



Africa Centre of Excellences for Water Management
Addis Ababa University
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**IMPACTS OF URBANIZATION ON KICUKIRO WATER SUPPLY NETWORK:
SPATIO-TEMPORAL INVESTIGATION USING GEOSPATIAL MODELS AND
WATERGEMS**

By

Jimmy Victor MURENZI

A thesis submitted to the African Centre of Excellence for Water Management (ACEWM) in
partial fulfilment of the requirement for Master's Degree in Water Management
(Water Supply& Sanitation) of Addis Ababa University

October, 2020

Addis Ababa

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Advisor: Dr. Gudina Legese Feyisa

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November, 2020

ADDIS ABABA UNIVERSITY
AFRICA CENTER OF EXCELLENCE FOR WATER MANAGEMENT

Thesis Approval Form

APPROVED BY BOARD OF EXAMINERS

This is to certify that we the undersigned, have examined this MSc thesis entitled “**IMPACTS OF URBANIZATION ON KICUKIRO WATER SUPPLY NETWORK: SPATIO-TEMPORAL INVESTIGATION USING GEOSPATIAL MODELS AND WATERGEMS**” and that in our opinion; it is fully adequate, in scope and quality, as a MSc thesis for the degree of Master of Science in Water Management (Water Supply and Sanitation).

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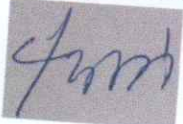
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Statement of the author

I, **Jimmy Victor MURENZI**, declare that this research report is my original effort and work and to the best of my knowledge, the findings have never been previously presented to the Addis Ababa University or elsewhere for the award of any academic qualification. Where assistance was sought, it has been accordingly acknowledged. The findings, interpretations and conclusions expressed in this study neither reflect the views of the Addis Ababa, African Centre of Excellence for Water Management (ACEWM), nor those of the individual members of the MSc Examination Committee.

Signature...



..... Date: October 20th, 2020

Acknowledgement

Firstly, I would like to express gratitude to my advisors Dr Gudina Legese Feyisa and Prof. Dr.-Ing. Esayas Alemayehu for their technical guidance throughout this research. I feel honoured to have had an opportunity to work on my thesis under their guidance. I also wish to express my gratitude to the Africa Centre of Excellence (ACEWM) for sponsoring my studies. Acknowledgement is also made to the World Bank Group through the ACE II Project.

I would like to extend my appreciation to Prof. Dr. Eng. Etienne Ntagwirumugara of the African Centre of Excellence in Energy for Sustainable Development (ACEESD) in Rwanda for all the support rendered to me during my exchange visit to ACEESD in preparation for research work.

I would also like to extend my gratitude to those who shared their knowledge and time during different stages of this thesis; Idrissa Shamsdeen Nkwanda, Ambrose Mubialiwo, Mukakarangwa Assoumpta and Tigist Alem. Without their intellectual support, I could have not finished this thesis.

I am equally indebted to the moral support of my family especially my esteemed wife Mahoro Douce Melissa and friends; Theoneste Twagirumuhire, Elias Habineza, Niyitegeka Hyacinthe, and Uyisenga Uwinkindi Dieudonne.

I would also like to acknowledge WASAC Ltd, Kicukiro district office and National Institute of Statistics of Rwanda for the provision of different Data used in this study.

Above all, I would like to thank Almighty God for the guidance, health and safety during the entire study period.

Abstract

In Kigali, the capital city of Rwanda, the population is growing faster than the provision of services with a strong population growth of average annual growth rate of 4.0 percent. The high population growth has led to expansion of Kigali city. Nevertheless, the expansion of the city does not have in parallel a clear viability plan of water supply, and also due to rapid urbanization, the burden on the existing Kigali water distribution network is increasing along with widening gap between supply and consumer water demand. The aim of this study was to investigate the spatio-temporal impacts of urbanization on Kicukiro water supply network and water availability in order to propose the sustainable adaptation strategies. Landsat imagery were used to examine spatio-temporal changes in urbanization. The result of accuracy showed that overall accuracy of land use/land cover (LULC) is 89.030 %, 93.715 %, 94.359 % and Kappa (K) is 85.40 %, 91.50 %, 89.80 % for 1999, 2013, 2019 respectively. The outputs showed that the total built-up land has grown by 31.52 km² from 1999 to 2019. Therefore, it was crucial to recognize that Kicukiro has clearly experienced significant and rapid expansion. It was observed that the existing water supply system of Kicukiro does not have a wider coverage of water distribution to some parts of the area. This will lead to persistence water shortage, water scarcity and lack of accessibility to the basic need of water for residential utility. The results indicate that the population of Kicukiro district will increase from 419,209 inhabitants in 2019 up 918,538 inhabitants in 2039. The results also showed that the current daily water demand (2019) is 76,854.98 m³ and 183,707.60 m³ for 2039. It was observed that there is a large gap between demand and supply of water and there is no sign of instant relief in the near future. At the end, WaterGEMS was used to analyze the existing water supply system of Kicukiro district and it was found that the resulting pressures at all the junctions and the flows with their velocities at all pipes are not enough to provide water to the study area. The outcome of this study will be an efficient tool for water management as well as to support planning processes and formulate policies to guide or redirect spatial growth in Kicukiro district; it will also provide a foundation for a long-term plan to maintain, repair, augment, or replace a water system when necessary in parallel with the urbanization. Furthermore, the result of this research will serve as baseline for future scientific researches by applying the remote sensing and GIS techniques in investigating impacts of urbanization on water supply system and water security.

Keywords: urbanization, water supply system, LULC mapping, ENVI, WaterGEMS

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Abbreviations and Acronyms

WHO:	World Health Organization.
EDPRS:	Economic Development and Poverty Reduction Strategy.
MDGs:	Millennium development goals.
ACEWM:	Africa Center of Excellence for Water Management.
MININFRA:	Ministry of Infrastructure, Rwanda.
JMP:	Joint Monitoring Program for Water.
EICV3:	Enquête Intégrale sur les Conditions de Vie, 3
WSS:	Water Supply System.
WDN:	Water Distribution Network.
EWSA:	Energy Water and Sanitation Authority.
NISR:	National Institute of Statistics of Rwanda.
WASAC:	Water and Sanitation Corporation.
Lpcd:	Liter per capita per day
Gpm:	Gallons per minute
SVM:	Support Vector Machine
ROI:	Region of interest
RSB:	Rwanda Standards Board
UTM:	Universal Transverse Convertor
WGS:	World Geodetic System

1. INTRODUCTION

1.1. Background

In the 21st century, rapid urbanization and urban growth have been one of the crucial issues of global change that affect the physical dimension of cities. With regard to the growing population of the world, the need of water will be increased gradually (Tavosi and Siosemarde, 2016) . It was reported that 3.6 billion of the world's population (52 percent) was urban dwellers. Globally, the level of urbanization is expected to rise to 67 percent in 2050. In the less developed regions, the proportion of the urban population is expected to rise from 47 percent in 2011 to 64 percent in 2050 (Nyakairu et al., 2013).

With Rwanda's population projected to rise to around 17 million by 2032 and 26 million by 2050, and increasing urbanization (at 4.4 percent per year), will put a significant pressure on scarce natural resources, notably land, fresh water and forests. There will certainly be increasing water demand putting further pressure on water resources (NISR, 2019).

In Kigali, Rwanda's capital city, the population is growing faster than the provision of services. In 1996, the population was 358,200, but by 2012, it had increased to 1,135,428. Much of the urban growth has taken place in unplanned settlements that now accommodate 62.6 percent of the population (NISR, 2014).

The urban water supply subsector shows an overall negative trend relative to 1990 baselines, whether estimated by Ministry of Infrastructure, Rwanda using provider data (76 percent in 2009) or the JMP using household surveys (77 percent in 2008). Meanwhile, Energy Water and Sanitation Authority (the public utility in charge of urban water supply and sanitation) puts current coverage at 71 percent. Again, the Joint Monitoring Program for Water trend line does not capture the drop-in services following the genocide. What the trend over the period also masks are very rapid urban expansion. There were nearly five times as many Rwandans living in urban areas in 2008 as compared to 1990; an increase of 1.4 million urban dwellers. Thus, despite the rapid expansion of number of connections since 2005; from 45,000 to about 78,000, the percentage of the urban population with access has inevitably dropped since 1990 and led to a need for greatly increasing the raw water supply to urban areas. JMP estimates of household connections also show a decreasing trend since 1990 (from 32 percent to 15 percent in 2008) (WASAC, 2017).

Among the three districts of Kigali city, Kicukiro district has the highest percentage 76.6 percent of households residing in unplanned urban housing, 6.6 percent households residing in agglomerations, 3.8 percent percentage of people living in isolated rural housing, 4.4 percent of households living in unplanned rural housing and 3.6 percent residing in Imidugudu (Kicukiro, 2018).

Access to improved water sources in Kicukiro district is still insufficient taking into account the MDGs target of 82 percent access and the vision 2020 target of 100 percent access to clean water. As Kicukiro District currently stands at 69 percent access, it implies that 31 percent do not have access to improved water sources or clean water and this is the highest percentage that the district has to cater for in as far access to clean water is concerned. It had been also identified that the existing water does not fulfill the requirements of clean water (Kicukiro, 2018).

Therefore, an integrated study using geospatial models and hydraulic model (WaterGEMS) serving to understand and to identify not only the characteristics of ongoing changes but also the future impacts of urbanization on Kicukiro district water supply network is needed.

1.2. Statement of the problems

Kigali city is among fastest growing cities in Africa with a strong population growth of average annual growth rate of 4.0 percent (NISR, 2014). Kigali has grown from a population of 6000 people in 1962 (when Rwanda gained its independence) to over 1 million inhabitants today. The high population growth has led to expansion of Kigali city due to the big migration of people from rural areas for employment and business opportunities and also due to returning refugees after 1994 (G Nduwayezu et al., 2017).

Nevertheless, the expansion of the city does not have in parallel a clear viability plan of water supply, and also due to rapid urbanization, the burden on the existing Kigali water distribution network is increasing along with widening gap between supply and consumer water demand. Secondly, the existing water network is old, if not damaged. In addition to that, water flow in Nyabarongo and Nyabugogo rivers (two of the main sources of water in Kigali) or other small rivers in Kigali has diminished due to the degradation of environmental conditions including deforestation and soil erosion (Rubogora, 2017).

Some studies have been undertaken related to urbanization and water supply network of Kigali city; for instance, Nduwayezu et al. (2017), modelled urban growth in Kigali city using remote sensing and GIS; Rubogora (2017) assessed most affected communities with the persistent shortage of water in Kigali; Hagenimana and Masanja (2011) suggested an optimal solution with the minimum design cost for the Kigali water distribution network using Linear Programming models.

However, all the above studies, considered the entire Kigali city; yet information at small scale, like district level, is crucial for proper planning. Nduwayezu et al. (2017) did not show the level urbanization is affecting Kigali water supply network; Rubogora (2017) did not map the areas which are most affected and they also did not estimate water demand in Kigali; Hagenimana and Masanja (2011) did not use hydraulic models to optimize the system and they also did not analyze the suitability of existing water distribution network to meet either current or future water demand.

In addition, Kicukiro district's current planning approach requires more data integration, multi-disciplinary and composite analysis regarding its expansion, and need faster and more precise information for all decision-makers and stakeholders (NISR, 2017).

Hence, detailed and integrated studies about the expansion trend of Kigali as well as investigation of impacts of urbanization on Kigali's water supply systems and water security are scarce and not available in an integrated setup for Kigali and for Kicukiro district as well. Therefore, an integrated study using geospatial models and hydraulic model (WaterGEMS) serving to understand and to identify not only the characteristics of ongoing changes but also the future impacts of urbanization on Kicukiro district water supply network is needed.

1.3. Objective

1.3.1. General objective

To determine the spatio-temporal impacts of urbanization on Kicukiro water supply network in order to propose the sustainable adaptation strategies.

1.3.2. Specific objectives

- I. To estimate and map the rate of urban expansion in Kicukiro district.
- II. To map Kicukiro water supply network and identify the areas that require the extension within Kicukiro district.
- III. To determine the current and future water demand in Kicukiro district.
- IV. To analyze the suitability of existing water supply network to meet water demand of Kicukiro due to urban growth.

1.4. Research questions

1. How Kicukiro district is expanding spatio-temporally and how its growth with respect to the water supply can be managed in a sustainable way?
2. What is the extent of Kicukiro water supply network? Which areas require water supply network extension?
3. What is the current and future water demand in Kicukiro district?
4. Can the existing water supply network meet Kicukiro district water demand? What improvement can be made on the existing water supply network (if any)?

1.5. Significance of the study

The outcome of this study will be an efficient tool for water management as well as to support planning processes and to formulate policies to guide or redirect spatial growth in Kicukiro district. The results of this study will also provide a foundation for a long-term plan to maintain, repair, augment, or replace a water system when necessary in parallel with the urbanization.

A careful evaluation of supply and demand projections will be used to help identify any vulnerabilities. The information will be used by decision makers to make reasonable decisions about investments in water use efficiency and new supplies. This will improve the water supply and distribution in the Kicukiro district.

Last, but not least, the result of this research will serve as baseline for future scientific researches by applying the techniques of geospatial models and hydraulic models analysis in investigating impacts of urbanization on water supply system and water Security.

1.6. Scope of the study

The study was conducted in Kicukiro district which is one of the three districts of Kigali city, Rwanda. Three scenarios of urbanization were assessed within the previous 20 years by looking only at the built-up lands using geospatial models: ENVI 5.2 as remote sensing tool and ArcMap 10.4. The study particularly focused on the current and future water demands. Existing water distribution network and future expansion were analyzed using WaterGEMS V8i as one of the hydraulic models.

2. LITERATURE REVIEW

2.1. Introduction

This chapter highlights the various studies related to the current research, gaps emanating from these works, and how the present study contributes to fill some gaps identified. Literature review for this study is done thematically under the following sections; urbanization, water supply network, water security, geospatial models, WaterGEMS and an Overview of Kicukiro district with respect to urbanization and water supply.

2.2. Urbanization

Urbanization is a process in which increasing number of people migrate from rural to urban areas. Ultimately it leads to horizontal or vertical growth of urban areas. A country is considered to urbanize when over 50 per cent of its population live in the urban areas. The criteria used to define urban can include population size, space, density and economic organization (Hassan et al., 2018).

Urbanization in Rwanda was analyzed here by disaggregating the general concept of ‘urbanization’ into three related but distinct processes: urbanization (the increase in the proportion of the national population living in urban areas), urban growth (the increase in the absolute number of people living in urban areas), and urban expansion (the physical enlargement of built-up areas) (World bank group, 2017).

2.2.1. Definitions of important terms

Urban (area)

The definition of ‘urban’ varies from country to country, and, with periodic reclassification, can also vary within one country over time, making direct comparisons difficult. An urban area can be defined by one or more of the following: administrative criteria or political boundaries (e.g., area within the jurisdiction of a municipality or town committee), a threshold population size (where the minimum for an urban settlement is typically in the region of 2,000 people, although this varies globally between 200 and 50,000), population density, economic function (e.g., where a significant majority of the population is not primarily engaged in agriculture, or where there is surplus employment) or the presence of urban characteristics (e.g., paved streets, electric lighting, sewerage) (Pirozzi et al., 2012).

Urban growth

The (relative or absolute) increase in the number of people who live in towns and cities. The pace of urban population growth depends on the natural increase of the urban population and the population gained by urban areas through both net rural-urban migration and the reclassification of rural settlements into cities and towns (Unicef, 2012).

Rate of urbanization

The increase in the proportion of urban population over time, calculated as the rate of growth of the urban population minus that of the total population. Positive rates of urbanization result when the urban population grows at a faster rate than the total population (Pirozzi et al., 2012).

Urban Development

Urban development is the process of emergence of the world dominated by cities and by urban values (Wakode, 2016). The rise of great cities and their growing spatial influence initiated a change from largely rural to predominantly urban places and patterns of living that has affected most countries over the last two centuries. Currently not only do large number of people live in or immediately adjacent to towns and cities, but whole segments of the population are completely dominated by urban values, expectations and life styles (Mashagbah et al., 2012)

2.3. The Concept of Land Use/ Land Cover Change

The terms land use and land cover are often used interchangeably even though there is a distinction between the two terms. Many authors define land use as; the intended employment of land management strategy placed on the land cover by human agents, or land managers to exploit the land cover and reflects human activities such as industrial zones, residential zones, agricultural fields, grazing, forestry, and mining, just to mention a few (Bello *et al.*, 2018; Zubair, 2006). On the other hand; Land cover refers to the surface cover on the ground, whether vegetation, urban infrastructure, water, bare soil, or other. It should be noted that LC does not describe the use of land, and the use of land may be different for lands with the same cover type. In simple terms, land use indicates how people are using the land, whereas land cover indicates the physical attribute of the land. Both types of data (land use/ land cover) are most often obtained from the analysis of either satellite or aerial images. Land cover data shows how much of the region is covered by grass, forest, impervious surfaces and croplands, and water types (wetlands or open water). Land

use data shows how people are using the landscape whether for development, agriculture, recreation, conservation, or mixed uses.

Originally Land cover had a different meaning from what it has now. It used to refer to the kind and state of vegetation, such as forest or grass cover but it has broadened in subsequent usage to include other things such as human infrastructures, soil type, biodiversity, surface and groundwater (Meyer 1999).

Brief review of SVM applications

Support Vector Machine is a non-parametric statistical learning algorithm, which was originally aimed at binary classification by defining optimal hyperplane providing maximum margin separating two classes. In case of nonlinear classification, SVMs can perform the classification by using various types of kernels which turns nonlinear boundaries to linear ones in the high-dimensional space to define optimal hyperplane. SVMs are based on the principle called Structural Risk Minimization (SRM) maximizing the margin between a separating hyperplane and data points closest to the hyperplane. Theoretically error penalty (C) that allows for misclassification plays an important role on SVM classification accuracy and researchers are currently focused on analyzing the behaviour of this property more in depth (Ustuner et al., 2015).

Accuracy Assessment of Land Use Land Cover Classification

Land use land cover analysis can be done from processed aerial photographs, Satellite images (Landsat image, Quick bird image) and Google Earth. Since remote sensed data from the earth orbit can be obtained repeatedly over the same area, they have been very useful to monitor and analyze LUCC in various regions of the earth and greatly contribute to planning and management of available resources, especially in the developing countries where other kinds of background data are often lacking (Dash, 2005; Fakeye *et al*, 2015). After doing of land use land cover classification, the accuracy of special data should be defined. Accuracy assessment or validation is an important step in the processing of remote sensing data which determines the information value of the resulting data to a user

For doing of accuracy assessment we use

1. Ground verification using Global Position System (Observing the area)

2. Compares of the classified image to an image which is assumed to be correct (such as an aerial photograph, Google Earth Image)

3. Asking questions for concerned bodies those they have previous information. Google earth (<http://earth.google.com>) provided by Google Inc., is a virtual globe programming that maps the earth by superimposition of high-resolution satellite images and Aliakbar, 2013). Since it was released in June 2005, Google Earth has aims to provide viewers with “a more realistic view of the world”. Beside Google Earth, map data and positional measurement can be obtained using different methods such as conventional or modern land survey methods, Global positional System (GPS) and remote sensing satellite imagery. Google earth high-resolution imagery accuracy assessment by comparing of point by point basis. A random set of points is generated for the area and then using the Google Earth the value for each point is identified Therefore, this study was intended to examine the accuracy of Land Use Land Cover Classification using Google Earth in the case of in Kilite Awulalo, Tigray State, Ethiopia (Tilahun, 2015)

2.4. Water supply system

Water supply system produces and delivers potable water to the consumers using a complex network of pipes, pumps, valves, tanks, and treatment plants. Water supply system (WSS) can be divided roughly into three parts: water sources, water distribution network (WDN) and water consumers (Sunela, 2017).

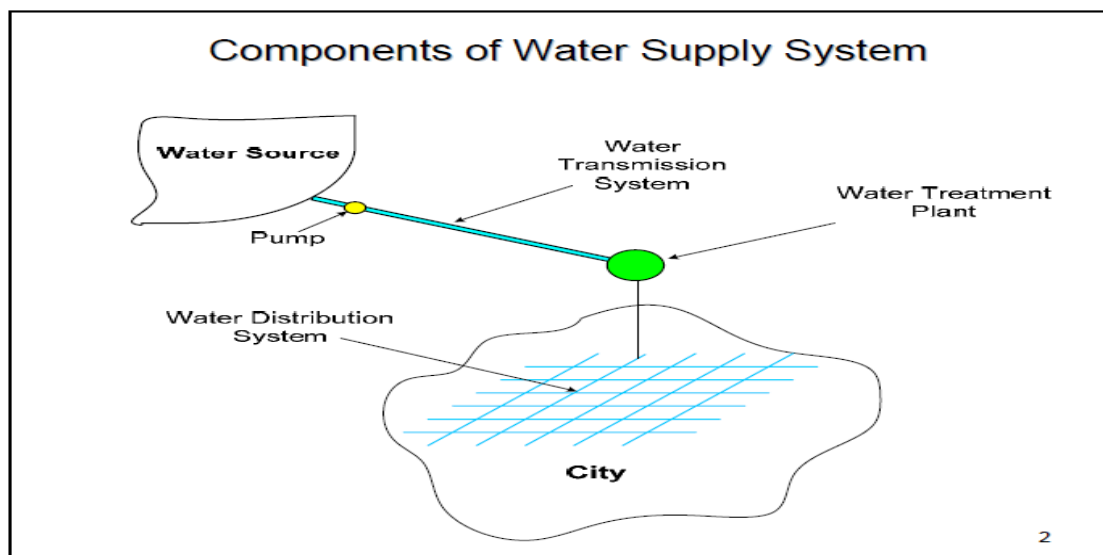


Figure 1: Components of water supply system

Source: (Ostfeld, 2015).

2.4.1. Water distribution system

A water distribution system is a complex assembly of hydraulic control elements connected together to convey quantities of water from sources to consumers. It is designed to adequately satisfy the water requirements for a combination of the following demands: domestic, commercial, industrial, fire-fighting. The system should be capable of meeting the demands at all times and at satisfactory pressure (Ostfeld, 2015).

The main elements of the distribution system are: pipe systems, pumping stations, storage facilities, fire hydrants, house service connections, meters, and other appurtenances. Distribution systems may be classified as: branching systems, grid systems, or a combination of branching and grid systems. The configuration of the system is dictated by: street patterns, topography, degree and type of development of the area, location of the treatment and storage works (Tessema, 2015).

2.4.2. Water demand

The indicator for measuring the level of water consumption is the amount of water consumed per capita per day (l/c/d). Water consumption is a function of availability, religion, climate conditions, and affordability. Another indicator used in measuring the level of water consumption is the quality of delivered water. In general, water utilities have to follow WHO standards for domestic water (Trifuovi, 2006).

The demand for water supplied by a municipal water system has two driving components: 1) consumer consumption: the amount of water in gpm or gallons per day that is used by all of the taps on the water mains to supply single-family homes, multiple-family residences of all types, health care facilities, schools at all levels of education, commercial enterprises, industrial complexes, and adjunct uses (street cleaning; water fountains; watering public grass areas; shrubs, trees, and flowers; parks and recreation including swimming pools; and the sale of water to contractors for building roads, structures, etc.) and 2) an adequate and reliable water supply for fire protection (Harry, 2008).

The three basic demand types described below:

- Customer demand is the water required to meet the non-emergency needs of users in the system. This demand type typically represents the metered portion of the total water consumption.

- Unaccounted-for water (UFW) is the portion of total consumption that is “lost” due to system leakage, theft, unmetered services, or other causes.
- Fire flow demand is a computed system capacity requirement for ensuring adequate protection is provided during fire emergencies.

2.4.3. Projecting Future Demands

Water distribution models are created not only to solve the problems of today, but also to prevent problems in the future. With almost any endeavour, the future holds a lot of uncertainty, and demand projection is no exception.

Long-range planning may include the analysis of a system for 5-, 10-, and 20-year time frames. When performing long-term planning analyses, estimating future demands is an important factor influencing the quality of information provided by the model.

Scenario management tools in models help make this process easier. Even the most comprehensive scenario management, however, is just another tool that needs to be applied intelligently to obtain reasonable results.

2.5. Water security

Water security is the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability (UN-WATER, 2015).

Water security can be achieved with the creation or acquisition of an appropriate level of a mix of infrastructure and water management capacity. Thus, water security is achieved when communities are resistant to the impact of water resources; so that lack of access to water and water related services and vulnerability to the adverse impacts of water (drought, floods, disease, etc.) cannot create significant barriers to growth. It is considered now that water security is under severe pressure from many sources: the world population explosion, rapid shifts of people from rural to urban areas, the impact of dietary change as countries develop, increasing pollution of water resources, the over-abstraction of groundwater and the significant issues created by climate change (Frone and Frone, 2015).

2.6. Applicability of Geospatial models for Urban Growth and water supply study

Industrialization and economic growth stimulate demographic growth and peri-urban development, leading to massive suburban expansion of cities. Urban area does not grow evenly in all directions of the city, even during the same time period. In some parts of the city, it is dynamically more active and, in some parts, it shows less development or expansion activities. Satellite time series data offer great potential for a quantitative assessment of urban expansion, urban sprawl and for monitoring of land-use changes and soil consumption (Wakode, 2016).

Satellite remote sensing, in conjunction with geographic information systems (GIS), has been widely applied and been recognized as a powerful and effective tool in detecting land use and land cover change (Wakode, 2016). Satellite remote sensing provides cost-effective multi-spectral and multi-temporal data, and turns them into information valuable for understanding and monitoring land development patterns and processes and for building land use and land cover data sets. For most of the land use models, GIS technology is indispensable. It provides the foundation for handling land use change tendency from spatial and temporal perspectives. With the development of spatial and spectral resolution in remote sensing, remotely sensed images provide invaluable data source for land cover in a time series. The integration of satellite remote sensing data and GIS techniques has been proved effective approach for analyzing the direction, rate, and spatial pattern of land use change using Landsat images (Gour et al., 2014).

2.6.1. Estimation of Node Demands

Node demand is an important input parameter of a hydraulic model representing the water consumption rate in units of volume per time. Demands are grouped by customer type (e.g. residential, commercial, industrial, or institutional) or magnitude (e.g. average daily, maximum daily, peak hourly, or fire flow). Manual estimation of node demands from customer billing records is a cumbersome process. Modelers, therefore, have traditionally resorted to approximate methods such as uniform distribution of the residential water use across all nodes followed by adding the nearest commercial and industrial use at various nodes (Baumberger et al., 2007).

GIS allows implementation of more accurate demand estimation methods. One such method utilizes the GIS to geocode (or geolocate) all individual water users (defined by the address at which each meter is located) and to assign the metered water consumption rates for each meter

location to the nearest node in the model. The geocoding process links a street address to a geographic location and finds the coordinates of a point location based on its street address.

This method assumes that a computer file (spreadsheet or delimited text file) containing meter addresses and metered water use for specified durations (e.g. quarterly or monthly) can be produced from the utility's billing database.

If this information is available, the following procedure can be used to assign demands to nodes.

1. Create a GIS layer (e.g. a shapefile) representing all nodes in the model.
2. Obtain a street centerline layer of the service area with address ranges. Such data can also be purchased from commercial GIS data vendors.
3. Obtain and pre-process customer meter location and consumption database.
4. Process the meter address and street address range data in GIS to geocode the meter locations into a point layer registered to model node layer.
5. Assign and aggregate individual meter demands to nearest nodes.
6. Analyze the assigned metered demand to determine unaccounted for- water and metered demands that were not successfully geocoded. Uniformly distribute these remaining demands across nodes.
7. Load the node demand data into the hydraulic model (Shamsi, 2004).

The above procedure produces a highly accurate distribution of water use across the nodes. The intermediate product of point locations with associated demands can also be used to visualize the spatial distribution of individual demand points throughout the system. A metered demand database can also be created to include customer classes as defined in the billing system. This data can be used to assign differing demand patterns to residential, commercial, and industrial demand classes for use in extended period simulations.

2.7. Applicability of WaterGEMS for analyzing water supply networks.

2.7.1. WaterGEMS

WaterGEMS is a hydraulic modeling application for water distribution systems with advanced interoperability, geospatial model building, optimization, and asset management tools. From fire flow and constituent concentration analyses, to energy consumption and capital cost management, WaterGEMS provides an easy to use environment for engineers to analyze, design, and optimize water distribution systems (Mehta et al., 2017).

2.7.1.1. Superior Interoperability

WaterGEMS users enjoy the power and versatility afforded by working across CAD, GIS, and stand-alone platforms while accessing a single, shared, project data source. With WaterGEMS, utilities and consultants can choose to model from within four interoperable platforms:

- Windows stand-alone for ease of use, accessibility, and performance
- ArcGIS for GIS integration, thematic mapping, and publishing
- Micro Station for bridging geospatial planning and engineering design environments
- AutoCAD for CAD layout and drafting

Modeling teams can leverage the skills of engineers from different departments, and engineers can flatten learning curves by choosing the environment they already know and provide results that can be visualized on multiple platforms (Nandavadekar, 2013)

2.7.1.2. Streamlined Model Building

Engineers can leverage geospatial data, CAD drawings, databases, and spreadsheets to jumpstart the model building process. WaterGEMS provides synchronized database connections, geospatial links, and advanced model-building modules that connect with virtually any digital data format. WaterGEMS includes Load Builder and TRex modules to help engineers allocate water demands and node elevations based on geospatial data found in shapefiles, geodatabases, various types of DEMs, and even CAD drawings.

These modules help engineers avoid potential manual-input mistakes.

WaterGEMS also provides drawing and connectivity review tools to guarantee a hydraulically coherent model. Skelebrator automatically removes network complexity, while maintaining hydraulic equivalence, to efficiently tackle a wider range of modeling applications (Velickov, 2011).

2.7.1.3. Model Calibration, Design, and Operations

WaterGEMS includes state-of-the-art genetic algorithm optimization engines for automated calibration, design and rehabilitation, and pump operations. Darwin Calibrator evaluates millions of possible solutions to let users quickly find a calibration hypothesis that best matches measured flows, pressures, and on/off status, empowering users to make reliable decisions based on accurate hydraulic simulation of the real world.

WaterGEMS' SCADA Connect module lets modelers automatically acquire supervisory control and data acquisition (SCADA) data, creating a real-time system simulator that accurately represents current system conditions. It also enables WaterGEMS model results to be published to a utility's existing SCADA control room screen(s), helping to forecast operating conditions and potential issues (Velickov, 2011).

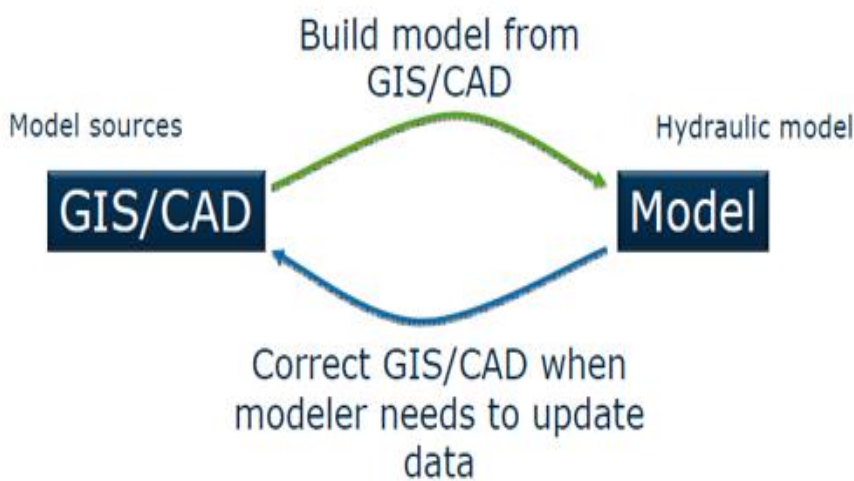
Branch (2014) is public domain optimization software in which program is developed to design the branched water distribution networks. Branch software takes certain parameters like elevation data, pipe lengths, coefficient of friction and demand of nodes as inputs over the cost as function. The output is optimized length and diameters of pipes so that overall cost of network is the least once.

DisNet (2014) is powerful and efficient water distribution software and offers great simplicity in building water distribution networks. Key strengths of DisNet include its simplicity and appealing user interface with maximum accuracy in output with optimum input details. Along with design of water distribution, DisNet is used in the modeling of stream hydrology, generation of unit hydrographs and establishing interrelationships between them. DisNet is integrated with CAD as its inbuilt management tool and used in modeling different types of water distributions networks for different topographical conditions.

Sumithra (2013) has carried out the feasibility analysis of water distribution system of Tirunelveli Municipal Corporation, Tamilnadu, India with the help of LOOP and WaterGEMS softwares packages for design period of 30 years. The variety of analysis has been carried out yielding wide range of results for diameter of pipes, pressure at different nodes, cost analysis, etc. The network analysis has been done pertaining to the criteria of 135 lpcd water supply with the minimum head of 7.0 m. It has also been discussed as a result that LOOP and WaterGEMS softwares are highly efficient to do various hydraulic and costing analysis. WaterGEMS found extremely user friendly

with variety of hydraulic and graphical analysis options. It is also less time consuming for the renovating and reanalyzing the network.

Softwares like the LOOP, EPANET, and WaterCAD has been already used for hydraulic simulation of the water distribution system though the latest software WaterGEMS is the most advanced and powerful tool. In EPANET, the pipe flow rates are computed using linear formulae, improper graphical representation of the results, limitation in demand allocation are main constraints for not using this software in this analysis though several work on efficiency study, simulation of hydraulic parameters of distribution system. Simulation of the hydraulic parameters can be done more effortlessly with WaterGEMS (Roy et al., 2015).



Source: (Velickov, 2011).

Figure 2: Bi-direction synchronization between GIS data and Hydraulic Model

2.8. Overview of Kicukiro district with respect to urbanization and water supply

This chapter portrays the overview of Kicukiro District by clearly showing the District status i.e. achievements of the District in the years 2012-2017 and challenges that the District faces that may hinder development and growth

2.8.1. Urbanization

Though the District saw some important improvements in urban settlement, there is still a long way to go when it comes to planned settlements. The main objective of urbanization is to contribute to sustainable economic growth and the wellbeing of the Rwandan population and Kicukiro District in particular by improving settlements and urban infrastructure.

The District has a program of modernization of existing and new settlements, especially in the planned settlement, with interventions to curb the proliferation of unplanned housing and to improve living standards in informal neighborhoods (Kicukiro, 2018).

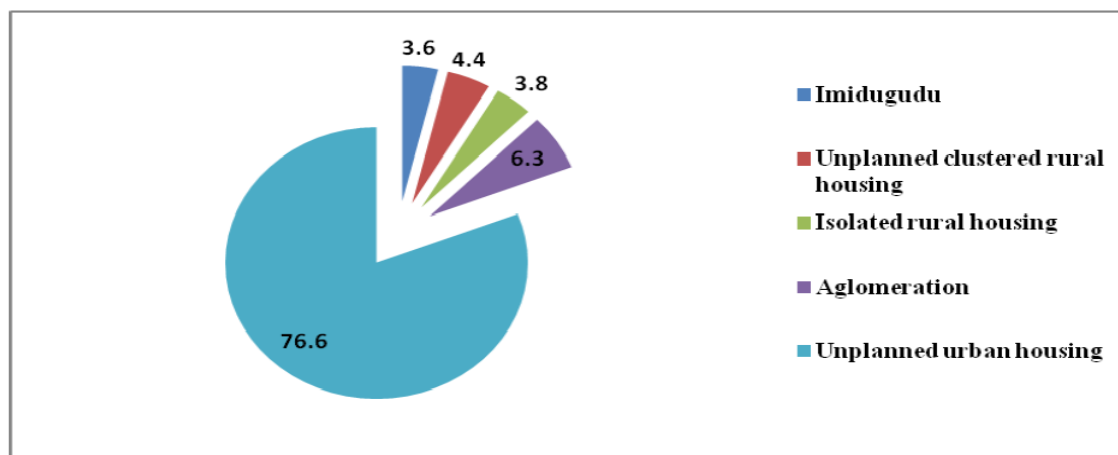


Figure 3: Kicukiro District Type of habitat (% of people)

Source: EICV3 survey results 2010/11

As demonstrated in figure 3, Kicukiro District has a highest percentage 76.6% of households residing in unplanned urban housing, 6.6% households residing in agglomerations, 3.8% percentage of people living in isolated rural housing, 4.4% of households living in unplanned rural housing and 3.6% residing in Imidugudu. Kicukiro District needs to put much effort in urban planning guided by the available Kigali city conceptual master plan.

2.7.2. Water and sanitation

The EICV3 results show that 69.7% of households in Kicukiro district use an improved drinking water source. Improved drinking water sources include protected springs, public standpipes, water piped into dwelling/yard, boreholes, protected wells and rainwater collection, as defined by the World Health Organization (WHO). Figure 2 shows that 20.7% of households in Kicukiro district

use a public standpipe or water piped into dwelling/yard. However, 31 percent of households in this District still use an unimproved drinking water, representing an estimated 93,000 households. Kicukiro district is still below the EDPRS national target for the water and sanitation sector, which is to increase access to drinking water to 85 percent by 2012 (Kicukiro, 2018).

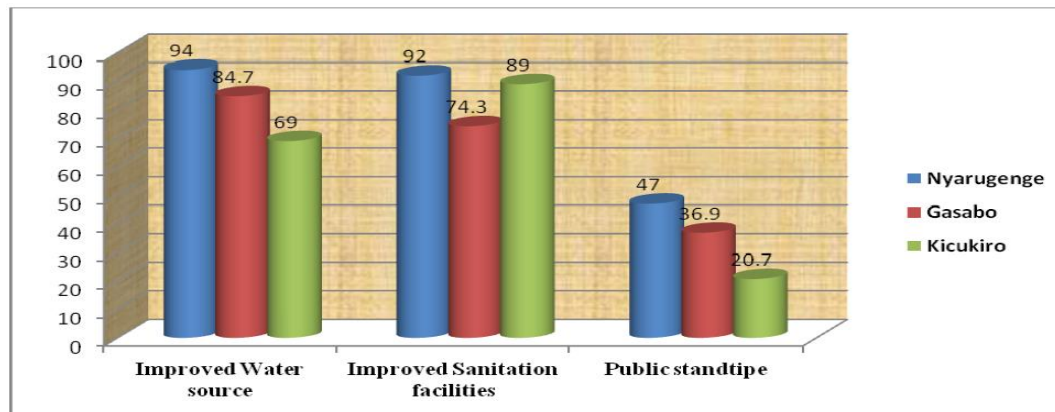


Figure 4: Improved water source, Sanitation facilities and Public standpipes

Source: **EICV3 survey Results 2010/11**

Kicukiro district has 89% of households with access to improved sanitation facilities, which is higher than the national average (74.4%). Compared to Gasabo, Kicukiro district has a high percentage in as far as access to improved sanitation facilities is concerned. Gasabo stands at 74.3% access to improved sanitation facilities. Kicukiro District is far below its sister districts in terms of public standpipe at 20.7% whereby Gasabo and Nyarugenge are at 36.9% and 47% public standpipe respectively. With an exception of high percentage of access to improved sanitation facilities, it has the lowest percentage on other water sources i.e. improved water source and public standpipe.

3. MATERIALS AND METHODS

This chapter describes precisely what was done and how it was done, what data were collected, the proposed tools or instruments to be used in data collection and the methods of analyzing the data. It included definition of terms, definition of variables, description of the study area, study period when data were collected, study design, description of population, ...etc.

3.1. Description of the study area

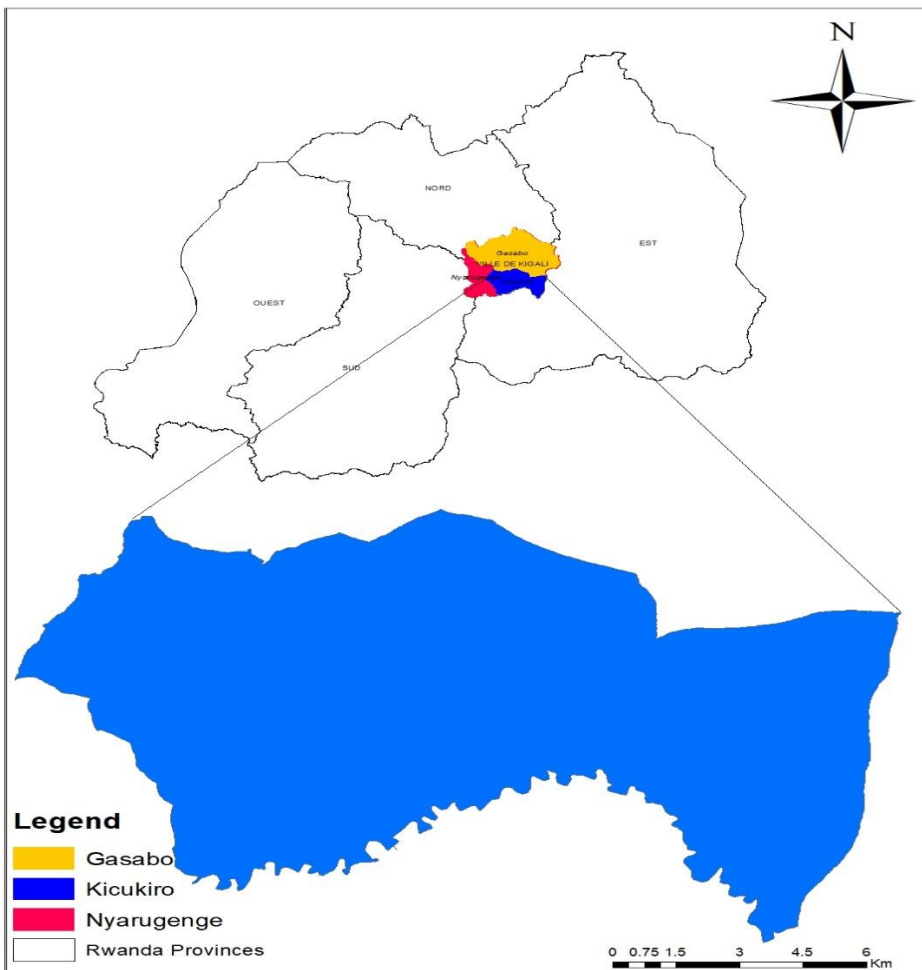


Figure 5: Kicukiro district as the study area in Rwanda

Kigali city is situated between 29°43'0''E and 29°44'0''E of Longitude and 2°35'0''S and 2°37'0''S of Latitude. The city is built on hilly landscape sprawling across four ridges, separated from each other by large valleys. Kigali city is one among five provinces which compose the

country of Rwanda. It is surrounded by the Northern Province on the North, Eastern Province on the East and South and Southern Province on the West. (G Nduwayezu et al., 2017).

Kicukiro District is one of the three Districts which constitute the City of Kigali. It is situated between 2° 0' 30.96"S of Latitude and 30° 8' 8.88"E of Longitude in the south-east city of Kigali, the capital of Rwanda. It is made up of ten (10) administrative sectors, 41 cells and 333 imidugudu or administrative villages. According to the recent population housing census of 2012, the total population of Kicukiro District was 319 661; with male population being 162 755 (50.9 percent) and female population 156 906 (49.1 percent).

Kicukiro District extends over a total area of 166.7 km² with about 319661 inhabitants, i.e. gross density of 1917 inhabitants per km². The elevation of the lower part is roughly 1400 m and the higher hills are at over 1845 m above the sea. The highest hill is Mount Kigali with 1850 m of elevation. This discontinuity is due to the existence of flood plains, swamp and steep slopes. The settlements were mostly developed on gently sloping hillsides and on flattened hilltops (Kicukiro, 2018).

Kicukiro is home to a thriving market, a number of both local and international NGO's and industries such as Bralirwa brewery, Inyange industries, among others. It is also home to the Rebero and Nyanza Kicukiro Genocide Memorial sites.

The hydrographs of the District are largely constituted by streams and rivers which form a part of the basin of the Akagera River. The main rivers are the Akagera and the Nyabarongo, which flows through the city of Kigali from Muhazi Lake. The District has four seasons: two rainy seasons and two dry seasons. These seasons are often irregular due to world climate changes. Lower or higher limits of each season cannot be determined accurately. The rainy season may drag on into the dry season and vice versa. Average temperature is 22°C for a rainfall varying between 900 and 1150 mm of annual rain (WASAC, 2017).

Kicukiro was selected as a case study due to following reasons (a) it is undergoing fast urban growth and development, (b) it has serious water scarcity issues and deficiencies in planning, and (c) it has serious impact on the environment in the neighboring region.

3.2. Sampling Technique

3.2.1. Purposive or judgmental sampling

This type of sampling is one of the non probability Sampling techniques, whereby purposive sampling is a strategy in which particular settings persons or events are selected deliberately in order to provide important information that cannot be obtained from other choices. It is where the researcher includes cases or participants in the sample because they believe that they warrant inclusion (Taherdoost and Group, 2017).

The study was designed as quantitative and qualitative research. As this research was associated with case study non probability sampling was used where purposive sampling was chosen to be used because the data were selected deliberately in order to provide important information. Both primary and secondary data were used in this research which was acquired through different means and sources. Primary data were ground reference data and particular field measurements. The secondary data ranged from geospatial data, land use land cover data, population data to all the distribution system parameters. The following subsequent section will explain how each data was acquired.

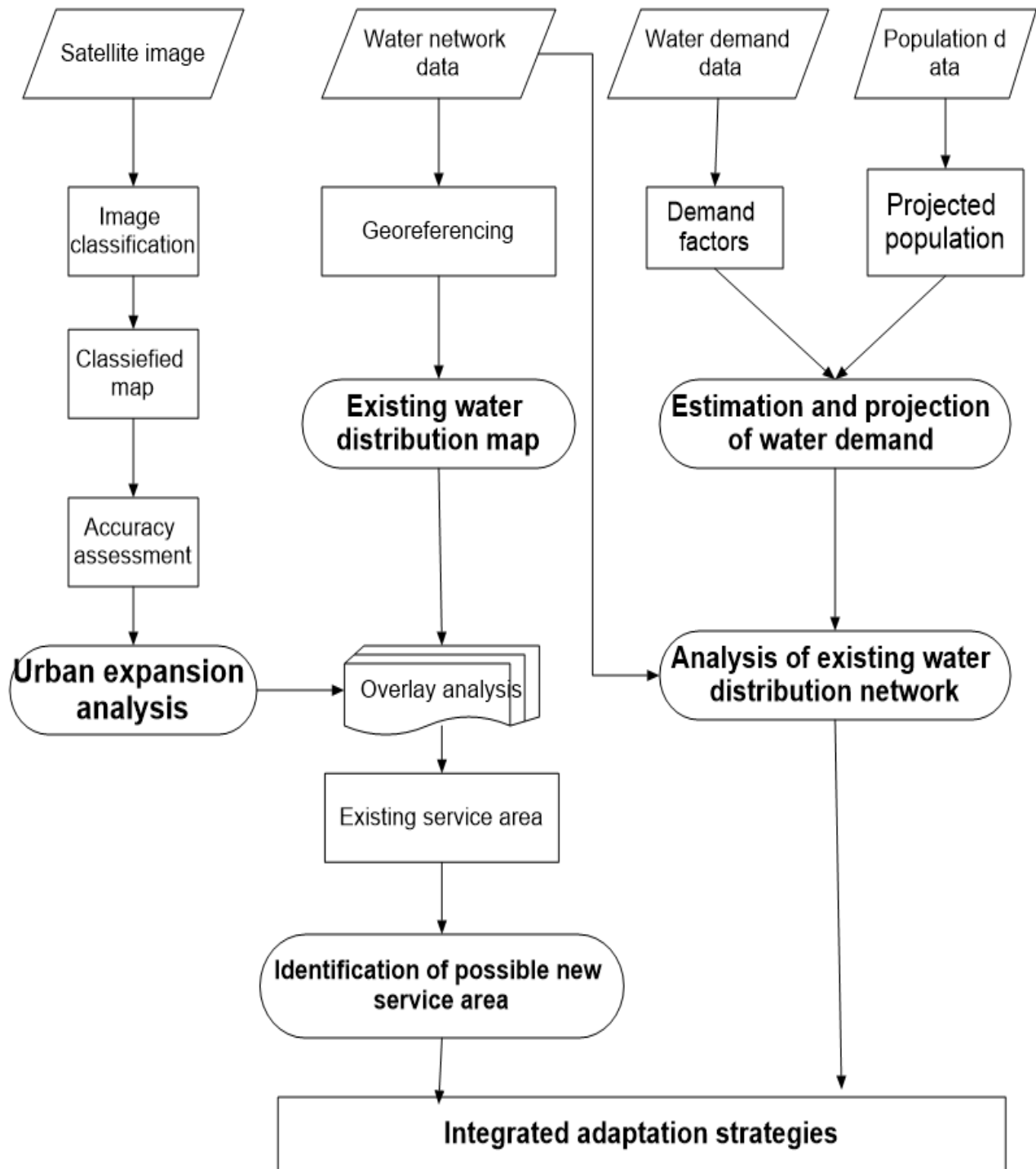


Figure 6: Proposed methodological flowchart of the research

3.3. Data collection

The most important step in any research study is data collection. Geospatial data were collected, in building the model of the distribution network, the secondary data were first gathered regarding all the distribution system parameters. Particular field measurements and visits were conducted.

3.3.1. Geospatial data

Different Landsat images to produce the land use and land cover map covering the entire study area were acquired.

Type of Data	Time period	Source	Resolution	Projection	Purpose
Landsat TM4,5	1999-08-July	USGS	30 m	WGS_1984_UTM_Zone_36N	Preparation of land use land cover maps.
Landsat OLI 8	2013-22-July	USGS	30 m	WGS_1984_UTM_Zone_36N	
Landsat OLI 8	2019-21-June	USGS	30 m	WGS_1984_UTM_Zone_36N	
Google earth	1999	-	0.9m	D_WGS_1984	They were used for verification, validation and accuracy assessment of classified images
Google earth	2013	-	0.9m	D_WGS_1984	
Google earth	2019	-	0.9m	D_WGS_1984	
GPS data	2019				

3.3.2. Water distribution network data

The existing water distribution system of the study area was collected from Rwanda Water and Sanitation Corporation LTD- WASAC in the form of shapefiles. The file included diameter of each pipe, length of pipe, elevation of junctions, definition of pump, and location of reservoir.

3.3.3. Water demand data

Water demand data were obtained from Kicukiro District office by acquiring different components of water demand in Kicukiro District such as population data to get domestic consumption, industries, commercial areas, and institutions.

Water consumption rate of each component were obtained from Rwanda Water and Sanitation Corporation LTD- WASAC. The consumption rate in Kigali was estimated to be 110 liter per capita per day (110 l/c/d).

3.3.4. Population data

Population data from district to village level will be collected from National Institute of Statistics of Rwanda (NISR) through Kicukiro district office and from published documents.

Table 1: Distribution (count) of the resident population of Kicukiro district in 2012 by Sector, Sex

Sector	Both sexes	Male	Female	% Female	Density (Inhabitants / km²)
Rwanda	10,515,973	5,064,868	5,451,105	51.8	415
Kigali City	1,132,686	586,123	546,563	48.3	1,552
Kicukiro District	318,564	163,445	155,119	48.7	1,911
Gahanga	27,808	13,853	13,955	50.2	756
Gatenga	48,640	25,027	23,613	48.5	3,911
Gikondo	17,146	9,211	7,935	46.3	5,065
Kagarama	14,385	7,601	6,784	47.2	1,800
Kanombe	44,426	22,499	21,927	49.4	1,932
Kicukiro	16,450	8,642	7,808	47.5	8,033
Kigarama	43,907	22,635	21,272	48.4	5,212
Masaka	39,548	19,536	20,012	50.6	750
Niboye	26,197	13,481	12,716	48.5	5,212
Nyarugunga	40,057	20,960	19,097	47.7	2,622

Source: Rwanda 4th Population and Housing Census, 2012 (NISR)

3.4. Data analysis

The data analysis of the first two objectives was performed and involved the different approaches: Landsat images of 1999, 2013, 2019 were classified using support vector machine to map Kicukiro land use land cover focusing on built up land in assessing the urban expansion of the district. The existing water supply network obtained from Rwanda Water and Sanitation Cooperation was mapped through georeferencing and overlaid with LULC map to establish areas that require the extension within Kicukiro district. The current and future water demand of Kicukiro were estimated. The existing water supply system was analyzed to assess its adequacy to meet water demand.

3.4.1. Generating land use land use and urban expansion maps

3.4.1.1. Acquiring satellite images

Landsat images of the study area were downloaded through <https://earthexplorer.usgs.gov/>. The targeted Images were for 1999, 2007, 2012 and 2019. 1999 was chosen because of population census conducted only in Kigali in 1999. The years of 2007 and 2012 were chosen as reference in terms of getting and comparing the population data as there were national census of population in 2007 and in 2012 as well. The year of 2019 were chosen as the current year to facilitate in analyzing the current situation and to use it as reference year while projecting the future scenarios. All the images were downloaded between month of June and August as the dry season of the study area to enhance the correlation during analysis and change detection stage. Some of the images were downloaded directly from the website and others were ordered and submitted later (one of 2019). To increase the chance of getting the good quality images land and scene cover were taken as less than 10 where was possible and less than 20 for other images.

Unfortunately, after downloading the Landsat images of 2007 and 2012 only available with Landsat7; those images were found with missing lines by Landsat due to defect in scan line corrector instrument on board Landsat7 and were rejected. To replace the above rejected images, Landsat images of 2009 and 2013 were downloaded to replace the images of 2007 and 2012, respectively. Therefore, only the Landsat images for 1999, 2013 and 2019 were used in this research as the image for 2009 was also rejected during classification due to its poor quality.

3.4.1.2. Satellites images pre- processing

This stage was crucial to improve the quality of the images. The following procedures were followed to process the acquired Landsat images: Set working directory (where to save and to store all required and all results from data processing and other following stages, Import image bands into software format (open as- Landsat- GeoTIFF with metadata). Image enhancement was being maneuvered by changing either stretching linearly or Gaussian.... Sub-settings (spatial by resizing and spectral sub settings were done directly during the process of radiometric calibration. The exact image of the study area was obtained by resizing the whole downloaded images by using the polygon or boundary of Kicukiro district in shapefile format. Each stage of above, was well saved in working directory.

During Radiometric correction, Radiometric calibration was used to calibrate the images (spatially and spectrally sub-set) conversion from raw DN to reflectance. Atmospheric Correction was performed by applying Quick atmospheric correction. At the stage of the **Image transformation**, since the spectral channels of band 1-5 and 7 have a pixel size of 30 x 30 m² and the panchromatic channel 8 has a pixel size of 15 x 15 m², to improve interpretation ability of the data, images with a resolution of 15 x 15 m² have been generated by merging resolutions of the spectral and the panchromatic channel. This process is also called as panchromatic sharpening of images. These new images have both a higher resolution and multispectral properties.

3.4.1.3. Images classification

Supervised classification was adopted in this research. Indeed, supervised classification identify known a priori through a combination of fieldwork, map analysis, and personal experience as training sites; the spectral characteristics of these sites are used to train the classification algorithm for eventual land-cover mapping of the remainder of the image. Every pixel both within and outside the training sites is then evaluated and assigned to the class of which it has the highest likelihood of being a member.

Support vector machine was used as one of the algorithms of supervised classification in attempting to classify features in an image using the elements of visual interpretation to identify homogeneous groups of pixels which represent various features or land use/cover classes of interest. Training dataset was created where Regions of Interest in ENVI were collected on-screen

using true color composite and google earth. Five classes were established to classify Landsat images for 1999, 2013 and 2019. Those five classes are: Built up land, agricultural land, vegetation, wetland and water body. Each class was described in the table below.

Table 2: Classes used in classifying images and their related description

Class	Description
Built up land	This class included pixels classified as land covered by man-made, impervious surfaces such as roofs, roads, airport, stadiums and other infrastructure.
Agricultural land	It was defined broadly as land used primarily for production of food and fiber such as Cropland and Pasture and other agricultural land.
Vegetation	Natural vegetated areas where the vegetative cover is not planted by humans but influenced by human actions. natural forests were included in this class. Previously cultivated areas which have been abandoned and where vegetation is regenerating are also included in this class.
Wetland	It included forested wetland and non-forested wetland such as marshes, mudflats, and swamps.
Water body	Streams, canals, reservoirs.

The purpose of the study was to look only at built-up land cover whereby LULC maps built-up area was extracted and visualized. A number of built-up pixels in each time span were quantified and the built-up area of each year was calculated.

3.4.1.4. Accuracy assessment

There are several methods for the accuracy assessment. Error or confusion matrix is considered as one of the common techniques for the measurement of thematic map accuracy. It was calculated by obtaining a sample from a particular class of a classified map and then the actual class was validated from the field. Producer's, user's and overall accuracies were calculated where overall accuracy was acquired for each class and was affirmed as producer's and user's accuracy. Producer's accuracy was also calculated by dividing the number of sampling points which are accurate in one class by the total number of points that are taken from the reference data. For the

computation of user's accuracy classified units that are correct in a class are divided by the total number of units that are already classified in that particular class (Mondal et al., 2012).

In addition, Kappa coefficient was calculated using confusion matrix in ENVI. Kappa coefficient is expressed as the discrete multivariate technique used for the measurement of accuracy of maps derived from remote sensing and error matrices. Kappa can be used as a measure of agreement between model predictions and reality or to determine if the values contained in an error matrix represent a result significantly better than random (Tilahun, 2015).

To obtain the confusion matrix, combination of various approaches was used. Independent set of ROIs for accuracy assessment were collection from unclassified images, Google earth and from field by using GPS. Google earth data were used for all images as Google Earth represents a powerful and attractive source of positional data that can be used for investigation and preliminary studies with suitable accuracy and low cost. Therefore, images from Google Earth with high spatial resolution are free for public and can be used directly in land use land cover mapping (Tilahun, 2015). To assess accuracy of 2019 image, Google earth data, data collected from the unclassified image and GPS data were used as GPS data were only available for the current year of 2019.

ArcGIS was used to convert the samples (KML to layer), merge them in one file and create a shapefile. Go to Classification/Post Classification/Confusion Matrix Using Ground Truth ROIs. After different trials the best values of parameters were identified on SVMs classification, as their optimum selection increased the classification accuracy. Radial basis function was chosen as kernel type, Gamma kernel function was 0.160, Penalty parameter was 100, pyramid level was 0 and 0.05 was set as classification probability threshold. The ground thruthing data used are appended in appendix part in table 17.

3.4.1.5. Analysis and compiling maps using ArcGIS

After the above stated stages, images were imported into ArcGIS (after setting the coordinates into projected coordinates (WGS 1984 UTM zone 36N) ArcGIS was used to produce a well labeled map with inserting North Arrow, scale bar, legend, coordinates& grids, new data frame and titles.

Since the images from ENVI were raster format and they were not editable; ArcGIS was used to change them to Polygons (raster conversion to polygon) and from there, Images were analyzed and the results were easily obtained.

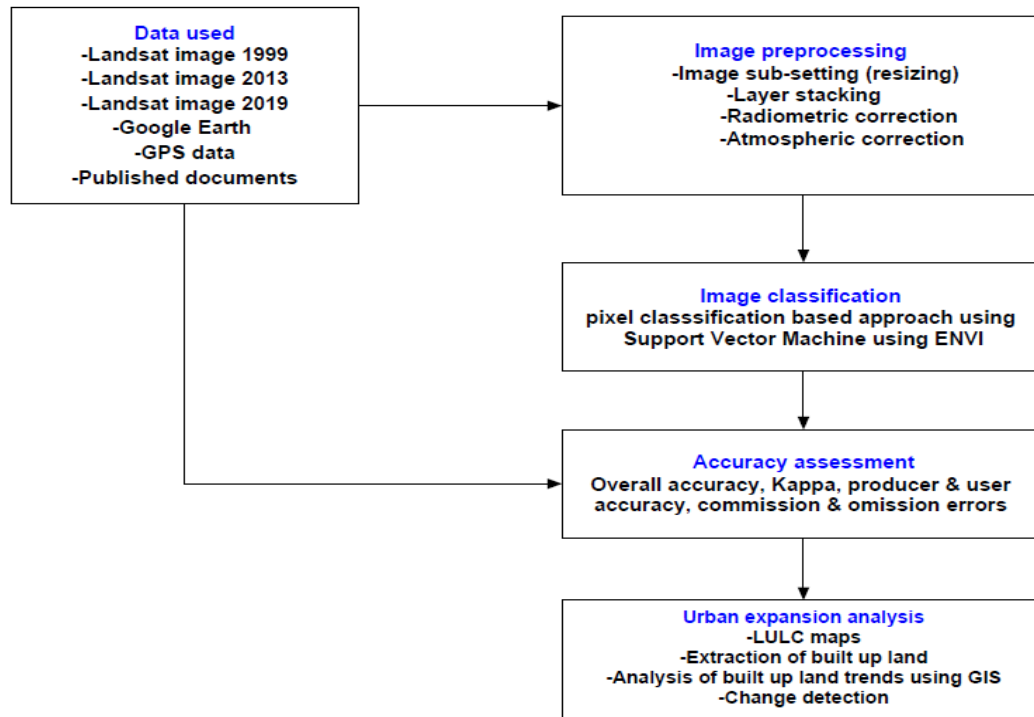


Figure 7: Summarized procedures followed in generating land use land cover and urban expansion maps

3.4.2. Mapping Kicukiro water supply network and identify the areas that require the extension within Kicukiro district

ArcGIS techniques were used to map the existing water distribution system of Kigali whereby the shapefiles of the network were filtered and georeferenced. After mapping water distribution system of Kigali, Kicukiro water supply system was extracted, visualized and mapped. To achieve to those maps and to increase the neatness of the map, only primary, secondary and tertiary pipes were merged together and mapped within the boundary of Kicukiro district. The remaining components of the network such as water sources, pumps, junctions and others were georeferenced and presented in different maps separately.

The map of the existing water distribution system of Kicukiro was put on top of the prepared built up land map for the current year of 2019 using overlaying techniques in ArcGIS. The existing service areas and the areas which need extension within Kicukiro district were easily visualized, identified and quantified.

3.4.3. Estimating the current and future water demand in Kicukiro district

Population data of the study area were used to project population up to 2039. The year 2039 was selected because of the following reasons: 20-year period was the target future timeline and it was also selected in order to compare with the available population data of the year 2032 and the year 2050. Water demand in the study area (i.e. the total consumption rate of the population and other components) were calculated using spreadsheets by considering some safety factors (Ji et al., 2012).

Total Water demand of Kigali city is: 290,038m³ per day and in the urban area water supplied is estimated at 187,293 m³/day. There is a gap of 102,745 m³/day which results in water rationing in some urban areas (WASAC, 2019).

3.4.3.1. Population estimation and projection

Geometric increase method of population forecasting was adopted for this research because this method is mostly applicable for growing towns and cities having vast scope of expansion, like Kigali city. It is based on the assumption that the percentage increase in population remains constant. The formula that has been adopted for population projection is presented below (Zhou, 2018).

$$P_n = P_o * (1+K)^n$$

Where: P_o: Initial population

P_n: Population at n years

n: Number of years

K: Percentage (geometric) increase

3.4.3.2. Domestic water demand

The demand for water depended very much on local circumstances. The domestic consumption rate in Kigali was estimated to be 110 liters per capita per day (l/c/d) (RSB, 2015). The spreadsheet was used to estimate this type of demand by multiplying the domestic consumption per person per day by the number of persons to be supplied.

Non-domestic water demand

The water distribution system is designed to cope mainly with the domestic demand. As it is common in Rwanda; appropriate allowances should be made for industrial demand and other special features. Different non-domestic water demands normally represent different fractions of total municipal demand. As Kicukiro water supply system is assumed to be a slightly leaking supply system, the fractions can typically be: Industrial: ~15%, Commercial: ~10%, Public: ~ 5%, and fire demand ~10% (Trifuovi, 2006), (RSB, 2015).

Total daily average demand

Once total domestic and non-domestic municipal water demands have been estimated, the total municipal demand is simply their sum. This is the average demand (AD); It is used in estimating peak demand using peak demand factors.

Peak day demand

$$D_{PD} = PDF * D_{av} \{PDF \text{ range: } 1.5 - 2.0\}$$

1.8 was used as peak day factor as advised by WASAC office.

Peak Hourly demand

$$D_{PH} = PDF * D_{av} \{PDF \text{ range: } 3.6 - 4.0\}$$

4 was used as peak day factor as advised by WASAC office as they are always predicting the worst scenario.

Those above-mentioned demand are net demands while gross demand includes system water losses (Unaccounted for Water, UfW). 30% was assumed as UfW as described in (RSB, 2015).

Future Water Demand

The population of Kicukiro district will be around one million by 2039. The projection was based on the national population census of Rwanda, 2012. In estimating the future water demand, future population increases should be taken into account together with any predicted variations in per capita consumption. The population growth rate is considered to be 4 % per annum (NISR, 2019). After projecting the population to 2039, the future domestic water demand was estimated by using 120 l/c/d. The future non-domestic were also determined following the assumed percentages of the total future demand.

3.4.4. Analyzing the suitability of existing water supply network to meet the water demand due to urban growth.

This section presents the analysis of Kicukiro district water distribution network. The hydraulic modeling was performed to evaluate the adequacy of existing facilities for conveying current and future flows, and to aid in determining improvements that would ensure future viability of the distribution system. This section describes how all the model parameters and data necessary to run the model were set.

The following Steps to run the model for analyzing the existing water distribution system were carried out using WaterGEMS:

1. Tracing of existing network on WaterGEMS by importing the GIS packages of Kigali city network and by putting AutoCAD file of Kicukiro master plan on background;
2. Filter and cropping the whole Kigali network in line of remaining with Kicukiro network;
3. Color coding the network on the bases on diameter of pipe;
4. Verifying and inserting elevation and base demand at each junction;
5. Verifying and inserting reservoir elevation;
6. Verifying and inserting pump definition in the software;
7. Validate and run a hydraulic analysis. (Dipali, 2017).

The analysis of water distribution network included determining quantities of flow and head losses in the various pipe lines, and resulting residual pressure at various demands in the network junctions.

The general methodology of this hydraulic modelling analysis was to examine the current distribution system during various demand. Deficiencies were noted and distribution system improvements proposed.

Hydraulic modelling in WaterGEMS

Assigning base water demands to each node:

The use of water, also known as water demand, is the driving force behind the hydraulic dynamics occurring in water distribution systems. Anywhere that water can leave the system represents a point of consumption, including a customer's faucet, a leaky main, or an open fire hydrant

Three questions related to water consumption must be answered when building a hydraulic model:

- (1) How much water is being used?
- (2) Where are the points of consumption located? And
- (3) How does the usage change as a function of time?

The following steps outline a typical example of the process the modeler might follow.

1. Allocate average-day demands to nodes.
2. Develop peaking factors for steady-state runs or diurnal curves for EPS runs
3. Estimate fire and other special demands.
4. Project demands under future conditions for planning and design.

Baseline Demands

Determining baseline demands to which a variety of peaking factors and demand multipliers can be applied, or to which new land developments and customers can be added. Baseline demands typically include both customer demands and unaccounted-for water. Usually, the average day demand in the current year is the baseline from which other demand distributions are built.

To assign base demand to each supply node, it is necessary to know the houses around each supply node.

Base Demand for a supply node = (Population served by that node) / (Total Population) * Total water demand of the city per day.

The following are some examples of demand events frequently considered:

- **Average-day demand:** The average rate of demand for an average day (past, present, or future)
- **Maximum-day demand:** The average rate of use on the maximum usage day (past, present, or future)
- **Peak-hour demand:** The average rate of usage during the maximum hour of usage (past, present, or future)
- **Maximum day of record:** The highest average rate of demand for the historical Record

Hydraulic Design criteria and parameters

The hydraulic design of water transport and distribution systems requires thorough calculations due to the significant impact of each component on the overall operation. Opting for a larger diameter, reservoir volume or pump unit will always offer more safety in supply but implies a substantial increase in investment costs. This reserve capacity can only be justified by estimating the potential risks of irregular situations; otherwise the distribution system will become in part a dead asset causing considerable maintenance problems (Trifuovi, 2006).

Hydraulic design primarily deals with pressures and hydraulic gradients. In addition, the flow velocities, pressure- and flow fluctuations are also relevant design factors.

The pressure criterion is usually formulated as the minimum/maximum pressure required, or allowed, at the most critical point of the system.

Pressure

The pressure at nodes depends on the adopted minimum and maximum pressures within the network, topographic circumstances, and the size of the network.

Minimum pressure requirements usually depend on company policy although they can also be standardized, i.e. prescribed by legislation. The minimum pressure should be maintained to avoid water column separation and to ensure that consumers' demands are provided at all times.

Maximum pressure limitations are required to reduce the additional cost of pipe strengthening. Moreover, there is a direct relation between (high) pressure and leakages in the system. The maximum pressure constraints result from service performance requirements such fire needs or the pressure bearing capacity of the pipes, also limit the leakage in the distribution system, especially that there is a direct relationship between the high pressure and the increasing of leakage value in the system (Trifuovi, 2006).

The operating pressures in the distribution network according to Rwanda Standard Board with WASAC report shall be 20 to 120 ranges and 160m in some areas where the topography is very high (RSB, 2015)

Hydraulic gradients

The design criteria for hydraulic gradients depend on the adopted minimum and maximum pressures, the distance over which the water needs to be transported, local topographic circumstances and the size of the network, including possible future extensions (A Saminu, IAbubakar, U Tsoho, 2013).

The following values can be accepted as a rule of thumb:

- 5–10 m/km, for small diameter pipes,
- 2–5 m/km, for mid-range diameter pipes,
- 1–2 m/km, for large transportation pipes.

Velocity & Head loss

Velocity range can also be adopted as a design criterion. Low velocities are not preferred for hygienic reasons, while too high velocities cause exceptional head-losses. Head loss is related to velocity and pipe roughness. The maximum head loss with therefore be governed by the maximum velocity criterion. Standard design velocities are:

- 1 m/s, in distribution systems,
- 1.5 m/s, in transportation pipes,

– 1–2 m/s, in pumping stations.

According to Rwanda Standard Board with WASAC report, Water velocities must be maintained at less than 2.5 m/sec in distribution mains, maximum velocities of major transmission mains must be less than 3 m/s except in short sections & for pumps. Minimum velocities range 0.1-0.3 m/s within the system. Velocities in small diameter pipes (<DN100) may need even lower limiting velocities (RSB, 2015). Minimum static head is 20 m, which can supply a 4-storey building from the distribution system. Maximum static head within a pressure zone was limited to 120 m except in some areas where pressure was kept less than 160m. Minimum dynamic head was established at 10 m.

Model Calibration

Model calibration is normally conducted to compare the results of the actual element of the model with results generated by the model at the same locations. To calibrate the model, some junctions accessible and available for flow data measurement are selected and flow measurements, pressures measurements are taken using flow measuring instrument and manometer respectively.

Due to the short time of data collection, technical team assistance and the lack of data collection tools for field calibration, few field data for calibration were collected. also, using the information provided by the WASAC, the model was validated to meet the general calibration criteria for water demand, flow and pressure by using WaterGEMS tool (Validate). After allocating the necessary data in the existing networks successfully, then the complete network was designed and finally the network was computed. After computation of network, the next step was to validate the results and if there are errors in network then those errors are adjusted and further the network is validated until there were no problem as shown in **figure 8** below.

Successful validation indicates that the network components are operating correctly, demand is appropriately allocated, and the reservoir levels are correct. Besides, the correct calibration of the residual pressure indicates that the pipe roughness coefficients are set at the appropriate levels, similar to actual conditions.

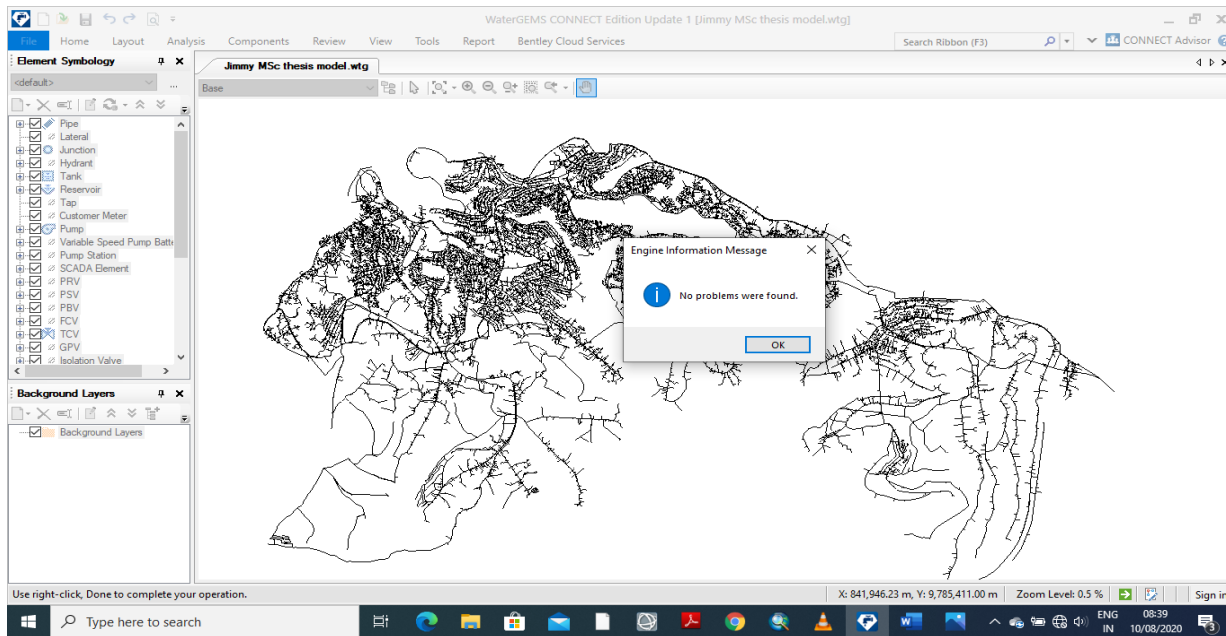


Figure 8: Validation of the network results

Calibration criteria for flow and pressure

1. Pressure Criteria

- (1) 85% of field test measurements should be within ± 0.5 m or $\pm 5\%$ of the maximum head loss across the system, whichever is greater.
- (2) 95% of field test measurements should be within ± 0.75 m or $\pm 7.5\%$ of the maximum head loss across the system, whichever is greater.
- (3) 100% of field test measurements should be within ± 2 m or $\pm 15\%$ of the maximum head loss across the system, whichever is greater.

2. Flow Criteria

- (1) Modeled trunk main flows (where the flow is more than 10% of the total demand) should be within $\pm 5\%$ of the measured flows.
- (2) Modeled trunk main flows (where the flow is less than 10% of the total demand) should be within $\pm 10\%$ of the measured flows (Trifuovi, 2006).

Table 3: Sample of field measurements collected for model calibration

S/N	PIPE NAME	LENGTH (m)	DIAMETER (mm)	FLOW (l/s)	PRESSURE (bars)
1.	Pipe_243547	133	160	4	4.2
2.	Pipe_243511	94	110	8.9	3.1
3.	Pipe_165884	15	40	0.15	6
4.	Pipe_119429	18	110	3.8	8
5.	Pipe_119758	20	63	0.26	12



Pressure measurement by using manometer at Remera (REMEJU84)



Flow measurement at Remera (Pipe_243546)

4. RESULTS AND DISCUSSIONS

The results obtained from this study follow the mentioned theme and are connected with each other. The results have also helped to derive the conclusions from this study about the impact of urbanization on Impacts of urbanization on water supply network and water security Kicukiro. This chapter links all the results with each other and gives the complete idea about the theme for this study. Also, the results obtained in this study are compared with findings from other studies conducted by different researchers.

4.1. Generating land use land use and urban expansion maps

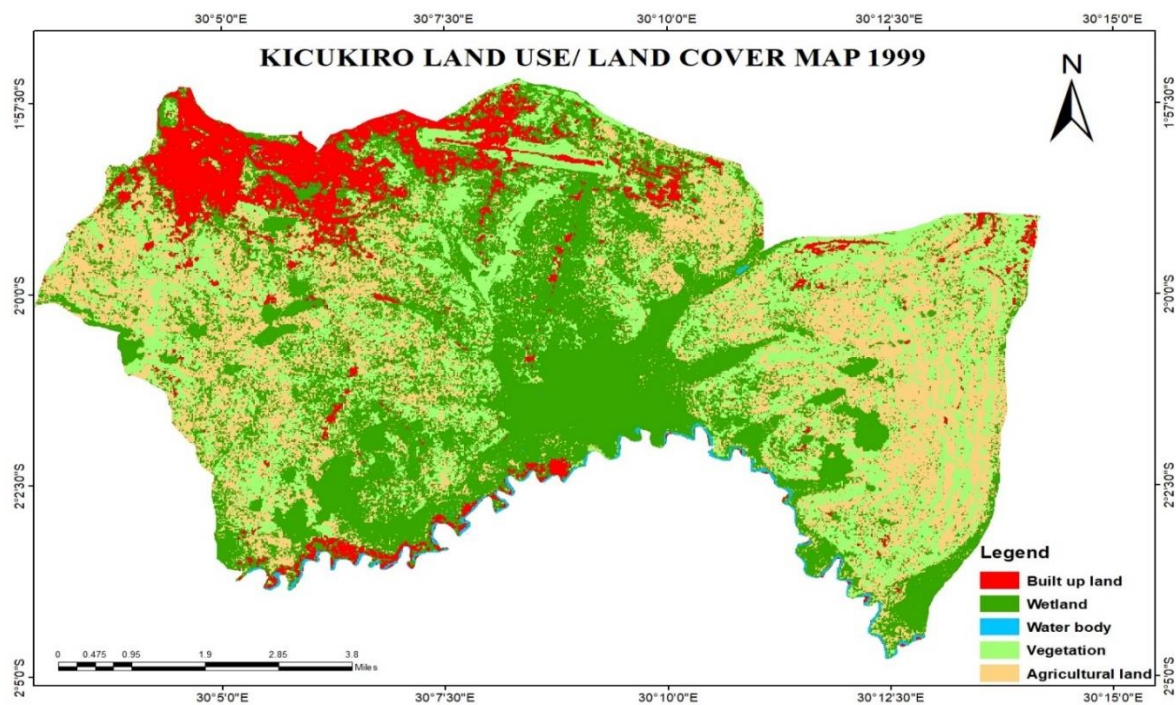


Figure 9: Map showing Kicukiro Land use land/ land cover in 1999

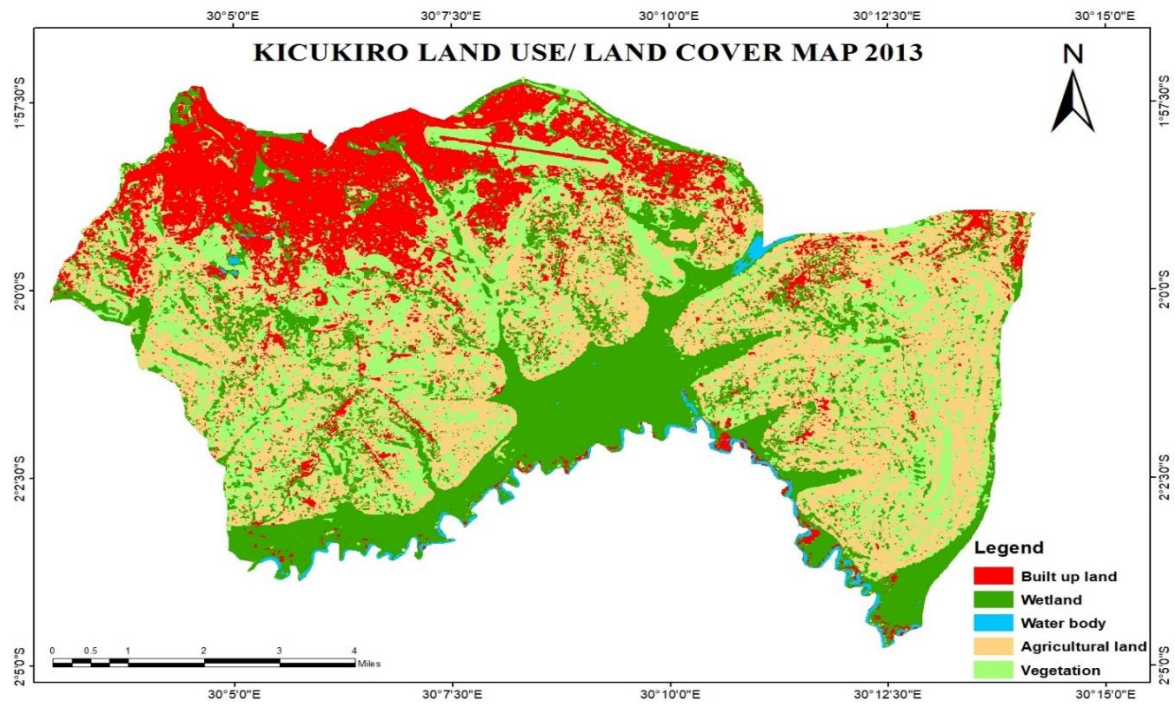


Figure 10: Map showing Kicukiro Land use land/ land cover in 2013

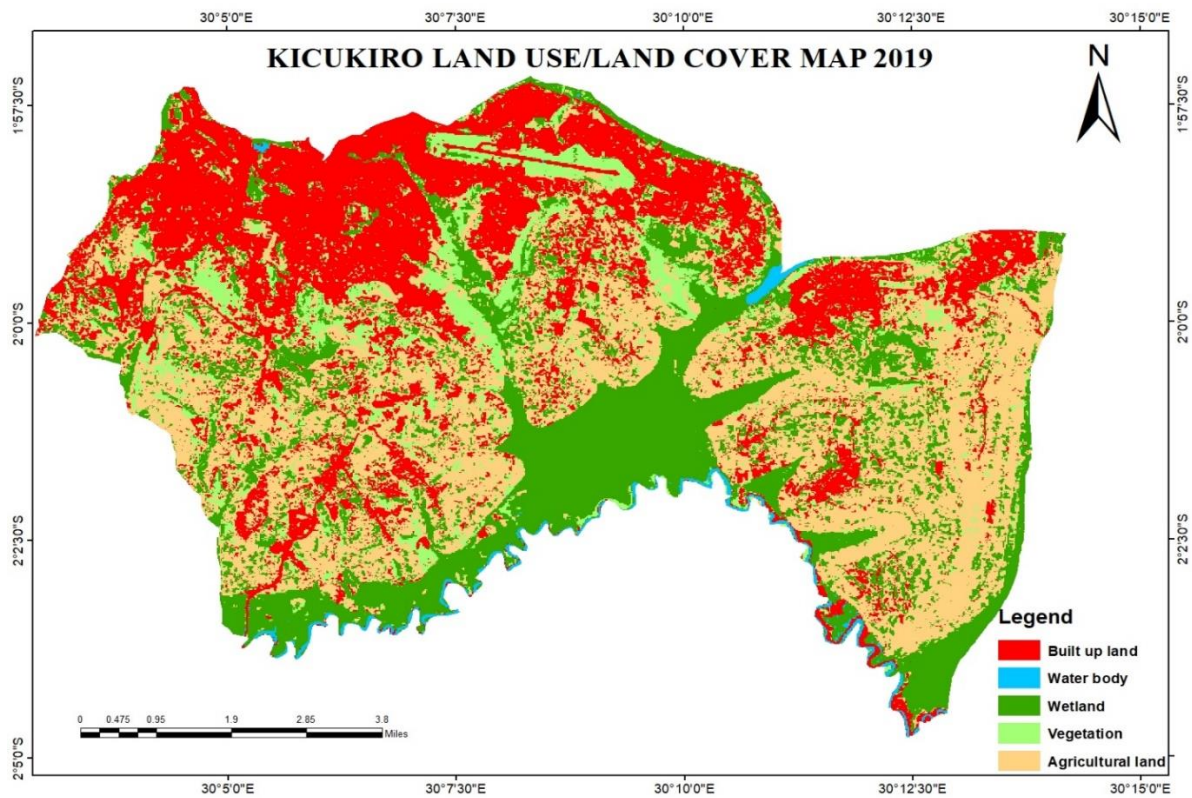


Figure 11: Map showing Kicukiro Land use land/ land cover in 2019

Table 4: Table showing the area covered by each class

Year	Area covered by each class (m ²)				
	Built up land	Wetland	Agricultural land	Vegetation	Water body
1999	16949025	65681100	43654050	39703275	1101375
2013	30283425	43844625	56964375	34119225	1877175
2019	48468375	43764525	13299750	59888925	1667250

Using satellite imagery, it is possible to evaluate changes in the amount of ‘built-up’ land in Kicukiro i.e. land covered by man-made, impervious surfaces such as roofs, roads, and other infrastructure.

A comparison of the maps in Figure 8, 9 and 10 shows that during 1999-2013, built-up land has increased considerably and Kicukiro district has experienced the most extensive urban expansion from 2013-2019, with significant growth of built-up areas in the core of periphery and fringe zones of the district. Between 2013 and 2019, there was a remarkable extension trend in all sides of the district. However, the tendency is higher to the Northern and Eastern sides while the Western was expanding slowly. Nduwayezu et al. (2017) in the Western direction of Kigali, the topography is critical for built-up since this part was protected by forests cover. Furthermore, some new built-up areas appeared in the hinterland of the Southern part. These are smaller and dispersed built-up patches compared to the Northern and Eastern development. Rural lands have been changed into built-up land due to the increase in urban activities (Bizimana et al., 2012)

While this is indicative of an urban expansion trend, some of these areas will still be predominantly rural in nature in terms of settlement pattern and economic activities, with relatively low-density settlement and dominated by agriculture-based economies.

The results showed that this urban expansion will obviously show increase in urban population. Alarming growth in urban population may pose serious challenges in the nearest future. This may hamper on the achievement of sustainable development goals of access to water and sanitation services.

4.1.1. Classification Accuracy

Table 5: Producer and user's accuracy of SVM classification based on confusion matrix

Year	Producer accuracy (%)					User accuracy (%)				
	Built up land	Wetland	Agricultural	Vegetation	Water body	Built up land	Wetland	Agricultural	Vegetation	Water body
1999	95.71	98.58	98.24	98.08	84.25	94.26	98.26	93.83	98.61	98.33
2013	97.42	96.06	93.31	98.37	92.68	96.23	97.64	93.79	93.70	93.40
2019	95.52	95.35	83.91	79.41	90.28	90.87	98.70	84.41	69.29	97.62

Table 6: Commission and Omission errors of SVM classification based on confusion matrix

Year	Commission (%)					Omission (%)				
	Built up land	Wetland	Agricultural	Vegetation	Water body	Built up land	Wetland	Agricultural	Vegetation	Water body
1999	0.74	1.74	6.17	1.39	1.67	4.29	0.42	1.76	1.92	15.75
2013	1.77	0.36	6.21	6.30	6.60	0.58	0.94	6.69	1.63	7.32
2019	9.13	1.30	15.59	30.71	2.38	0.48	4.65	16.09	20.59	9.72

Table 7: Overall accuracy and Kappa coefficient values obtained for SVM

Year	Overall accuracy (%)	Kappa Coefficient
1999	89.030	0.854
2013	93.715	0.915
2019	94.359	0.898

Error matrix has been calculated after classification of raw satellite image for the assessment of accuracy for both the classifications. Producer and user accuracy of each class were presented in table 4. Commission and Omission errors were also presented in table 5. Overall accuracy and Kappa coefficient values were shown in table 6. The result of accuracy shows that total (overall) accuracy of land use and land cover is 89.030 %, 93.715 %, 94.359 % and Kappa (K) is 85.40 %, 91.50 %, 89.80 % for 1999, 2013, 2019 respectively. Those values are acceptable in both accuracy total (overall) and Kappa accuracy (Ustuner et al., 2015).

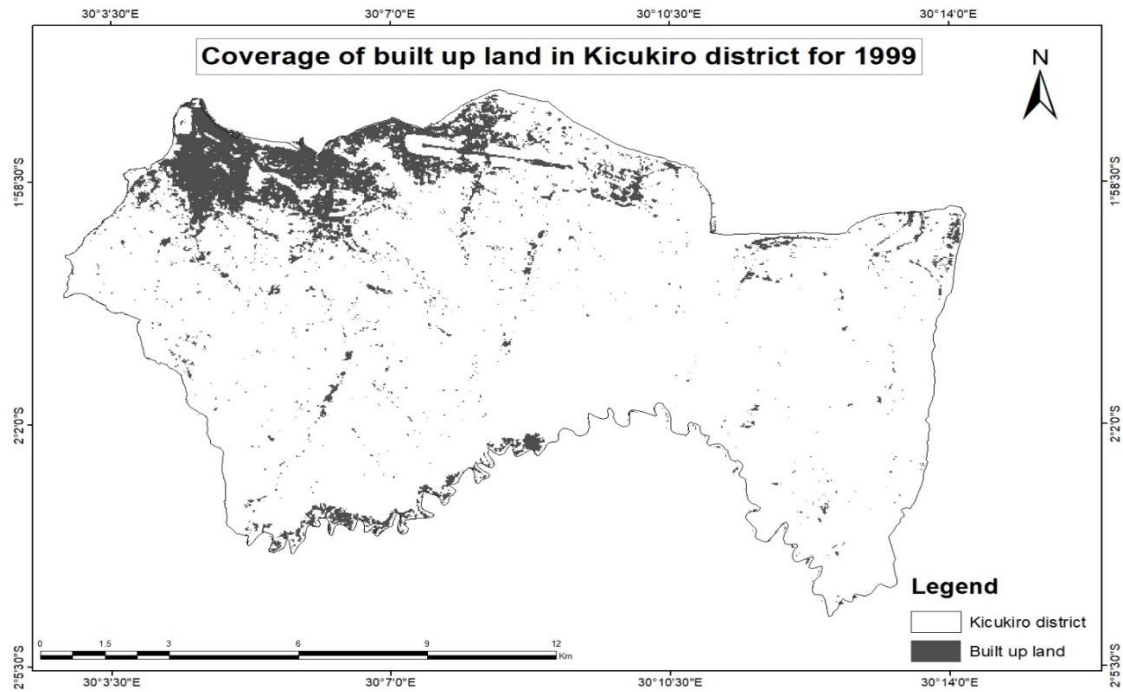


Figure 12: Map showing the coverage of built up land in Kicukiro district for 1999

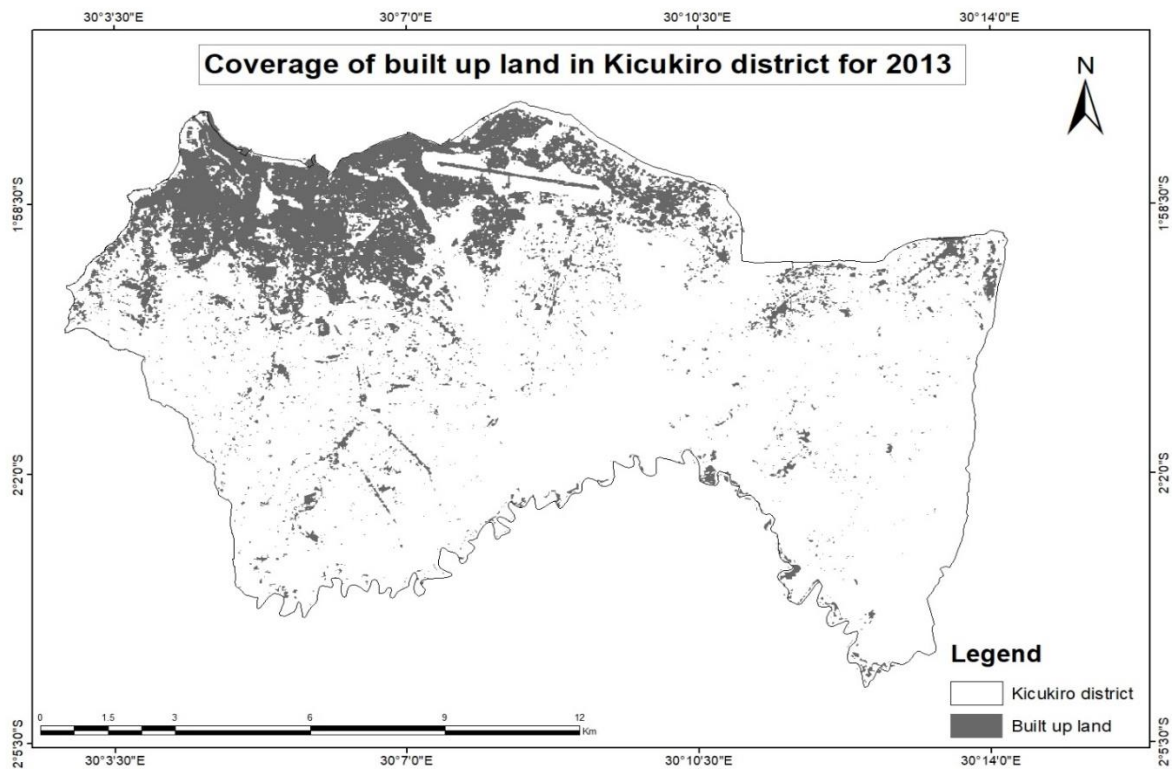


Figure 13: Map showing the coverage of built up land in Kicukiro district for 2013

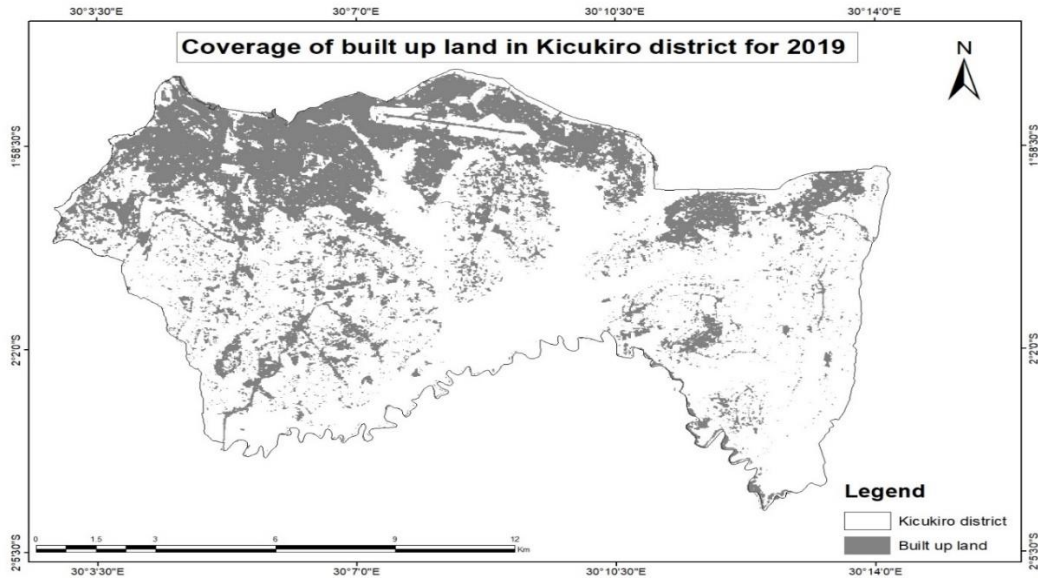


Figure 14: Map showing the coverage of built up land in Kicukiro district for 2019

Table 8: showing the area covered by built up land and its increment

Year	Area covered by Built up land		Increment (Km ²)
1999	16.95 Km ²	10.17 %	
2013	30.28 Km ²	18.16 %	13.33
2019	48.47 Km ²	29.08 %	10.19

To enhance on the above discussion, only built up lands for 1999, 2013 and 2019 were extracted from the maps in figure 8,9 and 10. The results presented in table 7 showed that built up lands almost tripled from 1999- 2019 from 16.95 km² (10.17 %) in 1999 to 29.08 % in 2019. The increment of the urban expansion of the district between 1999-2013 (the time span of 14 years) was found as 13.33 km² and 10.19 km² between 2013-2019 which as only the time span of 6 years. This is due to the urbanization of the district. These maps show a clear pattern of increased urban expansion of Kicukiro. It could be as a result of improvement in economy.

From a strictly spatial-demographic point of view, therefore, it is crucial to recognize that Kicukiro has clearly experienced significant and rapid increases in both the absolute size (urban growth) and the proportion of the population (urbanization) living in identifiably 'urban' areas over the past two decades.

4.2. Mapping Kicukiro water supply network

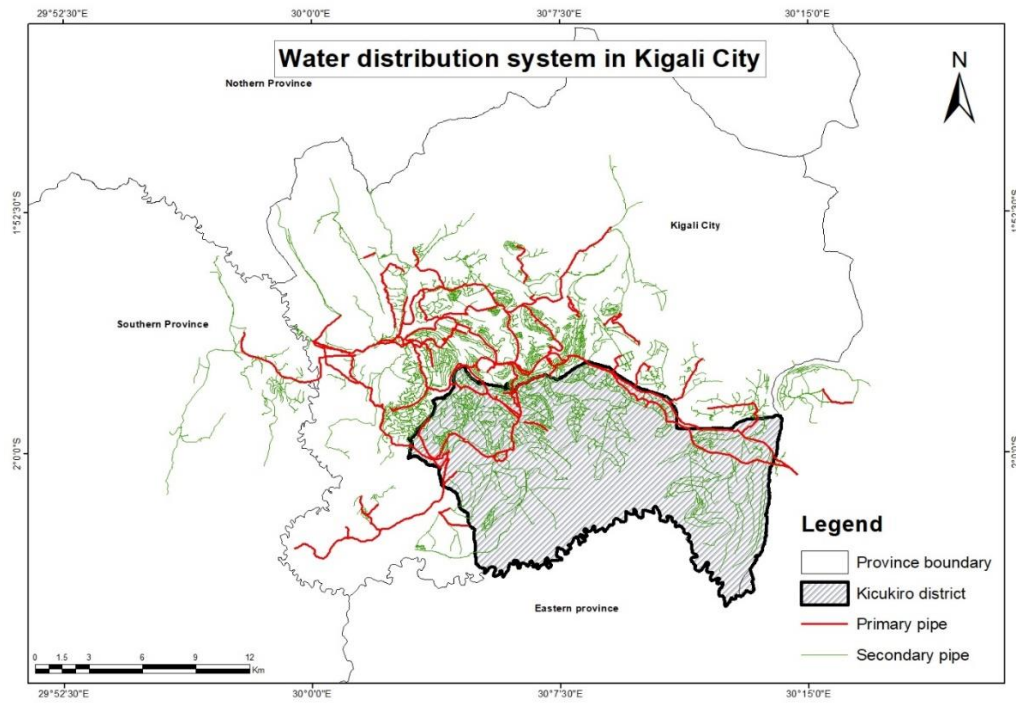


Figure 15: Map showing Kigali water distribution system

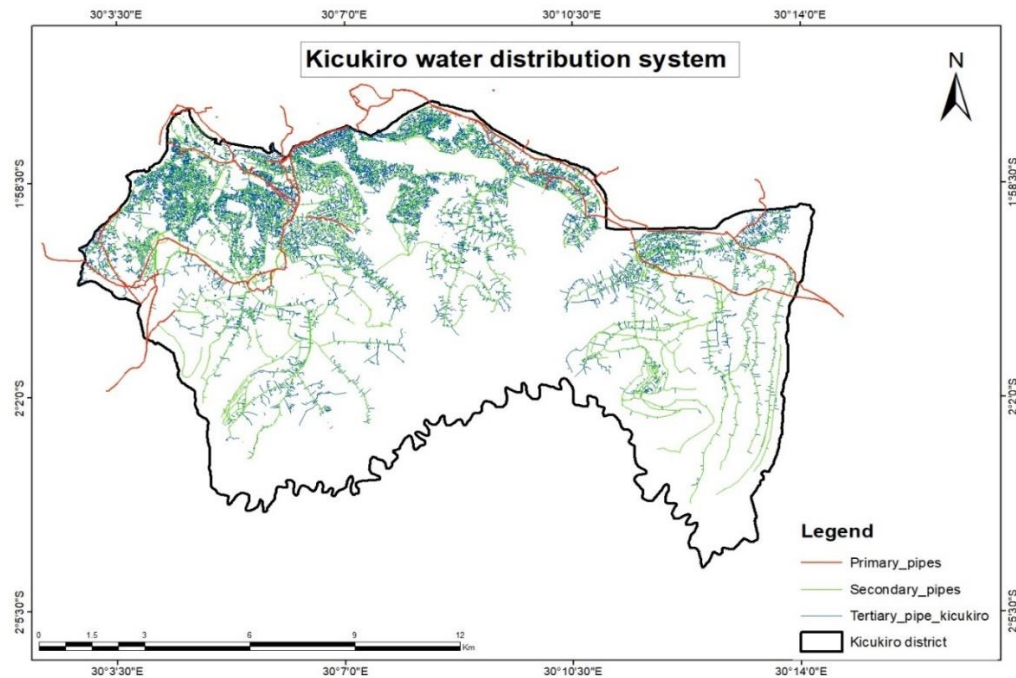


Figure 16: Map showing Kicukiro water distribution system

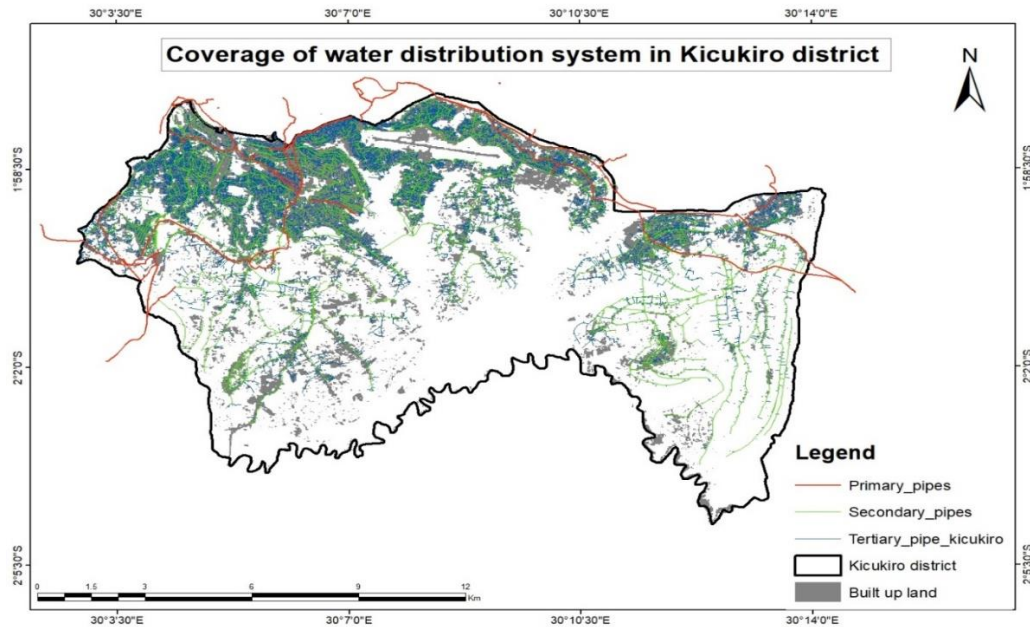


Figure 17: Map showing the coverage of water distribution system in Kicukiro district

It was observed from the map in figure 17 (which resulted from overlay of map in figure 16 and the map in figure 14) that the existing water supply system of Kicukiro does not have a wider coverage of water distribution to some parts of the area; this is as a result of rapid residential expansion in the area. There may be challenges of distribution network coverage in the present situation and also in the nearest future. This may lead to persistence water shortage, water scarcity and lack of accessibility to the basic need of water for residential utility.

Moreover, it can be observed that some residential areas are beyond the reach of the existing pipelines and that is why water has become a scarce resource to the point some regions of Kicukiro such Gikondo, Kanombe, Busanza, Gahanga...; they have become familiar with the situation. This water crisis has been still not resolved and from current study in this thesis showed that it has been expanding to more regions in Kicukiro. Rubogora (2017) has also mentioned about this crisis and considered different most affected areas in Kigali city where Kicukiro district is situated as well. In this thesis, the current situation was mapped.

With the growth in population and rates of built up lands discussed above, mapping and pinpointing these areas is very importance as planning efforts intensify for sustainable water management in Kicukiro district. This can serve as decision support for proposing new service areas by concerned authorities.

4.3. Estimation of the current and future water demand in Kicukiro district

4.3.1. Population estimate and projection

From the population size of Kicukiro district for 2012 collected from the National Institution of Statistics Rwanda, the projected population of the target years was estimated:

Table 9: Estimated population for target periods

Year	Estimated population	Increment
2012	318,564	
2019	419,209	100,645
2039	918,538	499,329

Population growth in urban areas has been accompanied by rapid expansion of built-up areas, particularly in the periphery and fringe zones of Kicukiro district. The results presented in table 8 showed that the population of Kicukiro district will increase from 419,209 inhabitants in 2019 up 918,538 inhabitants in 2039. This high population increase, will increase the demand of water which will create also a significant pressure on the existing water supply system.

This high population increase, will increase the demand of water which will create also a significant pressure on the existing water supply system.

4.3.2. Water demand estimation

In Kigali city, in Urban area water supplied is estimated at 187,293m³ per day and water demand is 290,038 m³ per day. There is a gap of 102,745m³ per day which results in water rationing in some urban areas (WASAC, 2019).

Table 10: water demand estimation of Kicukiro district in 2019

DOMESTIC WATER DEMAND		
Population	Specific demand (l/c/day)	Total water demand (m ³ per day)
419,209	110	46,112.99
NON-DOMESTIC WATER DEMAND		
Industrial (15%) (m ³ per day)		11,528.25
Institutional/commercial (10%) (m ³ per day)		7,685.50

Public (5%) (m ³ per day)	3,842.75
Fire demand (10) (m ³ per day)	7,685.50
TOTAL DAILY WATER DEMAND OF KICUKIRO	76,854.98

Table 11: water demand estimation of Kicukiro district in 2039

DOMESTIC WATER DEMAND		
Population	Specific demand (l/c/day)	Total water demand (m ³ per day)
918,538	120	110,224.56
NON-DOMESTIC WATER DEMAND		
Industrial (15%) (m ³ per day)		27,556.14
Institutional/commercial (10%) (m ³ per day)		18,370.76
Public (5%) (m ³ per day)		9,185.38
Fire demand (10%) (m ³ per day)		18,370.76
TOTAL DAILY WATER DEMAND OF KICUKIRO		183,707.60

The results in table 9 and in table 10, showed that the current daily water demand (2019) is 76,854.98 m³ and 183,707.60 m³ for 2039. The increase within 20 years will be 106,852.62 m³ which is greater than the current water demand. Comparing to WASAC (2019), the future water demand for 2039 will be almost the same as the water supplied currently in Kigali which was estimated at 187,293 m³ per day. These findings are believed to be true because the current population of Kigali city is estimated to over 1 million inhabitants (G. Nduwayezu et al., 2017) and the population of Kicukiro is expected to be around 1 million inhabitants in 2039.

It was observed that there is a large gap between demand and supply of water and there is no sign of instant relief in the near future. So, there is urgent need of proper evaluation and management of the available water resources. The continuous urban growth has put lot of stress on the surrounding environment.

4.4. Analysis of existing water supply network to meet the water demand.

In this research the existing water distribution network of Kicukiro district was studied, analysed and Reliability was concluded. It consists of 72592 pipes, 71902 junctions, 58 tanks, 7 reservoirs and 20 pumps. The pipeline network of the existing distribution system in WaterGEMS is as shown in the Figure 18 below.

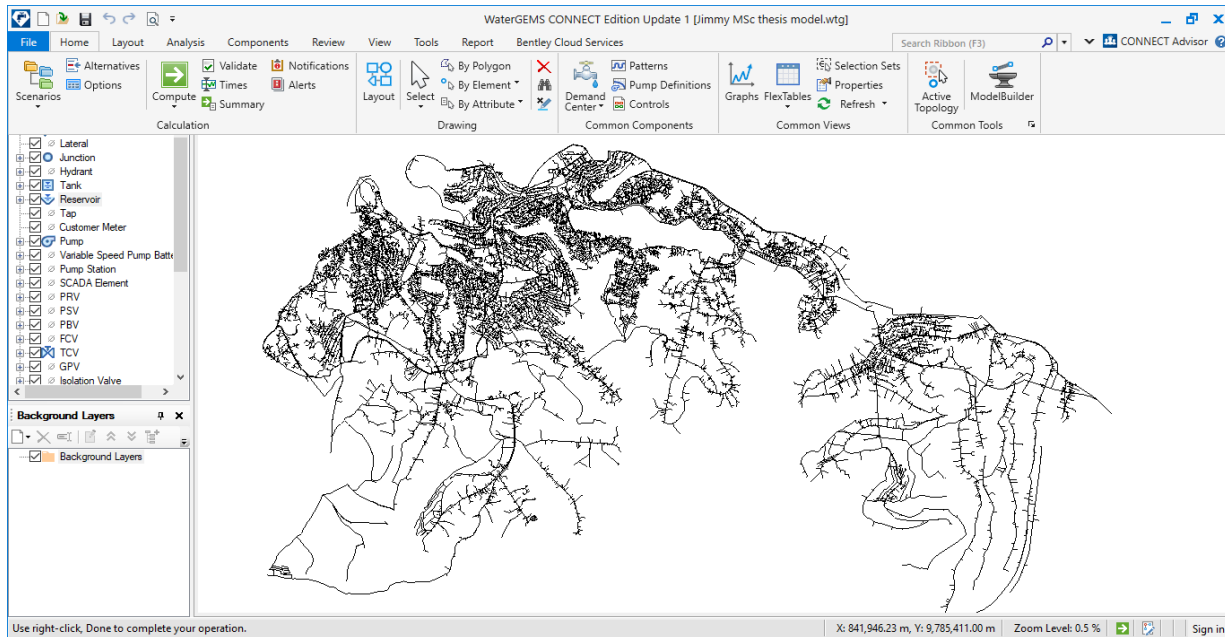


Figure 18: Pipeline network of Kicukiro district

Finally, the results for the existing network of Kicukiro district were obtained as follows:

The results of the existing water supply network provided 72592 pipes of different diameters and other different parameters. To present the entire results of pipe report containing those above-mentioned number of pipes was difficult. Therefore, only few pipes of the above-mentioned number of pipes, were used to represent the results of pipe report from Flex tables as shown in table 11 located in appendix part. Same as on the pipe report, due to a large number of junctions in the existing network of Kicukiro which was 71902 junctions, only few junctions were used to represent the results of junction report from Flex table as presented in table 12 situated in appendix part.

Study of the pipes

There are 72592 pipes in the Kicukiro supply system. The laying period of the pipes ranges from 1960 up to now. This indicated that the network is old and exposed to the repeated damages. The material of the pipes is various and consists of ductile iron, PVC (especially secondary pipes),

HDPE and galvanized pipe (especially tertiary pipes). The value of Hazen-Williams C is 140, 130 and 120. The pipe diameter ranges from 25 mm to 2,514.6 mm and length ranges from 1 m to 4,639.24 m; the total length of network is 1,864,818.81 m. Flow, velocity and head loss were calculated by the WaterGEMS.

From the results of the pipe report as shown in table 11, The flow in the conduits is ranging from -392 liters per second. (due to looping in the network) to 384 liters per second. In some cases, there is back flow in the system in number of pipes. This may be explained by some portions of the system are looped so that there is a possibility of back flow. The results of the velocities in the pipes were obtained as 0.00028 meter per second (m/s) to 7.15 meter per second (m/s) which were beyond of the desired range of WASAC and international standards as suggested also by Trifuovi (2006). The output of the headloss was obtained in a range of 0.000 m/km to 103.724 m/km at different instances. According to Trifuovi (2006) the maximum value of head loss should not be more than 10m/km.

Study of the junctions

The input data of the junctions are elevation and demand. By computing the existing network, WaterGEMS generates simulated values of pressure and hydraulic grade. Some of the simulated results were verified by the process of validation discussed in earlier section of the study. The elevations of the junctions were ranging from 1,337 m to 1,640 m depending on the natural topography of the network in Kicukiro.

Table 12 shows some of the results of the junctions. After analyzing the network using WaterGEMS, hydraulic grade was ranging from 1,472.76 m to 1,932.33 m. the outputs of the pressure were obtained as from -69.63 m to 270.72 m which are beyond of the acceptable range of WASAC and beyond of international standards (Trifuovi, 2006). The probable reason why some pressure heads were negative may be attributed to loss of head like frictional head loss, head loss due to pipe fittings, bends etc.

Also, the result obtained revealed a problem of low pressure in some portions of the existing network; this may point toward the likelihood of a closed valve in the area, or as result of several factors such as: illegal connections, leakages and extension of water services to other areas without improving the designed water supply demand from the treatment plant.

Table 12: Summary of hydraulic results

SUMMARY OF HYDRAULIC RESULTS			
Parameter	Results found	Design criteria	Implication
The flow (l/s)	-392 to 384	Depending on the other parameters	In some cases, there is back flow in the system in number of pipes. This may be explained by some portions of the system are looped so that there is a possibility of back flow
The velocity (m/s)	0.00028 to 7.15	0.1 m/s to 3 m/s (Trifuovi, 2006) and (RSB, 2015)	Low velocities are not preferred for hygienic reasons, while too high velocities cause high head-losses and pipe damages and erosion.
Headloss (m/km)	0.000 to 103.724	head loss should not be more than 10m/km. (Trifuovi, 2006)	The high head loss shows the reduction in the head or pressure of the water as it flows through a hydraulic system. It also represents the energy used in overcoming friction caused by the walls of the pipe and other equipments.
Pressure (m)	-69.63 to 270.72	20 to 120 ranges. (RSB, 2015) and (Trifuovi, 2006).	Negative and low-pressure heads may be attributed to loss of head like frictional head loss, head loss due to pipe fittings, illegal connections, leakages and extension of water services to other areas without improving the designed water supply demand from the treatment plant. High pressure may be attributed to hilly terrains in Kigali and may cause pipe damages.

5. CONCLUSION

For the urbanization of Kicukiro district the following conclusions have been made from the analysis result and findings. The results have showed that using geospatial models such as remote sensing and GIS techniques; the process of urbanization can be analyzed effectively. The easily available satellite images google earth and other related field data like GPS data along with demographic information from census data has helped in detection of the change in land-use and land cover over the period of time in Kicukiro district. The result of accuracy showed that total (overall) accuracy of land use and land cover is 89.030 %, 93.715 %, 94.359 % and Kappa (K) is 85.40 %, 91.50 %, 89.80 % for 1999, 2013, 2019 respectively. The outputs showed that the total urban built-up land has grown by 31.52 km² from 1999 to 2019. Therefore, it was crucial to recognize that Kicukiro has clearly experienced significant and rapid increases in both the absolute size (urban growth) and the proportion of the population (urbanization) living in identifiably ‘urban’ areas over the past two decades. This will hamper on the achievement of sustainable development goals of access to water and sanitation services.

It was observed that the existing water supply system of Kicukiro does not have a wider coverage of water distribution to some parts of the area; this is as a result of rapid residential expansion in the area. This will lead to persistence water shortage, water scarcity and lack of accessibility to the basic need of water for residential utility.

The results showed that the population of Kicukiro district will increase from 419,209 inhabitants in 2019 up 918,538 inhabitants in 2039. This high population increase, will increase the demand of water which will create also a significant pressure on the existing water supply system. The results also showed that the current daily water demand (2019) is 76,854.98 m³ and 183,707.60 m³ for 2039. The increase within 20 years will be 106,852.62 m³ which is greater than the current water demand. The future water demand for 2039 will be almost the same as the water supplied currently in the entire Kigali city which was estimated at 187,293m³. It was observed that there is a large gap between demand and supply of water and there is no sign of instant relief in the near future.

At the end of the Analysis of the existing water supply system of Kicukiro district it was found that the resulting pressures at all the junctions and the flows with their velocities at all pipes are not enough to provide water to the study area.

6. RECOMMENDATIONS AND ADAPTATION STRATEGIES

From the conclusion made, the following recommendations have been made:

- Remote sensing and GIS technology should be wholly embraced in the management of the water utility for optimal utilization.
- Based on the findings of this study, in view of the increasing population and urbanizations process, a better urban planning to accommodate growing urban population and to provide them with basic amenities is necessary. A proper control and management of urban growth and protection of natural resources from urban encroachment should also be a priority.
- This study has shown that Kicukiro district is fast growing in population. Consequent upon this, the pressure of population and demand mounted on existing water distribution system and supply efficiency is of great concern to planners and concerned authorities.
- Use the outcome to inform the concerned government agency on what should be done to ensure adequate water supply to various consumers who reside in Kigali and Kicukiro area as well.
- Replacement of small distribution pipes;
- Augmentation of storage capacity and construction of pressure break tanks;
- Extension of network in new development areas;
- Construction of water distribution reservoirs to avoid direct pumping into the network;
- Purchase of leak detection and pressure management equipment;
- Rehabilitation of pump stations to improve energy efficiency.

Recommendations for future researchers

- Since the satellite images, aerial photos with higher resolutions but for expensive prices and the detailed demographic data are available now, the detailed land use and land cover analysis should be considered.
- Urban expansions considering the different scenarios can be predicted in the next step of this study.
- Use one of the optimization techniques to optimize the existing network in order to resolve the observed deficiencies.
- Use one of the optimization software to develop a model of the new design /expansion, and then simulate flow characteristics and capacities for optimum distribution of water in the area.

- Taking into account that this amount of water is to be pumped in different periods of time for different zones. A study the way of operation, zoning, and changing valves setting in the distribution system is necessary.
- Also, further research is recommended to incorporate other sources of water supply and economic determinants such as volumetric pricing, as this research focused more on piped born water supply and urban population change as the main determinant. This will give insight to development of alternatives to tackling the problem of water availability and accessibility within the study area.

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8. APPENDIX

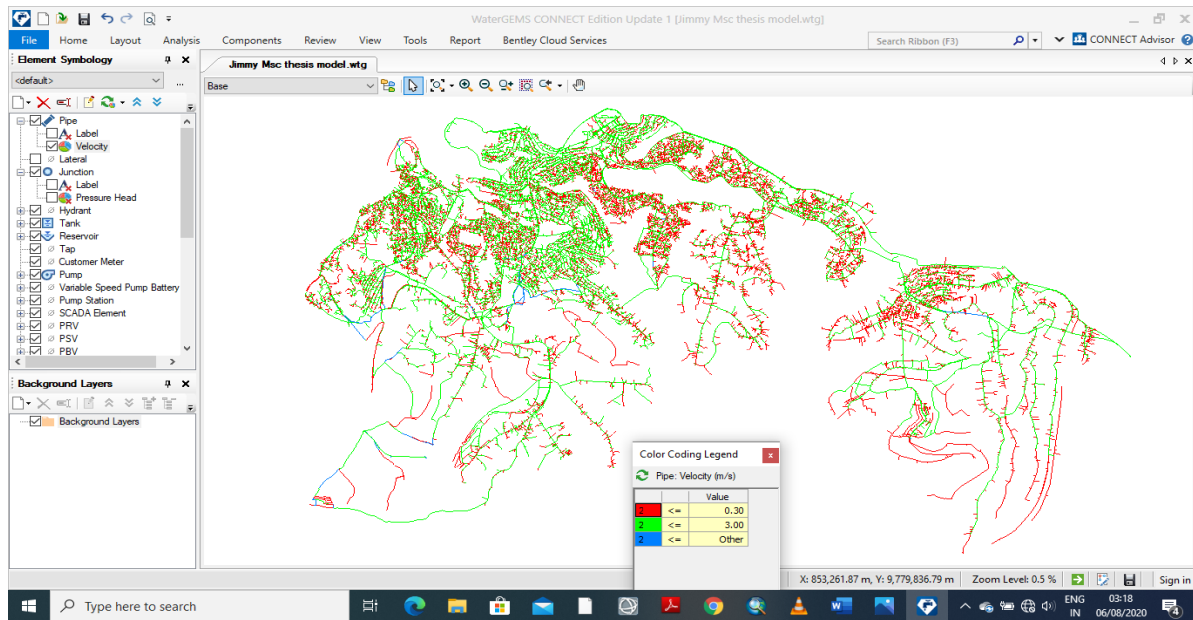


Figure 19: Color coding (pipe velocity)

Color coding was used to help to see quickly what is going on in the WaterGEMS model. It was used also to change the color and or size of elements based on the value of data that you select.

The information in the figure 18 shows the way velocities were being color coded by checking the pipes having the velocities ranging within the acceptable limits.

The results of the existing water supply network provided 72592 pipes of different diameters and other different parameters. To present the entire results of pipe report containing those above-mentioned number of pipes was difficult. Therefore, only few pipes of the above-mentioned number of pipes, were used to represent the results of pipe report from Flex tables as shown in table 11 below:

Table 13: *kicukiro water distribution system: pipe report*

Label	Length (Scaled) (m)	Diameter (mm)	Hazen- Williams C	Flow (L/s)	Velocity (m/s)	Headloss Gradient (m/km)
Pipe_243647	5	110.0	140.0	-3.20	0.34	1.25
Pipe_243646	11	110.0	140.0	-3.19	0.34	1.27
Pipe_243644	18	110.0	140.0	-3.19	0.34	1.25
Pipe_243642	9	110.0	140.0	-3.18	0.33	1.25
Pipe_243638	2	110.0	140.0	-3.17	0.33	1.26
Pipe_243637	26	110.0	140.0	-3.11	0.33	1.20
Pipe_243636	22	110.0	140.0	-3.11	0.33	1.20
Pipe_243634	29	110.0	140.0	-3.10	0.33	1.19
Pipe_243632	57	110.0	140.0	-3.10	0.33	1.19
Pipe_243631	1	110.0	140.0	-3.07	0.32	1.13
Pipe_243630	2	110.0	140.0	-3.06	0.32	1.15

Pipe_243625	6	110.0	140.0	-3.25	0.34	1.29
Pipe_243624	3	110.0	140.0	-3.24	0.34	1.33
Pipe_243594	2	110.0	140.0	-3.09	0.33	1.23
Pipe_243572	5	110.0	140.0	-3.04	0.32	1.16
Pipe_243569	6	110.0	140.0	-1.44	0.15	0.30
Pipe_243568	1	110.0	140.0	-1.36	0.14	0.17
Pipe_243559	4	110.0	140.0	-1.33	0.14	0.25
Pipe_243558	6	110.0	140.0	-1.32	0.14	0.25
Pipe_243554	45	110.0	140.0	-1.32	0.14	0.25
Pipe_243553	6	160.0	140.0	4.15	0.21	0.35
Pipe_243551	18	160.0	140.0	4.14	0.21	0.33
Pipe_243550	15	160.0	140.0	4.14	0.21	0.32
Pipe_243549	5	160.0	140.0	4.15	0.21	0.33
Pipe_243548	25	160.0	140.0	4.15	0.21	0.33
Pipe_243547	133	160.0	140.0	4.17	0.21	0.33
Pipe_243546	41	160.0	140.0	4.17	0.21	0.33
Pipe_243545	28	160.0	140.0	4.17	0.21	0.33
Pipe_243539	6	160.0	140.0	4.14	0.21	0.34
Pipe_243533	4	160.0	140.0	4.11	0.20	0.35
Pipe_243532	14	160.0	140.0	4.13	0.21	0.33
Pipe_243527	25	160.0	140.0	4.11	0.20	0.33
Pipe_243526	3	160.0	140.0	4.11	0.20	0.28
Pipe_243525	6	160.0	140.0	3.22	0.16	0.19
Pipe_243523	26	160.0	140.0	4.10	0.20	0.32
Pipe_243518	42	160.0	140.0	3.21	0.16	0.21
Pipe_243516	25	32.0	140.0	0.85	1.06	44.86
Pipe_243511	94	110.0	140.0	-9.11	0.96	8.78
Pipe_243510	361	110.0	140.0	-9.10	0.96	8.78
Pipe_243509	31	40.0	140.0	0.17	0.13	0.76
Pipe_243508	81	40.0	140.0	0.17	0.14	0.77
Pipe_243507	178	40.0	140.0	0.16	0.13	0.71
Pipe_243505	121	40.0	140.0	0.16	0.13	0.66
Pipe_2435	2	110.0	140.0	8.04	0.85	6.96
Pipe_243499	11	110.0	140.0	-9.07	0.95	8.71
Pipe_243498	8	110.0	140.0	-9.07	0.95	8.72
Pipe_243491	6	110.0	140.0	-9.05	0.95	8.69
Pipe_243490	7	110.0	140.0	-9.03	0.95	8.64
Pipe_243489	5	160.0	140.0	3.09	0.15	0.20
Pipe_243488	6	160.0	140.0	3.09	0.15	0.19
Pipe_243471	67	160.0	140.0	2.83	0.14	0.16
Pipe_243470	177	160.0	140.0	2.84	0.14	0.16
Pipe_243463	12	160.0	140.0	2.67	0.13	0.14
Pipe_243462	31	160.0	140.0	2.68	0.13	0.15
Pipe_243460	19	160.0	140.0	2.81	0.14	0.16
Pipe_243452	33	75.0	140.0	0.23	0.05	0.06
Pipe_24345	9	25.0	120.0	-0.03	0.05	0.31
Pipe_243449	31	75.0	140.0	0.24	0.05	0.07
Pipe_243448	4	75.0	140.0	0.24	0.05	0.07
Pipe_243445	31	75.0	140.0	0.24	0.05	0.07

Pipe_243442	129	75.0	140.0	0.25	0.06	0.07
Pipe_243413	0	32.0	120.0	1.36	1.69	141.70
Pipe_243403	3	90.0	140.0	2.53	0.40	2.18
Pipe_243402	6	90.0	140.0	2.53	0.40	2.17
Pipe_243401	16	90.0	140.0	2.53	0.40	2.18
Pipe_243399	14	110.0	140.0	3.23	0.34	1.29
Pipe_243398	18	110.0	140.0	3.24	0.34	1.29
Pipe_243393	11	40.0	120.0	0.47	0.38	6.73
Pipe_243392	18	40.0	120.0	0.48	0.38	6.84
Pipe_243380	2	40.0	120.0	0.47	0.37	6.58
Pipe_243379	2	40.0	140.0	0.45	0.36	4.68
Pipe_243378	4	40.0	140.0	0.45	0.36	4.72
Pipe_243377	1	40.0	120.0	0.49	0.39	7.24
Pipe_243376	3	40.0	120.0	0.49	0.39	7.19
Pipe_243363	17	63.0	120.0	0.55	0.18	0.97
Pipe_243362	21	63.0	120.0	0.55	0.18	0.97
Pipe_243360	89	63.0	120.0	0.55	0.18	0.98
Pipe_243359	12	63.0	120.0	0.57	0.18	1.03
Pipe_243358	25	63.0	120.0	0.58	0.19	1.06
Pipe_243357	27	63.0	120.0	0.58	0.19	1.09
Pipe_243356	19	63.0	120.0	0.59	0.19	1.12
Pipe_243353	16	63.0	120.0	0.61	0.20	1.18
Pipe_243351	37	63.0	120.0	0.81	0.26	2.01
Pipe_243350	106	63.0	120.0	0.82	0.26	2.04
Pipe_243330	4	32.0	140.0	0.05	0.07	0.28
Pipe_243329	14	50.0	140.0	0.13	0.06	0.15
Pipe_243328	2	50.0	140.0	0.13	0.07	0.15
Pipe_243326	19	32.0	140.0	0.05	0.07	0.27
Pipe_243311	8	63.0	120.0	0.80	0.26	1.97
Pipe_243294	2	63.0	140.0	0.31	0.10	0.25
Pipe_243283	17	63.0	140.0	0.23	0.07	0.15
Pipe_243282	2	63.0	140.0	0.24	0.08	0.12
Pipe_243281	3	63.0	140.0	0.29	0.09	0.22
Pipe_243273	5	63.0	140.0	0.20	0.06	0.09
Pipe_243270	8	63.0	140.0	0.18	0.06	0.09
Pipe_243269	19	63.0	140.0	0.16	0.05	0.08
Pipe_243251	2	63.0	140.0	0.16	0.05	0.06
Pipe_243241	33	75.0	140.0	1.91	0.43	3.15
Pipe_243240	2	75.0	140.0	1.92	0.43	3.19
Pipe_243238	2	75.0	140.0	1.92	0.43	3.15
Pipe_242984	33	160.0	140.0	2.84	0.14	0.17
Pipe_242983	3	160.0	140.0	2.87	0.14	0.16
Pipe_242982	13	160.0	140.0	2.88	0.14	0.17
Pipe_242980	5	160.0	140.0	2.88	0.14	0.18
Pipe_242979	12	160.0	140.0	2.89	0.14	0.17
Pipe_242978	6	160.0	140.0	2.89	0.14	0.17
Pipe_242977	19	160.0	140.0	2.87	0.14	0.17
Pipe_242973	6	160.0	140.0	2.90	0.14	0.15
Pipe_242972	4	160.0	140.0	2.91	0.14	0.20

Pipe_242971	5	160.0	140.0	2.89	0.14	0.15
Pipe_242970	5	160.0	140.0	2.90	0.14	0.19
Pipe_242968	6	160.0	140.0	2.91	0.14	0.16
Pipe_242967	10	160.0	140.0	2.91	0.14	0.17
Pipe_242966	5	160.0	140.0	2.92	0.15	0.18
Pipe_242963	3	160.0	140.0	2.93	0.15	0.21
Pipe_242962	10	160.0	140.0	2.93	0.15	0.17
Pipe_242960	23	160.0	140.0	2.93	0.15	0.17
Pipe_242959	9	160.0	140.0	2.94	0.15	0.18
Pipe_242958	10	160.0	140.0	2.94	0.15	0.17
Pipe_242957	3	160.0	140.0	2.95	0.15	0.17
Pipe_242956	13	160.0	140.0	2.96	0.15	0.18
Pipe_242951	4	160.0	140.0	2.98	0.15	0.17
Pipe_242950	21	160.0	140.0	2.99	0.15	0.18
Pipe_242949	9	160.0	140.0	3.15	0.16	0.19
Pipe_242948	11	160.0	140.0	3.15	0.16	0.20
Pipe_242947	3	160.0	140.0	3.15	0.16	0.19
Pipe_242946	7	160.0	140.0	3.15	0.16	0.21
Pipe_242945	4	160.0	140.0	3.12	0.16	0.19
Pipe_242943	2	160.0	140.0	3.11	0.15	0.21
Pipe_242942	2	160.0	140.0	3.12	0.16	0.18
Pipe_242941	10	160.0	140.0	3.10	0.15	0.19
Pipe_242940	3	160.0	140.0	3.10	0.15	0.18
Pipe_242938	5	160.0	140.0	3.09	0.15	0.17
Pipe_242933	9	160.0	140.0	3.20	0.16	0.22
Pipe_242931	5	160.0	140.0	3.13	0.16	0.18
Pipe_242930	23	160.0	140.0	3.13	0.16	0.20
Pipe_242925	9	160.0	140.0	3.10	0.15	0.20
Pipe_242924	5	160.0	140.0	3.11	0.15	0.19
Pipe_242919	222	160.0	140.0	2.67	0.13	0.15
Pipe_242916	22	160.0	140.0	2.81	0.14	0.16
Pipe_242913	216	125.0	140.0	-5.45	0.44	1.82
Pipe_242912	51	125.0	140.0	-5.45	0.44	1.82
Pipe_242880	13	110.0	140.0	-9.02	0.95	8.63
Pipe_242879	12	110.0	140.0	-9.00	0.95	8.60
Pipe_242878	11	110.0	140.0	-9.00	0.95	8.58
Pipe_242873	11	110.0	140.0	-9.06	0.95	8.68
Pipe_242872	8	110.0	140.0	-9.06	0.95	8.70

Same as on the pipe report, due to a large number of junctions in the existing network of Kicukiro which was 71902 junctions, only 150 junctions were used to represent the results of junction report from Flex table as presented in table 12 below:

Table 14: kicukiro wdn: junction/ node report

Label	Elevation (m)	Demand (L/s)	Hydraulic Grade (m)	Pressure (kPa)	Pressure Head (m)
wNode_32	1,640.00	0.00	1,639.60	-4	-0.40
wNode_30	1,410.00	0.03	1,397.37	-124	-12.63
wNode_3	1,463.00	0.17	1,476.53	133	13.53
wNode_29	1,410.00	0.12	1,555.53	1,426	145.53
wNode_2	1,463.00	0.00	1,476.46	132	13.46
RUSM6JU7	1,387.00	0.05	1,483.81	949	96.81
RUSM6JU36	1,384.00	0.05	1,483.81	978	99.81
RUSM6JU22	1,354.00	0.05	1,445.16	894	91.16
RUSM6JU20	1,369.00	0.21	1,445.14	746	76.14
RUSM6JU18	1,349.00	0.13	1,445.14	942	96.14
RUSM6JU17	1,345.00	0.33	1,445.12	981	100.12
RUSM6JU15	1,386.00	0.00	1,483.81	959	97.81
RUSM6JU11	1,387.00	0.00	1,483.81	949	96.81
RUSM6JU10	1,387.00	0.00	1,483.81	949	96.81
RUSM6JU1	1,387.00	0.00	1,483.81	949	96.81
RET4JU89	1,524.00	0.00	1,539.25	150	15.25
RET4JU78	1,528.00	0.79	1,539.25	110	11.25
RET4JU77	1,525.00	0.07	1,539.28	140	14.28
RET4JU76	1,525.00	0.00	1,539.33	140	14.33
RET4JU75	1,525.00	0.00	1,539.38	141	14.38
RET4JU74	1,525.00	0.00	1,539.46	142	14.46
RET4JU73	1,525.00	0.51	1,539.45	142	14.45
RET4JU72	1,513.00	0.00	1,539.05	255	26.05
RET4JU7	1,513.00	0.00	1,532.73	193	19.73
RET4JU68	1,528.00	0.63	1,539.00	108	11.00
RET4JU66	1,528.00	0.17	1,539.00	108	11.00
RET4JU62	1,526.00	0.00	1,539.12	129	13.12
RET4JU61	1,528.00	0.00	1,539.00	108	11.00
RET4JU60	1,528.00	0.11	1,538.98	108	10.98
RET4JU6	1,511.00	0.00	1,528.09	168	17.09
RET4JU58	1,528.00	0.00	1,539.58	113	11.58
RET4JU55	1,528.00	0.00	1,539.55	113	11.55
RET4JU52	1,528.00	0.00	1,539.55	113	11.55
RET4JU49	1,528.00	0.00	1,539.54	113	11.54
RET4JU48	1,524.00	0.00	1,531.46	73	7.46
RET4JU44	1,523.00	0.00	1,532.69	95	9.69
RET4JU4	1,481.00	0.00	1,520.91	391	39.91
RET4JU39	1,528.00	0.06	1,539.50	113	11.50
RET4JU36	1,521.00	0.00	1,537.78	164	16.78
RET4JU35	1,505.00	0.00	1,539.03	334	34.03
RET4JU34	1,499.00	0.00	1,538.99	392	39.99
RET4JU33	1,485.00	0.86	1,537.23	512	52.23
RET4JU32	1,505.00	0.00	1,533.07	275	28.07
RET4JU31	1,505.00	0.00	1,537.28	316	32.28
RET4JU30	1,495.00	0.40	1,537.10	413	42.10
RET4JU3	1,493.00	0.41	1,520.89	273	27.89

RET4JU29	1,485.00	0.00	1,536.91	509	51.91
RET4JU27	1,446.00	0.22	1,536.91	891	90.91
RET4JU24	1,456.00	0.10	1,535.30	777	79.30
RET4JU23	1,468.00	0.00	1,535.77	664	67.77
RET4JU22	1,490.00	0.00	1,537.10	462	47.10
RET4JU21	1,479.00	0.00	1,528.78	488	49.78
RET4JU2	1,504.00	0.07	1,521.72	174	17.72
RET4JU19	1,479.00	0.34	1,527.27	473	48.27
RET4JU17	1,479.00	0.19	1,527.27	473	48.27
RET4JU16	1,490.00	0.00	1,528.78	380	38.78
RET4JU15	1,487.00	0.00	1,521.72	340	34.72
RET4JU14	1,499.00	0.00	1,537.28	375	38.28
RET4JU13	1,509.00	0.00	1,533.07	236	24.07
RET4JU12	1,522.00	0.02	1,532.98	108	10.98
RET4JU111	1,446.00	0.00	1,533.82	861	87.82
RET4JU110	1,458.00	0.00	1,534.23	747	76.23
RET4JU107	1,479.00	0.00	1,527.11	472	48.11
RET4JU103	1,493.00	0.00	1,538.99	451	45.99
RET4JU102	1,493.00	0.33	1,538.99	451	45.99
RET4JU101	1,509.00	0.00	1,539.00	294	30.00
RET4JU100	1,513.00	0.35	1,539.03	255	26.03
RET4JU1	1,501.00	0.00	1,520.86	195	19.86
RET3JU9	1,497.00	0.46	1,523.36	258	26.36
RET3JU8	1,487.00	0.26	1,518.39	308	31.39
RET3JU66	1,508.00	0.00	1,520.86	126	12.86
RET3JU64	1,449.00	0.16	1,518.03	677	69.03
RET3JU61	1,453.00	0.00	1,514.14	599	61.14
RET3JU58	1,447.00	0.00	1,514.34	660	67.34
RET3JU57	1,463.00	0.00	1,514.55	505	51.55
RET3JU55	1,463.00	0.00	1,514.56	505	51.56
RET3JU4	1,464.00	0.00	1,516.50	515	52.50
RET3JU37	1,517.00	0.00	1,523.87	67	6.87
RET3JU36	1,510.00	0.00	1,523.86	136	13.86
RET3JU29	1,512.00	0.00	1,523.86	116	11.86
RET3JU27	1,512.00	0.00	1,523.86	116	11.86
RET3JU10	1,510.00	0.22	1,518.47	83	8.47
RET3JU1	1,464.00	0.10	1,516.55	515	52.55
RES3JU35	1,479.00	0.00	1,514.57	349	35.57
REMEJU99	1,495.00	0.00	1,514.52	191	19.52
REMEJU9	1,524.00	0.00	1,539.16	149	15.16
REMEJU88	1,510.00	0.22	1,518.40	82	8.40
REMEJU87	1,510.00	0.22	1,518.40	82	8.40
REMEJU86	1,510.00	0.00	1,523.75	135	13.75
REMEJU85	1,489.00	0.14	1,522.83	332	33.83
REMEJU84	1,510.00	0.00	1,520.86	106	10.86
REMEJU83	1,499.00	0.00	1,520.87	214	21.87
REMEJU82	1,493.00	0.00	1,538.99	451	45.99
REMEJU81	1,515.00	0.00	1,539.00	235	24.00
REMEJU189	1,480.00	0.24	1,516.46	357	36.46

REMEJU186	1,479.00	0.00	1,515.46	357	36.46
REMEJU185	1,487.00	0.14	1,518.39	308	31.39
REMEJU184	1,487.00	0.00	1,518.39	308	31.39
REMEJU183	1,488.00	0.00	1,518.39	298	30.39
REMEJU154	1,510.00	0.00	1,538.99	284	28.99
REMEJU149	1,437.00	0.00	1,523.78	851	86.78
REMEJU123	1,463.00	0.00	1,514.59	506	51.59
REMEJU122	1,463.00	0.00	1,514.57	505	51.57
REMEJU120	1,464.00	0.00	1,516.53	515	52.53
REMEJU12	1,479.00	0.00	1,515.46	357	36.46
REMEJU118	1,464.00	0.00	1,516.46	514	52.46
REMEJU116	1,453.00	0.01	1,514.13	599	61.13
REMEJU115	1,454.00	0.00	1,514.91	597	60.91
REMEJU114	1,432.00	0.00	1,523.76	899	91.76
REMEJU113	1,435.00	0.03	1,520.49	838	85.49
REMEJU112	1,447.00	0.18	1,520.30	718	73.30
REMEJU109	1,479.00	0.00	1,523.06	432	44.06
REMEJU108	1,479.00	0.00	1,523.10	432	44.10
REMEJU107	1,479.00	0.00	1,522.26	424	43.26
REMEJU106	1,479.00	0.08	1,522.64	428	43.64
REMEJU104	1,454.00	0.05	1,514.91	597	60.91
REMEJU103	1,454.00	0.00	1,514.92	597	60.92
REMEJU102	1,506.00	0.00	1,514.49	83	8.49
REMEJU101	1,506.00	0.09	1,514.49	83	8.49
REMEJU100	1,506.00	0.00	1,514.49	83	8.49
REMEJU10	1,525.00	0.04	1,539.16	139	14.16
NYE5JU15	1,542.00	0.04	1,773.33	2,267	231.33
NYE5JU14	1,542.00	0.00	1,773.33	2,267	231.33
NYARUP12JU5	1,402.00	0.01	1,410.70	85	8.70
NYARUP12JU4	1,402.00	0.00	1,402.81	8	0.81
NYARUP12JU18	1,402.00	0.00	1,402.69	7	0.69
NYARUP12JU16	1,402.00	0.21	1,417.22	149	15.22
NYARUP12JU15	1,402.00	0.00	1,417.12	148	15.12
NYARUP12JU12	1,402.00	0.00	1,410.49	83	8.49
NYARUP12JU1	1,402.00	0.00	1,402.74	7	0.74
NYARUN5JU9	1,400.00	0.00	1,481.64	800	81.64
NYARUN5JU8	1,400.00	0.00	1,481.64	800	81.64
NYARUN5JU7	1,400.00	0.00	1,481.64	800	81.64
NYARUN5JU6	1,395.00	0.22	1,481.56	848	86.56
NYARUN5JU5	1,407.00	0.00	1,481.75	733	74.75
NYARUN5JU4	1,417.00	0.00	1,481.95	637	64.95
NYARUN5JU26	1,408.00	0.00	1,481.69	722	73.69
NYARUN5JU23	1,395.00	0.00	1,481.63	849	86.63
NYARUN5JU22	1,389.00	0.00	1,481.63	908	92.63
NYARUN5JU21	1,401.00	0.00	1,481.63	790	80.63
NYARUN5JU20	1,389.00	0.00	1,481.63	908	92.63
NYARUN5JU19	1,389.00	0.03	1,481.63	908	92.63
NYARUN5JU18	1,384.00	0.00	1,481.62	957	97.62
NYARUN5JU17	1,384.00	0.00	1,481.64	957	97.64

NYARUN5JU16	1,401.00	0.00	1,481.64	790	80.64
NYARUN5JU15	1,401.00	0.00	1,481.64	790	80.64
NYARUN5JU14	1,401.00	0.00	1,481.64	790	80.64
NYARUN5JU12	1,395.00	0.01	1,481.64	849	86.64
Some of the junctions with the pressure head greater than 120 m					
Junction_45860	1,426.00	0.011	1,590.49	1,612	164.49
Junction_53518	1,533.00	0.025	1,697.32	1,611	164.32
130204JU4	1,510.00	0.034	1,673.87	1,606	163.87
Junction_41432	1,589.00	0.011	1,752.47	1,602	163.47
Junction_45710	1,589.00	0.011	1,752.40	1,602	163.4
Junction_41404	1,590.00	0.019	1,752.36	1,591	162.36
Junction_26771	1,475.00	0.012	1,637.26	1,590	162.26
Junction_42922	1,430.00	0.013	1,591.90	1,587	161.9
Junction_186817	1,549.00	0.015	1,710.00	1,578	161
Junction_46998	1,552.00	0.017	1,711.47	1,563	159.47
Junction_58811	1,478.00	0.01	1,637.22	1,561	159.22
Junction_141006	1,377.00	0.011	1,534.75	1,546	157.75
Junction_45915	1,433.00	0.032	1,590.19	1,541	157.19
Junction_51962	1,481.00	0.01	1,636.51	1,524	155.51
Junction_58789	1,486.00	0.023	1,637.21	1,482	151.21
Junction_46425	1,559.00	0.017	1,710.10	1,481	151.1
MASP9JU10	1,384.00	0.011	1,534.75	1,478	150.75
130402JU6	1,438.00	0.013	1,587.44	1,465	149.44
Junction_45920	1,441.00	0.011	1,590.39	1,464	149.39
Junction_44504	1,443.00	0.027	1,591.94	1,460	148.94
Junction_35457	1,489.00	0.012	1,637.27	1,453	148.27
Junction_36668	1,405.00	0.012	1,552.82	1,449	147.82
Junction_45992	1,443.00	0.011	1,590.37	1,444	147.37
Junction_45918	1,443.00	0.023	1,590.34	1,444	147.34
Junction_44948	1,441.00	0.011	1,588.17	1,442	147.17
Junction_3139	1,388.00	0.027	1,535.17	1,442	147.17
Junction_57739	1,487.00	0.022	1,634.02	1,441	147.02
Junction_41470	1,606.00	0.013	1,752.51	1,436	146.51
Junction_42989	1,544.00	0.011	1,689.96	1,431	145.96
Junction_43065	1,544.00	0.021	1,689.95	1,430	145.95
130704JU23	1,505.00	0.019	1,649.86	1,420	144.86
Junction_41486	1,608.00	0.012	1,752.57	1,417	144.57
Junction_146613	1,344.00	0.7	1,488.49	1,416	144.49
Junction_41434	1,608.00	0.01	1,752.46	1,416	144.46
Junction_41436	1,608.00	0.012	1,752.45	1,416	144.45
Junction_44482	1,448.00	0.012	1,591.96	1,411	143.96
Junction_43118	1,546.00	0.013	1,689.94	1,411	143.94
Junction_41774	1,544.00	0.01	1,687.80	1,409	143.8
Junction_140392	1,391.00	0.011	1,534.75	1,409	143.75
Junction_52234	1,494.00	0.017	1,637.10	1,403	143.1
Junction_41448	1,610.00	0.011	1,752.51	1,397	142.51
Junction_47464	1,494.00	0.011	1,636.51	1,397	142.51
Junction_44960	1,446.00	0.014	1,588.28	1,395	142.28

Junction_49992	1,548.00	0.032	1,689.90	1,391	141.9
Junction_159026	1,389.00	0.035	1,530.76	1,389	141.76
Junction_35233	1,411.00	0.012	1,552.46	1,387	141.46
Junction_186809	1,611.00	0.016	1,752.46	1,387	141.46
Junction_26573	1,496.00	0.016	1,637.16	1,384	141.16
Junction_27390	1,526.00	0.013	1,666.78	1,380	140.78
Junction_132918	1,368.00	0.011	1,508.18	1,374	140.18
Junction_146032	1,368.00	0.02	1,508.17	1,374	140.17
Junction_42546	1,466.00	0.014	1,605.71	1,369	139.71
Junction_35267	1,413.00	0.012	1,552.49	1,367	139.49
Junction_35232	1,413.00	0.025	1,552.47	1,367	139.47
Junction_197385	1,449.00	0.017	1,588.19	1,364	139.19
Junction_53698	1,452.00	0.011	1,590.76	1,360	138.76
Junction_38157	1,553.00	0.013	1,690.16	1,344	137.16
Junction_53572	1,553.00	0.016	1,689.95	1,342	136.95
Junction_27388	1,530.00	0.011	1,666.78	1,341	136.78
130102JU1	1,472.00	0.032	1,608.43	1,337	136.43
Junction_132921	1,372.00	0.011	1,508.18	1,335	136.18
Junction_150570	1,372.00	0.14	1,508.12	1,334	136.12
Junction_44131	1,501.00	0.014	1,637.06	1,334	136.06
Junction_49667	1,617.00	0.013	1,752.50	1,328	135.5
Junction_28820	1,399.00	0.01	1,522.18	1,207	123.18
Junction_48362	1,401.00	0.02	1,522.30	1,189	121.3
Junction_57921	1,507.00	0.011	1,628.17	1,188	121.17
Junction_31832	1,507.00	0.011	1,628.17	1,188	121.17
Junction_128462	1,391.00	0.024	1,512.11	1,187	121.11
Junction_27230	1,401.00	0.013	1,522.04	1,186	121.04
Junction_27232	1,401.00	0.011	1,522.03	1,186	121.03
Junction_25875	1,546.00	0.013	1,666.81	1,184	120.81
Junction_27342	1,402.00	0.01	1,522.22	1,178	120.22
Junction_42619	1,474.00	0.014	1,594.02	1,176	120.02
Some of the junctions with pressure head less than 20 m					
Junction_46190	1,687.00	0.01	1,706.20	188	19.2
Junction_181154	1,520.00	0.02	1,539.15	188	19.15
Junction_124438	1,486.00	0.012	1,505.13	188	19.13
Junction_152873	1,504.00	0.241	1,523.11	187	19.11
Junction_182793	1,450.00	0.057	1,468.81	184	18.81
Junction_34530	1,567.00	0.012	1,584.42	171	17.42
Junction_174390	1,511.00	0.129	1,528.06	167	17.06
Junction_91943	1,473.00	0.013	1,489.98	166	16.98
Junction_174323	1,519.00	0.012	1,535.92	166	16.92
Junction_31791	1,519.00	0.021	1,535.25	159	16.25
Junction_174337	1,507.00	0.014	1,522.64	153	15.64
Junction_174339	1,507.00	0.024	1,522.64	153	15.64
Junction_142371	1,526.00	0.023	1,541.49	152	15.49
110503JU13	1,428.00	0.011	1,443.44	151	15.44
Junction_34429	1,605.00	0.01	1,620.42	151	15.42
Junction_40516	1,706.00	0.026	1,721.13	148	15.13

Junction_152757	1,508.00	0.039	1,523.09	148	15.09
Junction_41670	1,626.00	0.011	1,640.54	143	14.54
Junction_40978	1,509.00	0.012	1,523.18	139	14.18
Junction_174349	1,507.00	0.011	1,520.86	136	13.86
Junction_32054	1,522.00	0.011	1,535.24	130	13.24
Junction_155768	1,510.00	0.015	1,523.23	130	13.23
Junction_155766	1,510.00	0.039	1,523.19	129	13.19
Junction_111672	1,500.00	0.101	1,513.18	129	13.18
Junction_171606	1,507.00	0.051	1,520.02	128	13.02
Junction_174353	1,508.00	0.056	1,520.09	119	12.09
Junction_58212	1,511.00	0.046	1,523.06	118	12.06
Junction_168874	1,511.00	0.179	1,522.99	117	11.99
Junction_173220	1,512.00	0.014	1,523.36	111	11.36
Junction_174705	1,513.00	0.012	1,523.38	102	10.38
Junction_173204	1,508.00	0.042	1,518.37	102	10.37
Junction_173200	1,508.00	0.072	1,518.36	102	10.36
Junction_174357	1,510.00	0.078	1,519.15	90	9.15
Junction_48125	1,811.00	0.011	1,820.00	88	9
Junction_174359	1,510.00	0.011	1,518.91	87	8.91
Junction_41993	1,611.00	0.012	1,618.61	75	7.61
Junction_49012	1,715.00	0.013	1,721.22	61	6.22
Junction_53422	1,460.00	0.268	1,466.14	60	6.14
Junction_174471	1,514.00	0.01	1,518.39	43	4.39
Junction_156694	1,514.00	0.019	1,518.39	43	4.39
Junction_34446	1,581.00	0.011	1,585.14	41	4.14
Junction_50172	1,532.00	0.011	1,535.75	37	3.75
Junction_38203	1,571.00	0.012	1,574.70	36	3.7
Junction_38313	1,571.00	0.05	1,574.58	35	3.58
Junction_34449	1,582.00	0.014	1,585.56	35	3.56
Junction_38329	1,572.00	0.01	1,574.65	26	2.65
Junction_38317	1,572.00	0.013	1,574.64	26	2.64
Junction_47249	1,639.00	0.011	1,640.58	15	1.58
Junction_144722	1,501.00	0.014	1,502.13	11	1.13
Junction_33570	1,539.00	0.011	1,539.56	6	0.56
130701JU12	1,754.00	0.013	1,754.32	3	0.32
Junction_33789	1,541.00	0.012	1,541.31	3	0.31
Junction_38211	1,578.00	0.068	1,574.38	-35	-3.62
Junction_31765	1,545.00	0.014	1,540.69	-42	-4.31
Junction_31751	1,552.00	0.032	1,547.10	-48	-4.9
Junction_52419	1,548.00	0.014	1,541.43	-64	-6.57
Junction_138655	1,472.00	0.232	1,464.50	-74	-7.5
Junction_52572	1,559.00	0.014	1,550.17	-87	-8.83
Junction_48119	1,724.00	0.031	1,714.76	-91	-9.24
Junction_48121	1,724.00	0.025	1,714.75	-91	-9.25
Junction_184101	1,516.00	0.02	1,505.92	-99	-10.08
Junction_32628	1,594.00	0.014	1,580.73	-130	-13.27
Junction_42092	1,643.00	0.013	1,628.79	-139	-14.21
Junction_168905	1,525.00	0.018	1,509.69	-150	-15.31

Junction_148134	1,560.00	0.053	1,541.67	-180	-18.33
Junction_32680	1,571.00	0.015	1,552.09	-185	-18.91
Junction_49009	1,741.00	0.011	1,721.26	-194	-19.74
130701JU7	1,753.00	0.02	1,731.17	-214	-21.83
Junction_32630	1,589.00	0.01	1,565.57	-230	-23.43
Junction_34498	1,582.00	0.022	1,556.73	-248	-25.27
Junction_32686	1,580.00	0.015	1,554.68	-248	-25.32

Table 15:kicukiro wdn: tank report

Label	Elevation (Base) (m)	Elevation (Maximum) (m)	Diameter (m)	Flow (Out net) (L/s)	Hydraulic Grade (m)
110503RE1	1,593.62	1,596.62	8.00	74.49	1,595.62
RET4RE3	1,536.62	1,540.62	14.00	222.09	1,539.62
RET4RE2	1,537.77	1,540.77	22.00	113.96	1,539.52
RET4RE1	1,530.64	1,534.64	12.00	13.01	1,533.64
RET3RE1	1,516.65	1,518.65	16.00	-14.00	1,518.40
NYD5RE1	1,448.62	1,450.62	3.05	24.70	1,450.37
NYARUP12RE2	1,401.67	1,403.67	10.00	21.54	1,403.42
NYARUP12RE1	1,400.98	1,402.98	5.64	-104.98	1,402.73
NYARUM5RE1	1,430.82	1,433.82	7.90	-126.83	1,433.57
NYARUK2RE2	1,465.29	1,469.29	4.00	-1.26	1,468.29
NIBX16RE2	1,395.62	1,397.62	5.00	0.00	1,397.37
NIBX16RE1	1,395.62	1,397.62	7.00	7,573.34	1,397.37
NIBX15RE3	1,478.58	1,480.58	2.00	-1.58	1,479.58
NIBX15RE2	1,519.62	1,523.62	14.00	-402.81	1,522.37
NIBX15RE1	1,519.62	1,523.62	14.00	-15.96	1,522.37
MASV7RE1	1,430.52	1,432.52	2.00	-5.75	1,432.27
MASS8RE1	1,508.73	1,510.73	4.00	4.38	1,510.48
MASS7RE1	1,383.36	1,385.36	3.00	0.00	1,385.11
MASS6RE1	1,413.62	1,415.62	4.00	-2.67	1,415.37
MASR7RE1	1,413.25	1,414.25	4.00	0.00	1,414.00
MASR5RE1	1,399.62	1,402.62	5.00	-6.89	1,402.37
MASP8RE2	1,572.62	1,574.62	3.00	390.05	1,573.62
MASP8RE1	1,484.82	1,488.82	6.00	-104.85	1,487.82
MASO9RE1	1,412.34	1,416.34	4.00	0.00	1,416.09
MASO8RE1	1,452.26	1,454.26	3.00	-12.32	1,454.01
MASO7RE1	1,482.39	1,485.39	8.00	-98.21	1,484.39
MASO6RE1	1,425.78	1,427.78	6.00	-107.33	1,427.53
KIGY11RE2	1,637.98	1,639.98	6.00	-73.04	1,639.73
KIGY11RE1	1,553.64	1,555.64	2.00	0.00	1,555.39
KIGX12RE3	1,639.16	1,641.16	5.00	-41.18	1,640.91
KIGX12RE2	1,569.46	1,571.46	2.00	-3.68	1,571.21
KIGX12RE1	1,625.59	1,629.59	5.00	-10.07	1,628.59
KICW14RE2	1,446.60	1,448.60	2.00	-3.93	1,447.60
KICW14RE1	1,457.97	1,459.97	2.00	-4.60	1,459.72

KANO3RE3	1,479.63	1,481.63	5.00	-1.22	1,480.63
KANO3RE2	1,498.62	1,500.62	5.00	-12.21	1,499.62
KANO3RE1	1,499.62	1,501.62	5.00	-6.85	1,500.62
KANN4RE1	1,431.16	1,433.16	2.00	-13.27	1,432.91
KANN3RE2	1,509.62	1,511.62	5.00	1.95	1,511.37
KANN3RE1	1,510.68	1,513.68	3.00	11.63	1,512.68
KANN2RE1	1,443.57	1,445.57	8.00	-9.73	1,445.32
KANM3RE1	1,489.49	1,491.49	3.00	-0.84	1,490.49
KANM2RE2	1,485.62	1,488.62	3.00	-7.36	1,488.37
KANM2RE1	1,480.84	1,482.84	4.00	-2.39	1,482.59
KANL1RE2	1,479.13	1,483.13	4.00	-16.49	1,482.13
KANL1RE1	1,439.38	1,441.38	5.00	-5.91	1,440.38
KACZ5H3RE01	1,474.62	1,480.62	22.00	-170.01	1,479.62
GIKW13RE1	1,540.62	1,543.62	10.00	12.46	1,542.62
GATZ12RE2	1,634.73	1,638.73	5.00	-30.03	1,637.73
GATZ12RE1	1,818.52	1,821.52	3.05	9.64	1,820.52
GAHZ14RE1	1,710.05	1,716.05	10.00	467.32	1,714.05
130103RE1	1,441.44	1,444.44	3.50	-24.03	1,443.44
110506RE2	1,391.51	1,394.51	2.00	-14.87	1,393.51
110506RE1	1,463.36	1,466.36	6.50	-14.21	1,465.36
110503RE5	1,542.10	1,545.10	2.00	-9.06	1,544.10
110503RE4	1,386.41	1,389.41	6.50	59.35	1,388.41
110503RE3	1,492.62	1,495.62	4.60	-19.30	1,494.62
110503RE2	1,514.23	1,517.23	4.60	-21.23	1,516.23

Table 16: kicukiro wdn: reservoir report

Label	Elevation (m)	Flow (Out net) (L/s)	Hydraulic Grade (m)
GATY14RE2	1,625.00	-42.05	1,625.00
GATY14RE1	1,700.00	164.35	1,700.00
GATAA12RE1	1,692.00	16.92	1,692.00
NIBX16WS1	1,387.50	-7,555.65	1,387.50
MBURABUTURO	1,404.00	32.67	1,404.00
MATA	1,379.00	-44.56	1,379.00
KIGY12RE1	1,760.00	140.43	1,760.00

Table 17: kicukiro wdn: pump report

Label	Elevation (m)	Hydraulic Grade (Suction) (m)	Hydraulic Grade (Discharge) (m)	Flow (Total) (L/s)	Pump Head (m)
MATAPU1	1,392.00	1,387.03	1,658.09	7.47	271.07
KIGY11PU3_3	1,640.00	1,639.52	1,932.33	1.12	292.81
KIGY11PU3	1,640.00	1,639.53	1,932.33	3.52	292.80
KIGY11PU2_2	1,640.00	1,639.52	1,932.33	1.12	292.81

KIGY11PU2	1,640.00	1,639.54	1,932.31	8.62	292.77
KIGY11PU1_1	1,640.00	1,639.53	1,932.33	1.12	292.80
KACZ5H3PU03	1,463.00	1,476.46	1,547.91	18.59	71.45
KACZ5H3PU02	1,463.00	1,476.82	1,547.92	4.91	71.09
KACZ5H3PU01	1,463.00	1,476.53	1,547.92	18.63	71.39
NYD5PU2	1,443.00	1,424.37	1,651.30	0.00	0.00
NYARUP12PU3	1,402.00	1,402.69	1,417.22	0.00	0.00
NYD5PU3	1,443.00	1,401.98	1,651.30	11.43	249.32
NYD5PU1	1,443.00	1,450.32	1,651.31	13.28	200.99
NYARUP12PU2	1,402.00	1,402.69	1,417.22	27.10	14.52
NYARUP12PU1	1,402.00	1,402.78	1,417.12	27.11	14.35
NIBX16PU2	1,410.00	1,397.37	1,555.53	8.66	158.16
NIBX16PU1	1,410.00	1,397.37	1,555.53	9.03	158.16
NIBX15PU2	1,519.00	1,522.33	1,529.51	54.81	7.18
NIBX15PU1	1,519.00	1,522.33	1,529.71	54.79	7.38
MATAPU2	1,392.00	1,384.32	1,658.00	7.32	273.68

Table 18: GROUND THRUTHING DATA USED IN ACCURACY ASSESSMENT

1. GIKONDO SECTOR GPS COORDINATES				
POINT	X	Y	Z	CODE/ ID
	508591	4780770	1434	COMMERCIAL AREA
	508523	4780756	1544	COMMERCIAL AREA
	508501	4780799	1542	COMMERCIAL AREA
	508730	4781042	1512	COMMERCIAL AREA
	508736	4780776	1415	COMMERCIAL AREA
	508678	4780742	1525	COMMERCIAL AREA
	508666	4780631	1524	COMMERCIAL AREA
	508627	4780590	1531	COMMERCIAL AREA
	508595	4780604	1534	COMMERCIAL AREA
	508336	4782716	1432	INFORMAL SETTLEMENT
	508172	4782985	1460	INFORMAL SETTLEMENT
	508150	4782998	1452	INFORMAL SETTLEMENT
	508023	4782974	1410	INFORMAL SETTLEMENT
	508265	4782690	1426	INFORMAL SETTLEMENT
	509261	4782327	1429	INDUSTRIAL AREA
	509323	4781791	1441	INDUSTRIAL AREA
	509198	4782234	1440	INDUSTRIAL AREA
	509518	4782071	1424	INDUSTRIAL AREA
	509566	4782119	1420	INDUSTRIAL AREA
	509549	4782236	1415	INDUSTRIAL AREA
	509403	4782263	1423	INDUSTRIAL AREA

	508620	4780570	1526	CADASTRAL AREA
	508595	4780598	1535	CADASTRAL AREA
	508606	4780412	1542	CADASTRAL AREA
	508657	4780407	1520	CADASTRAL AREA
	508669	4780426	1521	CADASTRAL AREA
	508531	4781319	1512	OFFICE
	508585	4781312	1514	OFFICE
	508590	4781313	1513	OFFICE
	508528	4781320	1514	OFFICE
	508453	4782100	1483	COMMERCIAL AREA
	508418	4782187	1478	COMMERCIAL AREA
	508403	4782180	1477	COMMERCIAL AREA
	508376	4782065	1485	COMMERCIAL AREA
	508286	4782796	1435	SCHOOL
	508369	4782844	1431	SCHOOL
	508193	4782963	1455	SCHOOL
	508141	4783054	1463	SCHOOL
	508369	4782962	1448	SCHOOL
	508354	4782944	1452	SCHOOL
	508184	4782479	1421	HEALTH CENTER
	508198	4782470	1422	HEALTH CENTER
	508197	4782495	1411	HEALTH CENTER
	507907	4782486	1418	HEALTH CENTER
	508482	4782668	1439	COMMERCIAL AREA
	508322	4782520	1432	COMMERCIAL AREA
	508276	4782678	1432	COMMERCIAL AREA
	508358	4782713	1432	COMMERCIAL AREA
	508411	4782746	1434	COMMERCIAL AREA
2. KICUKIRO – GATENGA SECTOR GPS COORDINATES				
POINT	X	Y	Z	CODE
1	507545	4781455	1467	HEALTH CENTER
2	507546	4781454	1464	HEALTH CENTER
3	507550	4781469	1466	HEALTH CENTER
4	507640	4781472	1445	HEALTH CENTER
5	507574	4781341	1458	HEALTH CENTER
6	507515	4781305	1467	HEALTH CENTER
7	507509	4781374	1474	HEALTH CENTER
8	507474	4781327	1480	HEALTH CENTER
9	507501	4781377	1475	HEALTH CENTER
10	507545	4781455	1467	HEALTH CENTER

1	507607	4781965	1395	COMMERCIAL AREA
2	507685	4781873	1416	COMMERCIAL AREA
3	507680	4781854	1414	COMMERCIAL AREA
4	507711	4781821	1417	COMMERCIAL AREA
5	507713	4781782	1420	COMMERCIAL AREA
6	507733	4781683	1419	COMMERCIAL AREA
7	507713	4781673	1427	COMMERCIAL AREA
8	507544	4781471	1467	COMMERCIAL AREA
9	507562	4781566	1458	COMMERCIAL AREA
10	507568	4781584	1454	COMMERCIAL AREA
11	507513	4781753	1452	COMMERCIAL AREA
12	507515	4781767	1446	COMMERCIAL AREA
13	507591	4781956	1411	COMMERCIAL AREA
1	507110	4779724	1615	OFFICE
2	507093	4779694	1616	OFFICE
3	507063	4779715	1612	OFFICE
4	507928	4781155	1611	OFFICE
5	507047	4779765	1606	OFFICE
6	507083	4779777	1603	OFFICE
1	507701	4781671	1430	COMMERCIAL AREA
2	507702	4781672	1427	COMMERCIAL AREA
3	507714	4781586	1428	COMMERCIAL AREA
4	507673	4781660	1436	COMMERCIAL AREA
5	507667	4781643	1433	COMMERCIAL AREA
6	507697	4781511	1438	COMMERCIAL AREA
7	507712	4781513	1434	COMMERCIAL AREA
8	507703	4781585	1431	COMMERCIAL AREA
1	507234	4781798	1426	INFORMAL SETTLEMENT
2	501792	4781889	1408	INFORMAL SETTLEMENT
3	500697	4781596	1400	INFORMAL SETTLEMENT
4	506989	4781522	1425	INFORMAL SETTLEMENT
1	508389	4780523	1568	CADASTRAL AREA
2	508088	4780529	1566	CADASTRAL AREA
3	508053	4780566	1560	CADASTRAL AREA
4	507999	4780565	1554	CADASTRAL AREA
5	507969	4780655	1543	CADASTRAL AREA

6	508466	4780728	1549	CADASTRAL AREA
POINT	X	Y	Z	CODE
1	511611	4780992	1494	COMMERCIAL AREA
2	511619	4780994	1493	COMMERCIAL AREA
3	511649	4780999	1497	COMMERCIAL AREA
4	511597	4780885	1496	COMMERCIAL AREA
5	511593	4780847	1497	COMMERCIAL AREA
6	511565	4780871	1495	COMMERCIAL AREA
7	511605	4780882	1496	COMMERCIAL AREA
1	511606	4780999	1505	CADASTRAL AREA
2	511623	4781001	1498	CADASTRAL AREA
3	511661	4781019	1497	CADASTRAL AREA
4	511618	4780995	1497	CADASTRAL AREA
5	511681	4781247	1497	CADASTRAL AREA
6	511670	4781253	1491	CADASTRAL AREA
7	511668	4781269	1497	CADASTRAL AREA
8	511553	4780897	1492	CADASTRAL AREA
9	511563	4780887	1497	CADASTRAL AREA
10	511637	4781255	1494	CADASTRAL AREA
11	511490	4780961	1479	CADASTRAL AREA
12	511555	4780903	1494	CADASTRAL AREA
13	511563	4780884	1497	CADASTRAL AREA
14	511572	4780880	1497	CADASTRAL AREA
3. KIGARAMA SECTOR GPS COORDINATES				
POINT	X	Y	Z	CODE
1	507545	4781455	1467	HEALTH CENTER
2	507546	4781454	1464	HEALTH CENTER
3	507550	4781469	1466	HEALTH CENTER
4	507640	4781472	1445	HEALTH CENTER
5	507574	4781341	1458	HEALTH CENTER
6	507515	4781305	1467	HEALTH CENTER
7	507509	4781374	1474	HEALTH CENTER
8	507474	4781327	1480	HEALTH CENTER
9	507501	4781377	1475	HEALTH CENTER
10	507545	4781455	1467	HEALTH CENTER
1	507607	4781965	1395	COMMERCIAL AREA
2	507685	4781873	1416	COMMERCIAL AREA
3	507680	4781854	1414	COMMERCIAL AREA
4	507711	4781821	1417	COMMERCIAL AREA

5	507713	4781782	1420	COMMERCIAL AREA
6	507733	4781683	1419	COMMERCIAL AREA
7	507713	4781673	1427	COMMERCIAL AREA
8	507544	4781471	1467	COMMERCIAL AREA
9	507562	4781566	1458	COMMERCIAL AREA
10	507568	4781584	1454	COMMERCIAL AREA
11	507513	4781753	1452	COMMERCIAL AREA
12	507515	4781767	1446	COMMERCIAL AREA
13	507591	4781956	1411	COMMERCIAL AREA
1	507110	4779724	1615	OFFICE
2	507093	4779694	1616	OFFICE
3	507063	4779715	1612	OFFICE
4	507928	4781155	1611	OFFICE
5	507047	4779765	1606	OFFICE
6	507083	4779777	1603	OFFICE
1	507701	4781671	1430	COMMERCIAL AREA
2	507702	4781672	1427	COMMERCIAL AREA
3	507714	4781586	1428	COMMERCIAL AREA
4	507673	4781660	1436	COMMERCIAL AREA
5	507667	4781643	1433	COMMERCIAL AREA
6	507697	4781511	1438	COMMERCIAL AREA
7	507712	4781513	1434	COMMERCIAL AREA
8	507703	4781585	1431	COMMERCIAL AREA
1	507234	4781798	1426	INFORMAL SETTLEMENT
2	501792	4781889	1408	INFORMAL SETTLEMENT
3	500697	4781596	1400	INFORMAL SETTLEMENT
4	506989	4781522	1425	INFORMAL SETTLEMENT
1	508389	4780523	1568	CADASTRAL AREA
2	508088	4780529	1566	CADASTRAL AREA
3	508053	4780566	1560	CADASTRAL AREA
4	507999	4780565	1554	CADASTRAL AREA
5	507969	4780655	1543	CADASTRAL AREA
6	508466	4780728	1549	CADASTRAL AREA
4. KANOMBE SECTOR GPS COORDINATES				
POINT	X	Y	Z	ID
1	511955	4781955	1466	HEALTH CENTER
2	511987	4782007	1455	HEALTH CENTER
3	512055	4781967	1460	HEALTH CENTER
4	512013	4781912	1468	HEALTH CENTER
1	512120	4781884	1469	CADASTRAL AREA

2	512106	4781858	1470	CADASTRAL AREA
3	512502	4781777	1473	CADASTRAL AREA
4	512281	4781820	1473	CADASTRAL AREA
1	512245	4781803	1488	INDUSTRIAL AREA
2	512184	4781821	1481	INDUSTRIAL AREA
3	512231	4781774	1483	INDUSTRIAL AREA
4	512223	4781757	1491	INDUSTRIAL AREA
5	512186	4781757	1484	INDUSTRIAL AREA
1	512051	4781880	1471	CADASTRAL AREA
2	512099	4781858	1468	CADASTRAL AREA
3	512114	4781875	1467	CADASTRAL AREA
1	512331	4781796	1476	CADASTRAL AREA
2	512245	4782765	1470	CADASTRAL AREA
3	512326	4781729	1480	CADASTRAL AREA
4	512333	4781749	1479	CADASTRAL AREA
1	512723	4781475	1460	HEALTH CENTER
2	512682	4781444	1472	HEALTH CENTER
3	512781	4781415	1470	HEALTH CENTER
4	512742	4781384	1482	HEALTH CENTER
1	512502	4781777	1473	CADASTRAL AREA
2	512281	4781820	1473	CADASTRAL AREA
3	512666	4781601	1467	CADASTRAL AREA
4	512841	4781321	1465	CADASTRAL AREA
5	513054	4780891	1468	CADASTRAL AREA
6	512896	4781015	1465	CADASTRAL AREA
7	513063	4781128	1450	CADASTRAL AREA
1	512344	4781715	1480	CADASTRAL AREA
2	512359	4781797	1478	CADASTRAL AREA
3	512571	4781716	1469	CADASTRAL AREA
4	512875	4781022	1473	CADASTRAL AREA
5	512443	4781334	1480	CADASTRAL AREA
6	512427	4781553	1479	CADASTRAL AREA
1	513304	4780802	1437	CADASTRAL AREA
2	513285	4780749	1437	CADASTRAL AREA
3	513134	4780846	1442	CADASTRAL AREA
4	513201	4780795	1444	CADASTRAL AREA
5	513214	4780874	1437	CADASTRAL AREA
1	512793	4780956	1461	CADASTRAL AREA
2	512875	4781016	1462	CADASTRAL AREA
3	512645	4781177	1466	CADASTRAL AREA
4	512567	4781234	1478	CADASTRAL AREA

5	512548	4781175	1472	CADASTRAL AREA
6	512552	4781161	1471	CADASTRAL AREA
1	513093	4780852	1446	CADASTRAL AREA
2	512742	4780938	1457	CADASTRAL AREA
3	512890	4781016	1469	CADASTRAL AREA
4	512698	4780831	1450	CADASTRAL AREA
1	512583	4781155	1476	OFFICE
2	512593	4781122	1477	OFFICE
3	512538	4781133	1475	OFFICE
4	512545	4781103	1473	OFFICE
1	513074	4780890	1446	SCHOOL
2	513049	4781112	1463	SCHOOL
3	513151	4780894	1458	SCHOOL
4	513092	4781157	1445	SCHOOL
5	513134	4780846	1442	SCHOOL
1	512476	4781104	1475	SCHOOL
2	512541	4781144	1474	SCHOOL
3	512552	4781223	1477	SCHOOL
4	512427	4781320	1479	SCHOOL
1	512577	4781337	1474	CHURCH
2	512518	4781324	1470	CHURCH
3	512567	4781251	1474	CHURCH
4	512501	4781296	1479	CHURCH
1	512415	4780014	1462	CADASTRAL AREA
2	512344	4779954	1469	CADASTRAL AREA
3	512307	4779921	1475	CADASTRAL AREA
4	512289	4779937	1480	CADASTRAL AREA
1	512575	4781258	1482	COMMERCIAL AREA
2	512580	4781272	1481	COMMERCIAL AREA
3	512562	4781262	1479	COMMERCIAL AREA
4	512571	4781273	1477	COMMERCIAL AREA
1	512426	4781528	1479	CADASTRAL AREA
2	512427	4781340	1473	CADASTRAL AREA
3	512230	4781450	1481	CADASTRAL AREA
4	512269	4781555	1492	CADASTRAL AREA
1	512221	4781466	1496	CADASTRAL AREA
2	512187	4781369	1487	CADASTRAL AREA
3	512384	4781303	1492	CADASTRAL AREA
4	512418	4781331	1482	CADASTRAL AREA
1	512347	4780584	1458	COMMERCIAL AREA
2	512321	4780615	1450	COMMERCIAL AREA

3	512283	4780555	1449	COMMERCIAL AREA
4	512330	4780565	1446	COMMERCIAL AREA
1	512261	4780554	1442	CADASTRAL AREA
2	512196	4780560	1452	CADASTRAL AREA
3	512203	4780541	1452	CADASTRAL AREA
4	512321	4780347	1458	CADASTRAL AREA
5	512351	4780250	1461	CADASTRAL AREA
1	512171	4780565	1457	CADASTRAL AREA
2	512183	4780561	1456	CADASTRAL AREA
3	512190	4780542	1453	CADASTRAL AREA
4	512316	4780340	1459	CADASTRAL AREA
5	512340	4780248	1462	CADASTRAL AREA
1	512454	4780062	1465	CADASTRAL AREA
2	512549	4780144	1440	CADASTRAL AREA
3	512512	4780233	1442	CADASTRAL AREA
4	512351	4780250	1461	CADASTRAL AREA
1	512393	4780061	1458	CADASTRAL AREA
2	512405	4780072	1453	CADASTRAL AREA
3	512426	4780020	1458	CADASTRAL AREA
4	512441	4780031	1460	CADASTRAL AREA
1	512286	4781023	1474	CADASTRAL AREA
2	512358	4780914	1469	CADASTRAL AREA
3	512076	4780790	1472	CADASTRAL AREA
4	512164	4780754	1469	CADASTRAL AREA
5	512434	4780750	1460	CADASTRAL AREA
1	512256	4780240	1468	CADASTRAL AREA
2	512340	4780248	1462	CADASTRAL AREA
3	512254	4780282	1463	CADASTRAL AREA
4	512122	4780226	1490	CADASTRAL AREA
5	511994	4780435	1485	CADASTRAL AREA
6	512127	4780515	1460	CADASTRAL AREA
1	512076	4780479	1470	CADASTRAL AREA
2	511984	4780455	1485	CADASTRAL AREA
3	511902	4780543	1495	CADASTRAL AREA
1	511544	4782589	1455	SCHOOL
2	511525	4782541	1452	SCHOOL
3	511466	4782583	1467	SCHOOL
4	511489	4782629	1473	SCHOOL
1	511522	4782524	1451	INFORMAL SETTLEMENT
2	511541	4782455	1452	INFORMAL SETTLEMENT
3	511540	4782447	1455	INFORMAL SETTLEMENT

4	511450	4782499	1460	INFORMAL SETTLEMENT
5	511462	4782571	1465	INFORMAL SETTLEMENT
1	511545	4780688	1513	HEALTH CENTER
2	511584	4780771	1505	HEALTH CENTER
3	5116700	4780624	1501	HEALTH CENTER
4	511626	4780639	1497	HEALTH CENTER
5	511552	4780685	1503	HEALTH CENTER
1	511646	4780947	1519	SCHOOL
2	511690	4781234	1524	SCHOOL
3	511661	4781482	1500	SCHOOL
4	511724	4781486	1499	SCHOOL
5	511994	4781453	1491	SCHOOL
6	512290	4781300	1477	SCHOOL
7	512433	4781270	1488	SCHOOL
1	512168	4781377	1497	CADASTRAL AREA
2	511978	4781464	1488	CADASTRAL AREA
3	511710	4781507	1498	CADASTRAL AREA
4	511687	4781507	1502	CADASTRAL AREA
5	511652	4781502	1503	CADASTRAL AREA
6	511556	4781846	1493	CADASTRAL AREA
7	511529	4782037	1483	CADASTRAL AREA
8	511480	4782266	1488	CADASTRAL AREA
9	511471	4782339	1476	CADASTRAL AREA
10	511576	4782296	1475	CADASTRAL AREA
11	511596	4782265	1472	CADASTRAL AREA
12	511834	4782020	1483	CADASTRAL AREA
1	511839	4782035	1476	CADASTRAL AREA
2	511703	4782157	1473	CADASTRAL AREA
3	511536	4782368	1454	CADASTRAL AREA
4	511490	4782339	1473	CADASTRAL AREA
1	511586	4782297	1463	COMMERCIAL AREA
2	511456	4782410	1467	COMMERCIAL AREA
3	511533	4782442	1462	COMMERCIAL AREA
4	511484	4782344	1470	COMMERCIAL AREA
5	511451	4782483	1460	COMMERCIAL AREA
1	511565	4782364	1452	INFORMAL SETTLEMENT
2	511549	4782375	1453	INFORMAL SETTLEMENT
3	511543	4782397	1456	INFORMAL SETTLEMENT
4	511555	4782458	1451	INFORMAL SETTLEMENT
5	511528	4782523	1452	INFORMAL SETTLEMENT
6	511544	4782568	1455	INFORMAL SETTLEMENT

7	511539	4782703	1470	INFORMAL SETTLEMENT
8	511717	4782770	1478	INFORMAL SETTLEMENT
9	511813	4782841	1479	INFORMAL SETTLEMENT
10	511931	4782857	1478	INFORMAL SETTLEMENT
1	512497	4783261	1495	CADASTRAL AREA
2	512583	4783257	1501	CADASTRAL AREA
3	512597	4783212	1497	CADASTRAL AREA
4	512682	4783299	1493	CADASTRAL AREA
5	512965	4783324	1494	CADASTRAL AREA
6	512961	4783344	1490	CADASTRAL AREA
1	511842	4780633	1482	CADASTRAL AREA
2	512054	4780780	1496	CADASTRAL AREA
3	511954	4780764	1496	CADASTRAL AREA
4	511943	4780761	1491	CADASTRAL AREA
5	511938	4780752	1491	CADASTRAL AREA
1	511893	4780565	1487	COMMERCIAL AREA
2	511885	4780572	1486	COMMERCIAL AREA
3	511887	4780625	1479	COMMERCIAL AREA
4	511937	4780612	1487	COMMERCIAL AREA
1	511488	4782724	1476	CADASTRAL AREA
2	511503	4782708	1475	CADASTRAL AREA
3	512511	4783188	1490	CADASTRAL AREA
4	512582	4783209	1488	CADASTRAL AREA
5	512509	4783249	1502	CADASTRAL AREA
6	512587	4783269	1500	CADASTRAL AREA
1	512028	4782697	1472	CADASTRAL AREA
2	511963	4782789	1473	CADASTRAL AREA
3	511932	4782831	1480	CADASTRAL AREA
4	512400	4783109	1495	CADASTRAL AREA
5	512550	4783158	1495	CADASTRAL AREA
6	512564	4783108	1494	CADASTRAL AREA
7	512608	4783103	1487	CADASTRAL AREA
8	513334	4782802	1461	CADASTRAL AREA
9	513483	4782360	1471	CADASTRAL AREA
10	513326	4782316	1447	CADASTRAL AREA
1	512609	4783105	1486	SCHOOL
2	512587	4783129	1484	SCHOOL
3	512550	4783164	1484	SCHOOL
4	512584	4783176	1492	SCHOOL
1	512702	4783167	1489	COMMERCIAL AREA
2	512619	4783270	1504	COMMERCIAL AREA

3	512688	4783220	1489	COMMERCIAL AREA
4	512936	4783292	1483	COMMERCIAL AREA
5	512968	4783239	1474	COMMERCIAL AREA
1	512978	4783233	1479	COMMERCIAL AREA
2	512953	4783295	1477	COMMERCIAL AREA
3	513076	4783326	1484	COMMERCIAL AREA
4	513372	4783161	1482	COMMERCIAL AREA
5	513438	4783002	1481	COMMERCIAL AREA
6	513353	4782855	1460	COMMERCIAL AREA
1	513412	4782939	1466	COMMERCIAL AREA
2	513440	4783001	1471	COMMERCIAL AREA
3	513497	4782924	1477	COMMERCIAL AREA
4	513593	4782950	1475	COMMERCIAL AREA
5	513721	4782929	1474	COMMERCIAL AREA
6	513881	4782909	1465	COMMERCIAL AREA
7	513675	4782941	1479	COMMERCIAL AREA
8	513552	4782961	1476	COMMERCIAL AREA
9	513403	4783148	1486	COMMERCIAL AREA
10	513414	4783156	1486	COMMERCIAL AREA
11	513423	4783155	1483	COMMERCIAL AREA
12	513490	4783150	1480	COMMERCIAL AREA
13	513598	4783116	1469	COMMERCIAL AREA
14	513888	4782981	1461	COMMERCIAL AREA
1	513470	4782410	1459	AIRPORT
2	513448	4782455	1470	AIRPORT
3	513477	4782963	1484	AIRPORT
4	513492	4782922	1478	AIRPORT
5	513536	4782938	1477	AIRPORT
6	513812	4782898	1469	AIRPORT
7	517759	4781886	1446	AIRPORT
8	517724	4781786	1451	AIRPORT
1	519934	4780345	1452	CADASTRAL AREA
2	519891	4780528	1424	CADASTRAL AREA
3	519826	4780608	1424	CADASTRAL AREA
4	519860	4780843	1424	CADASTRAL AREA
5	519903	4780958	1427	CADASTRAL AREA
6	519521	4781036	1440	CADASTRAL AREA
7	519006	4781429	1436	CADASTRAL AREA
8	518768	4781592	1438	CADASTRAL AREA
9	518711	4781467	1438	CADASTRAL AREA
1	518736	4781391	1421	CADASTRAL AREA

2	518706	478146	1427	CADASTRAL AREA
3	518035	4781789	1448	CADASTRAL AREA
4	517900	4782068	1431	CADASTRAL AREA
5	517847	4781873	1438	CADASTRAL AREA
6	517864	4781863	1453	CADASTRAL AREA
7	517916	4782096	1448	CADASTRAL AREA
8	515319	4783013	1462	CADASTRAL AREA
9	515000	4783146	1462	CADASTRAL AREA
10	513995	4782904	1462	CADASTRAL AREA
11	513739	4783022	1462	CADASTRAL AREA
12	513648	4783116	1447	CADASTRAL AREA
13	513549	4783139	1471	CADASTRAL AREA
14	513415	4783212	1471	CADASTRAL AREA
1	519279	4781103	1446	CADASTRAL AREA
2	519353	4781174	1447	CADASTRAL AREA
3	518890	4781431	1437	CADASTRAL AREA
4	518785	4781396	1444	CADASTRAL AREA