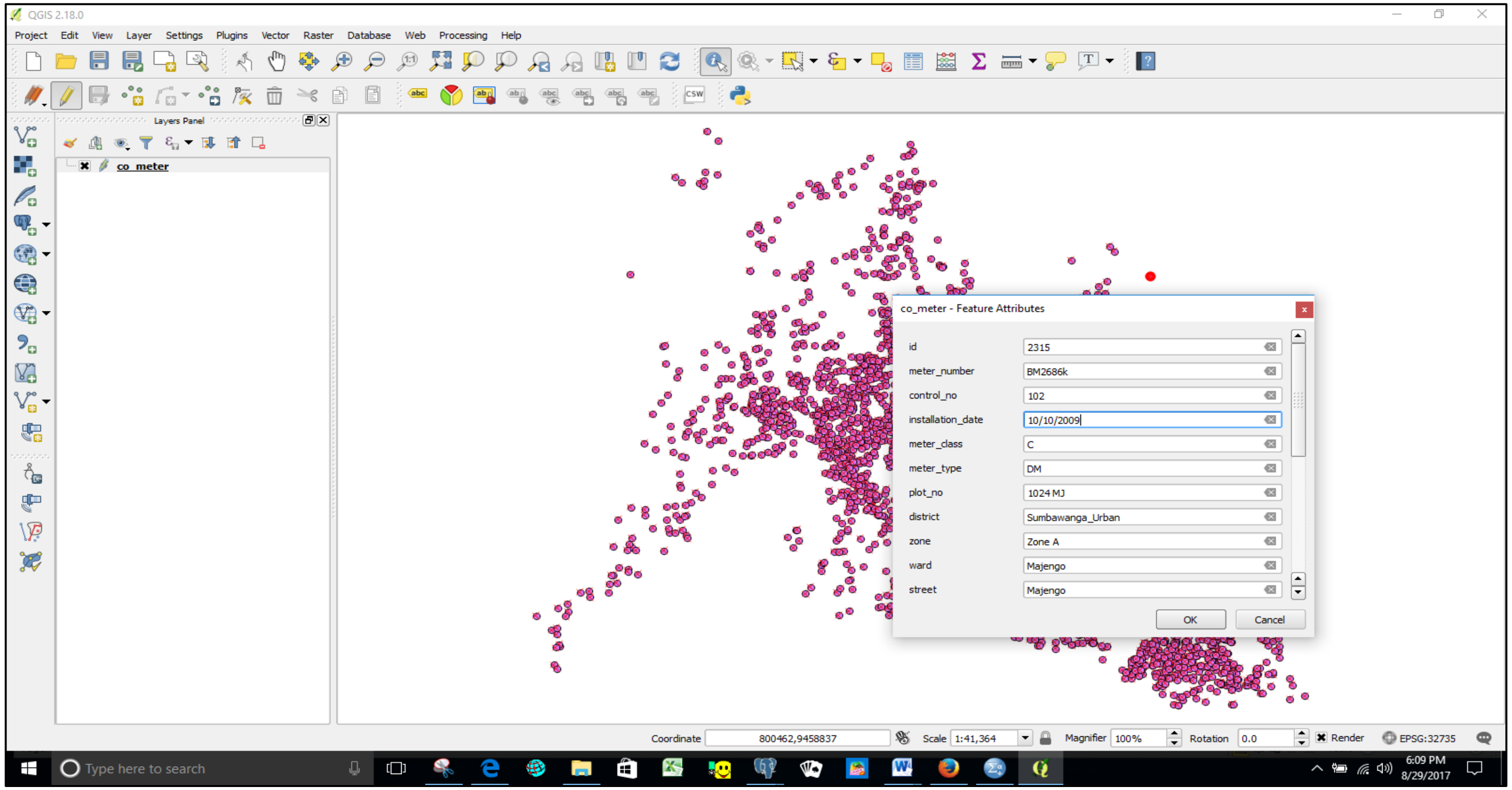

Figure 9: Geo-database Visualization in the QGIS
Source: Field data, 2019

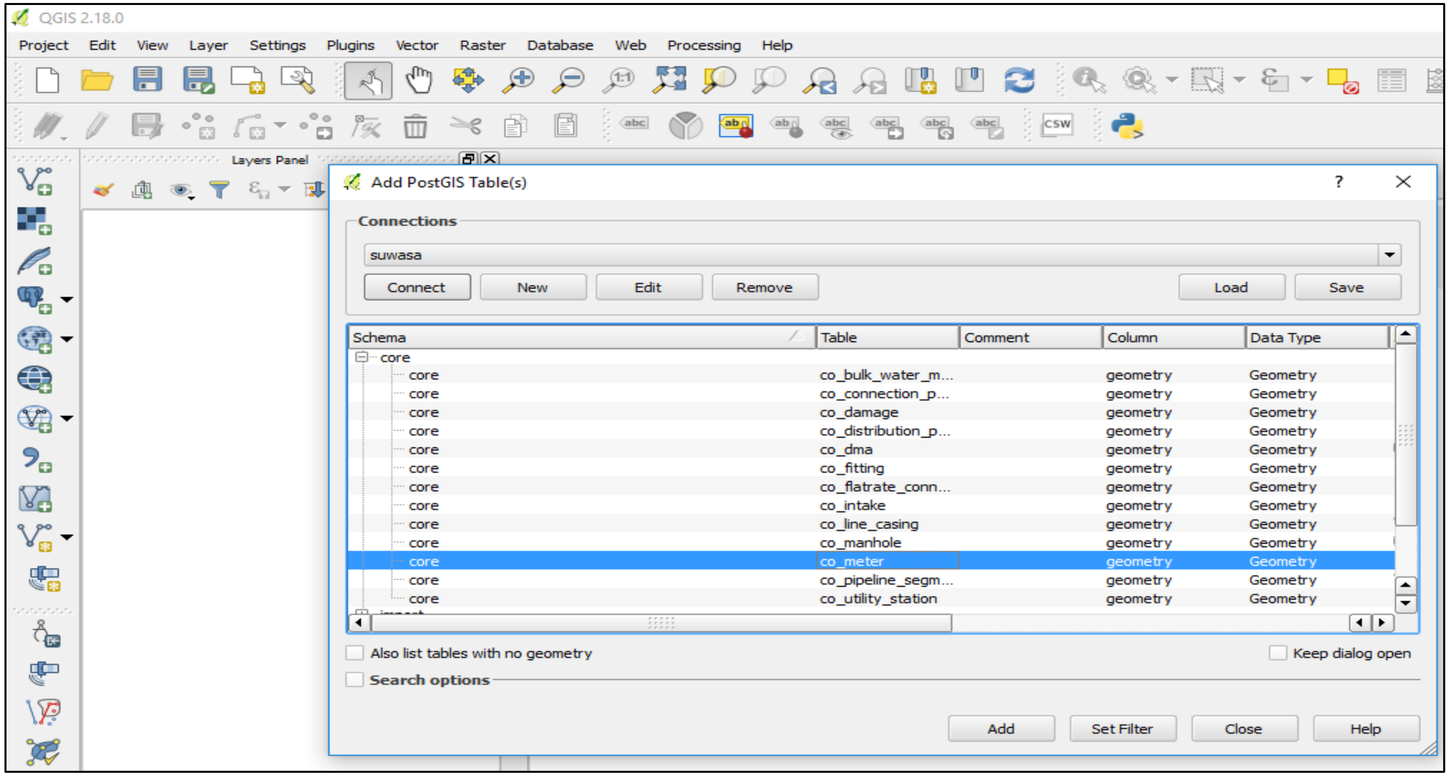

Figure 10: The Database Schemas for Storing Spatial Information
Source: Field data, 2019

Various information about all domestic users/customers of SUWASA are easily presented in QGIS (Figure 9). The information include: customer id, number, organisation, name, type, meter number, account number, customer status, customer bill, customer location, meter type, meter status, and water pressure. Through this information, it was easy to identify the number and locations of contributors of NRW, places with faulty meters, illegal connections, location of high pressure zones, and leaking pipes. In addition, the geo-database information stores the location of each faulty meter asset, connectivity of each faulty meter with other database information such as pipe segment, history of each asset, when and where it was stored, status of a meter (when it was installed, does it need replacement), and basic attributes of water assets that can be easily accessed by users to facilitate the reduction of NRW. All this information would assist in the management of NRW, better planning, and reducing water loss.

Figure 10 shows the database schemas of the developed geo-database with different information such as customers name, customer meters, meter status, legal and illegal connections, pipe types, pipe materials, pipe classes, pipe age, water pressure distribution, ward name, water reservoirs, manholes, valves and all water network infrastructures containing spatial and non-spatial/attribute information connected to the interactive GIS software (QGIS) for visualization, interpretation and analysis of the collected data. All database schemas can be connected and displayed at once on the interface (QGIS). However, only the interested schemas can be connected and displayed for the purpose of visualization of the information one is interested in, for example, location of leakages and burst points. Further, GIS can identify and locate the quantity of NRW for each zone and the causes of NRW, thus making it easier to control NRW based on time, priority, and location of the problem.

In the database, there are four types of people (users) with different power and tasks in data sharing and the management system (Figure 11). Both users 1 and 4 have privileges of updating, modifying, and inserting data collected into the database (Figure 12). User 2 can only insert data into the database system, while user 3 has the privilege of only viewing the data stored in the database system. All the four users can perform their tasks at the same time, which facilitates the sharing of data from one user privilege to another.

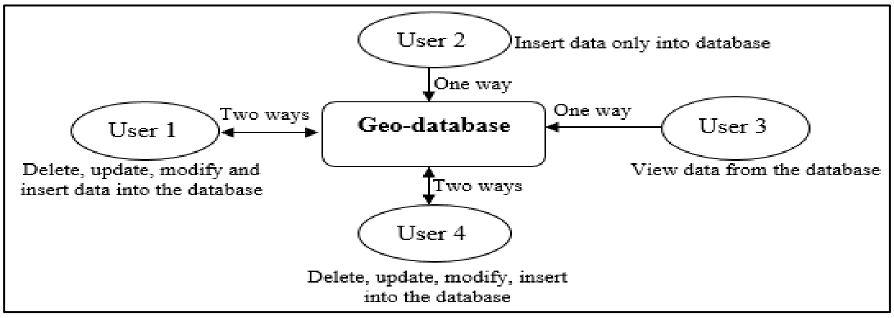

Figure 11: Network Management System and Data Sharing

Source: Field data, 2019

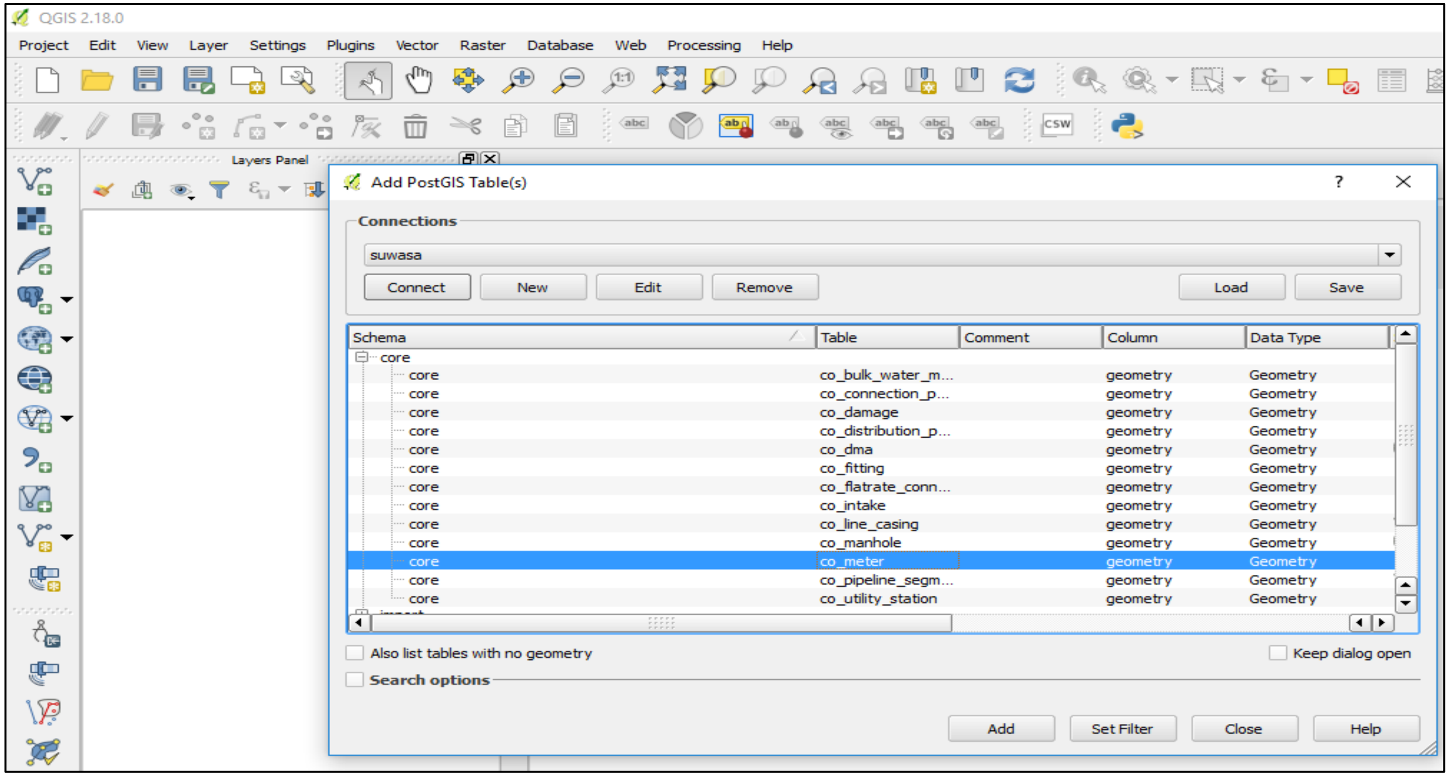

Figure 10: The Database Schemas for Storing Spatial Information
Source: Field data, 2019

Information on the pipeline network, customer meters, network fittings, DMA, pipe damages, identified illegal connections, utility stations and all attributes of the water network can be shared via the created geo-database (Figure 13). The information is likely to facilitate the performance of field crews and decision-making regarding the procurement and actions taken to reduce NRW. In other words, the information on the database is likely to be important in dealing with causative agents of NRW through maintenance and replacement of various assets such as aged pipes with frequent leaking problems.

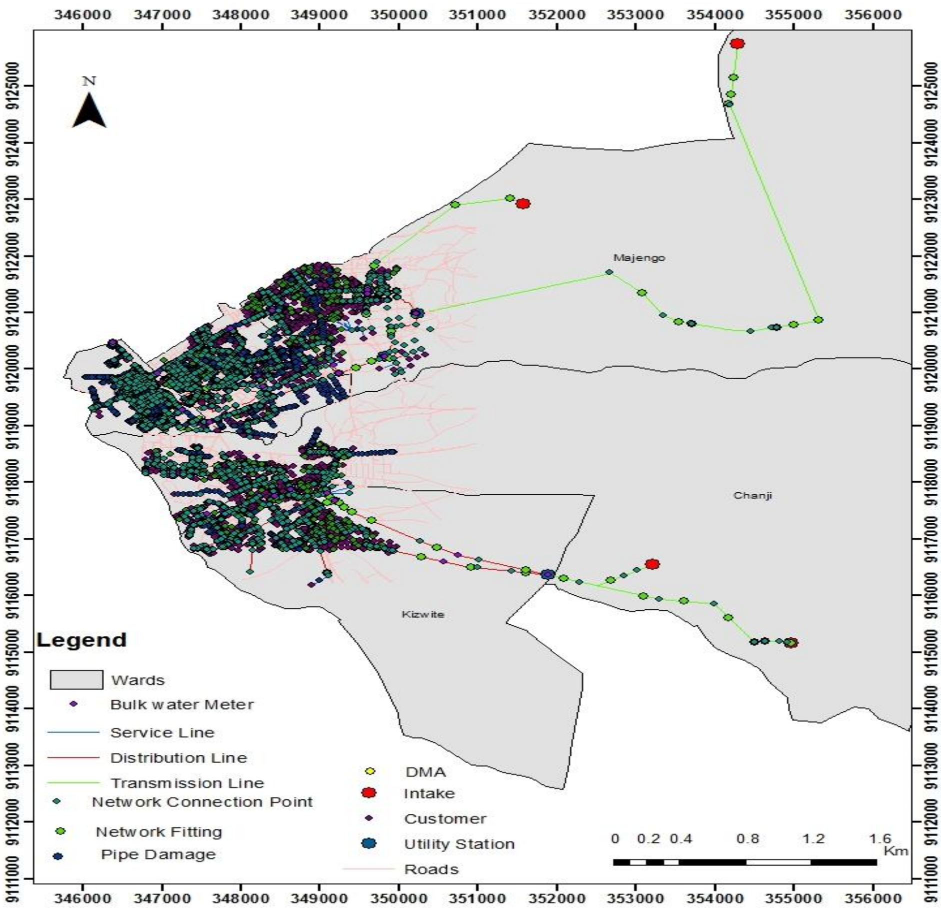

Figure 13: Water Network Assets Stored into the Database
Source: Field data, 2019

Various studies have indicated that controlling water loss and revenue management system operations in 'unplanned' water distribution networks is complex, and a major contributor to NRW in urban areas (Shamsaei et al., 2013). There is a lot of ambiguity and no consensus regarding the best ways to manage water loss or NRW in Africa. There is no one approach that has been accepted as the best for controlling NRW. According to Karadirek and Yilmaz (2012), performance assessment and modelling of old water distribution networks (WDNs) is an important step in managing NRW in unplanned urban areas. One of the pressure management studies in SSA has suggested hydraulic model simulations as a tool for effective reduction of water loss (Sharma & Kennedy, 2016). Due to the limitations of networks, data, and local conditions in SSA countries' minimum night flow (MNF), analysis is recommended as the best method that provides meaningful results in the determination of real water loss in distribution systems (Karadirek et al., 2012). A geospatial database is another tool considered as one of the best methods for managing water revenue, and increasing the efficiency of revenue collection and water allocation (Gupta & Kulat, 2018). In fact, GIS technology focuses on monitoring and managing water resources and promoting sustainable use of it. Through geospatial databases, water supply pipes and revenue collection can be monitored in real-time, while keeping the number of affected citizens to a minimum. Leaking water system components can also be identified and fixed in real-time, which is much possible due to the integration of supply systems with GIS (Merem et al., 2017).

According to AbdelBaki et al. (2019), a possible solution for improving the response time to water loss and revenue collection problems is the utilization of GIS and geodatabase as an enhanced technology. GIS technology can be used for spatial modelling of urban water networks, and as an interactive user environment for daily water management tasks (AbdelBaki et al., 2019). Given the spatial nature of the data used and generated by the database in GIS, it can be used to effectively enhance water resource management and modelling. Another merit of GIS is its ability to determine the condition of a water network and have its capacity information from existing databases, transform them into a geo-analysis environment, and produce reports and graphic information accordingly (Neji et al., 2015). This application consists of querying water services information for managing, visualizing, and storing geospatial data; and a GIS-based algorithm for optimal burst pipe isolation. This database application was successfully tested on the database of a Tehran's district in a water distribution network. This test demonstrated the operational viability of the application, and its potential as a platform for water loss and revenue-based solutions.

4. Conclusion and Recommendations

This study has revealed that water consumption in each of the zones studied was much lower during weekdays, compared to that of weekends. The weekend consumption was by far more than three times that of weekday consumption, which averaged at more than 50m^3. High consumption of water during weekends was caused by large numbers of consumers present at home. Furthermore, the study indicates that zone B contributes large amount of NRW in the Sumbawanga

Urban district. The results of NRW obtained from the three zones were greater than the maximum NRW of 20% recommended by EWURA and SUWASA's key performance indicators of 2015/2016–2016/2017. It was also above the target of 23% set by the World Bank for all utilities. This study informs planners and decision-makers that SUWASA should reduce the water loss problem, especially in zone B. In addition, the study found that change management strategies should apply GIS system through geo-database creation and development, instead of using traditional auditing system. The study further emphasizes on the use of GIS in determining optimal routes for effective and quick response to bursts as communicated by customers, and that it is important for plumbers to use the most possible optimal routes to attend reported problems and avoid losing a lot of water, which contributes to high NRW levels.

References

Abdel Meguid, H.S. (2011). Pressure, Leakage and Energy Management in Water Distribution Systems. PhD thesis, De Montfort University, Leicester: https://www.dora.dmu.ac.uk. Date accessed: 18th August 2017.

Adhikari, B., Di Falco, S. & Lovett, J.C. (2004). Household Characteristics and Forest Dependency: Evidence from Common Property Forest Management in Nepal. *Journal of Ecological Economics*, 48(2): 245–257.

Alizadeh, Z., Yazdi, J., Mohammadiun, S., Hewage, K. & Sadiq, R. (2019). Evaluation of Data Driven Models for Pipe Burst Prediction in Urban Water Distribution Systems. *Urban Water*, 16: 136–145.

Arctur, D. & Zeiler, M. (2004). *Designing Geodatabases*. ESRI Press.

Ardalan, A., Rad, M.K. & Hadi, M. (2019). Urban Water Issues in the Megacity of Tehran. in *Urban Drought*, pp. 263–288.

Aron, J. (2015). Assessment of Water Losses in Dar es Salaam: Case of Kawe Ward in Kinondoni District. (Mimeo).

Atabekova, A., Belousov, A. & Shoustikova, T. (2019). Web 3.0–Based Non-formal Learning to Meet the Third Millennium Education Requirements: University Students' Perceptions. *Procedia Social Behavioral. Science,* 214: 511–519.

Brown, A. (2007). Successful Utility Reforms in Africa. A Paper Presented for African Water Association (AFWA) Meeting, July 16: Kampala. AFWA Working Paper, Dakar, Senegal.

Brown, T. (2007). Conservation Project Saves $24M for Utilities. in J. Thornton (Ed.), *Water Loss Control Manual*. New York: McGraw-Hill.

Butler, D. & Memon, F. (2006). *Water Demand Management*. London, International Water Association (IWA).

Connolly, P. (2007). *Quantitative Data Analysis in Education: A Critical Introduction Using SPSS*. London & New York, NY: Routledge.

Creswell, J.W. (2009). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches* (3rd Ed.). Thousand Oaks, CA: Sage.

Cruz, H. (2016). A Geospatial Analysis of Income Level, Food Deserts and Urban Agriculture Hot Spots. (Mimeo).

Delipetrev, B. Jonoski, A. & Solomatine, D.P. (2014). Development of a Web Application for Water Resources Based on Open Source Software. *Computational Geoscience,* 62: 35–42.

Douglas, B.C. (2010). Applying the Theories of Sustainable Water Aid. (Mimeo).

Erickson, O.H, Loucks, O.L. & Strafford, N.C. (1999). The Context of Sustainability. In: *Sustainability Perspectives for Resources and Business*. USA. Esri. 2012d. Water utilities Data Model. http.support.Esri.com/en/ downloads/ datamodel/ detail/16 (Accessed: May 13: 2017).

Fanner, P., Liemberger, R. & Sturm, R. (2007). *Evaluating Water Loss and Planning Loss Reduction Strategies*. AWWA Research Foundation.

Farley M., Wyeth G., Ghazali, Z.B., Istandar A. & Signh, S. (2008). The Manager‘s Non-Revenue Water Handbook (*A Guide to Understanding Water Losses*). Bangkok, Rainhill Utilities Berhad and USAID.

Frauendorfer, R. & Liemberger, R. (2010). The *Issues and Challenges of Reducing Non-Revenue Water*. Mandaluyong, Philippines: Asian Development Bank.

Gikuhi, J.K. (2011). Use of GIS To Analyse the Revenue and Non-Revenue Water. (Mimeo).

Hildemar, C. (2016). A Geospatial Analysis of Income Level, Food Deserts and Urban Agriculture Hot Spots.

Itianingsih, A.V., Cahyono, D. & Choiron, A. (2018). Web-GIS Application Using Multi-Attribute Utility Theory Method as an Alternative Classification of New Highway Development with Heavy Traffic. *Advanced Science Letter,* 24: 9186–9192.

*International Water Association (*IWA). (2003). Leak Detection Practices and Techniques; a Practical Approach. http://www. findmoreleaks. com/ downloads/ Water21–2.pdf> Accessed, 15th April 2017.

Joseph, W.P. & Houlder, G. (2003). Water and Sewerage Authority Water Gain and Control Strategies Leak Reduction Point Lisas Industrial Estate. Available from: http://oocur.org/Proceedings/Presentations/JosephHoulder.pdf. Accessed Nov 2007.

KagayaL, S. & Smout, H. (2007). *Water Loss Management for Utilities in Low Income Countries: Case Study From Four African Water Utilities*: Bucharest, Romania.

Kangangi, M.I. (2015). The Determinants of Non-Revenue Water Services Provision in Kirinyanga County in Kenya: A Case of Kirinyanga Water and Sanitation Company. (Mimeo).

Kingdom, B., Liemberger, R. & Marin, P. (2006). The Challenge of Reducing Non-Revenue Water in Developing Countries. a Water Supply and Sanitation Sector Board Discussion Paper Series, Paper No.8.

Kothari, C. (2005). *Research Methods and Techniques,* 2nd Edition. New Delhi, Wesley Eastern Limited.

Kothari, C. R. & Garg, G. (2014). *Research Methodology Methods and Techniques* (3rd Ed.). New Dellhi: New Age International (P) Ltd.

Ku Mahamud, K.R. (2007). Identifying the Location and Magnitude of Non-Revenue Water: A Case Study of Felda Chuping, Perlis, Malaysia,.

Lambert, A. & Mckenzie, R. (2002). Development of Sample and Programmatic Approach to Benchmark Real Losses in Portable Water Distribution Systems in South Africa. BENCHLEAK Report TT159/01. South Africa Water Research Commission.

Madara, O.T. (2015). Factors Influencing Non-Revenue Water in Kimilili Water Supply, Bungoma County, Kenya: (Mimeo).

Mahmoudi, S. (2007). Managing UFW in Iran. In: IWA, *Water Loss*, 2007.

Maina, J.M. (2010). Determinates of High Non-Revenue Water: A Case of Water Utilities in Murang'a County, Kenya. (Mimeo).

Maina, J.M. (2016). The Impact of Non-Revenue Water on Water Utilities and Their Customers: A Case Study of Nairobi City Water and Sewerage Company. (Mimeo).

Mons, J. (2010). Strategies for NRW Management in Developing Countries: A Case Study of Kampala, Uganda. School of Applied Science. Bedfordshire, UK, Cranfield University. (Mimeo).

Motiee, H. & Ghasemnejad, S. (2019). Prediction of Pipe Failure Rate in Tehran Water Distribution Networks by Applying Regression Models. *Water Supply*, 19: 695–702.

Mulwafu, W., Chipeta, C., Chavula, G., Ferguson, A., Nkhoma, B.G. & Chilima, G. (2002). Water Demand Management in Malawi: Problems and Prospects for its Promotion. Paper presented at 3rd WaterNet/Warfsa Symposium, Dar es Salaam, 30–31 October.

Mutikanga, H.E, Sharma, S.K. & Vairavamoorthy, K. (2011). Assessment of Apparent Losses in Urban Water Systems. *Water and Environment Journal*, 25(3): 327–325.

Neji, H.B.B. & Turki, S.Y. (2015). GIS Based Multicriteria Decision Analysis for the Delimitation of an Agricultural Perimeter Irrigated With Treated Wastewater. *Agricultural Water Management*, 162: 78–86.

Ngece, K. (2003). *Forestry Conservation in East Africa*. Community-Based Forestry is the Answer. Nairobi: East African Ecotourism Development and Conservation Consultants.

Nightingale, A. (2009). Triangulation. In Kitchin, R. & Thrift, N. (eds.), *International Encyclopedia of Human Geography*, Volume 11 Elservier, Oxford.

Pieracci, B.A. (2010). Examining the Distribution of Break and Entrers Across Regina Neighborhoods Using Geographical Information System (GIS). (Mimeo).

Rad, T.G., Sadeghi-Niaraki, A., Abbasi, A. & Choi, S.M. (2018). A Methodological Framework for Assessment of Ubiquitous Cities Using ANP and DEMATEL methods. *Sustainable Cities*, 37: 608–618.

Saatsaz, M. (2019). A Historical Investigation on Water Resources Management in Iran. *Environmental Development Sustain*, 1–37.

Starik, M. & Kanashiro, P. (2013). Toward a Theory of Sustainability Management: Uncovering and Integrating the Nearly Obvious, *SAGE Journals*, 26(1): 7–30.

Sumbawanga Urban Water Supply and Sewerage Authority (SUWASA). (2016). The Annual Report. Sumbawanga, Tanzania. (Mimeo).

SWAN. (2011). Stated NRW (Non-Revenue Water) Rates in Urban Networks.

SWIM. (2013). Sustainable Water Integrated Management (SWIM) - Support Mechanism.

Tabesh, M. & Asadiani, Y.A.H. (2005). A Software Tool for Non-Revenue Water Calculations in Urban Water Systems in Conjunction with Hydraulic and GIS Models. Paper to IWA special conference on 'Leakage 2005'. September, Halifax, Canada, http://waterloss2007.com/Leakage2005.com/pdf. (Accessed 13March, 2017).

United Republic of Tanzania (URT). (2012). *Water Sector Status Report, 2009*. Ministry of Water and Irrigation, United Republic of Tanzania.

Vaitis, M., Feidas, H., Symeonidis, P., Kopsachilis, V., Dalaperas, D., Koukourouvli, N. & Taskaris, S. (2019). Development of a Spatial Database and Web-GIS for the Climate of Greece. *Earth Science Information,* 12: 97–115.

Van der Zaag, P. (2003). Urban Water Demand, IWRM 0.1 Lecture Notes, University of Zimbabwe, Harare, Zimbabwe. (Mimeo).

Vanier, D. (2004). Geographic Information Systems (GIS) as an Integrated Decision Support Tool for Municipal Infrastructure Asset Management. National Research Council Canada. http://www.nrc-cnrc.gc.ca/obj/ircdoc/pubs/ nrcc4675/ nrcc754.pdf. (Accessed: Feb. 19: 2018).

Wang, X.J. & Li, C.H. (2018). Design and Implementation of Tourism System Based on WebGIS. *Computational Technological Development*, 8: 31.