EVALUATING ADEQUACY OF DRINKING WATER SUPPLY IN KIGALI, RWANDA.

Case study of Nyamirambo Sector

THEODOMIR BARIFASHE
Enschede, The Netherlands, February, 2014

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Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfillment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation.

Specialization: Urban Planning and Management

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Dedicated to my wife Nicole Uwera

And

My daughter Aimée Lisa Iradukunda and my son Aimé Rick Irakoze

ABSTRACT

Cities of developing countries are nowadays facing a very fast sprawl. This rapid increase of the population living in urban areas has made urban infrastructure unable to provide better services in spite of many efforts deployed by governments. However, a better planning for services delivery requires a prior knowledge of an extent at which typical infrastructure is serving the population. An evaluation of urban drinking water supply system therefore requires to consider different indicators and approach different aspects marking the study area. To investigate the performance of drinking water supply, there is a need of examining five relevant indicators. These indicators are the physical access to water supply infrastructure, duration of water supply, quantity of water accessed, quality of water, and level of affordability for water.

This research attempts to assess the levels of performance of main drinking water supply indicators in Kigali using Nyamirambo sector as a case study. The performance level for each indicator is evaluated based on standards or towards goals established by recognized organizations. Using data collected from questionnaire-based survey that target 303 households quite equally distributed in the peri-urban area, urban planned and informal areas, semi-structured interview, direct observation, and documentation, the research uses geospatial and statistical tools to detect possible patterns of drinking water supply, specifically proximity analysis tool, and descriptive statistics and spatial prediction.

Considering the diversity of the study area, the population of Nyamirambo is differently supplied with drinking water. The proximity analysis has shown a better coverage of drinking water infrastructure for 72% of households. In addition to significant differences between the peri-urban area and urban areas (planned and informal), between low and high-income groups, the population is poorly served by public water sources. Only 20% of the households surveyed are within 200 metres established as a threshold for water service in urban zones. Nyamirambo is experiencing poor performance in terms of drinking water availability. The duration of supply is generally too short (10 hours/day). Only 30% receive drinking water 24 hours a day. Its performance is high within the low-income group, and in the peri-urban area which experiences a high density of open water sources. The mean drinking water obtained per capita per day (22 litres) is also considerably below the minimum required. A high level of service exists in urban areas and within high-income households. Despite these differences, a very small proportion of households (0.6%) is getting the required quantity of drinking water. An index developed using different parameters of drinking water (0.91) shows that the quality of drinking water is not a big issue in Nyamirambo. In addition to their own treatment, 85% of households use drinking water treated by proficient service. However, urban areas and high-income households are more privileged than the peri-urban area and the low-income group. The level of affordability level for drinking water is better for 66% of households. The high performance is prevailing in urban areas and within high-income households.

Through a drinking water supply index and predicted maps, the overall performance of drinking water supply has clearly revealed a spatial and social inequity. The peri-urban area and low-income households are more significantly deprived in terms of drinking water supply than urban areas and middle and/or high-income groups. This situation requires area and/or group-based interventions to reduce such unfairness.

Keywords: *Nyamirambo sector, Kigali, evaluation, indicators of drinking water supply, adequacy of water supply adequacy*

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ABBREVIATIONS

ANOVA: Analysis of Variance

CGIS: Centre for Geographic Information Systems and Remote Sensing

EWSA: Energy, Water, and Sanitation Authority

IDW: Inverse Distance Weighting

IWS: Improved Water Source

ITRF: International Terrestrial Reference Frame

MDG: Millennium Development Goals

MINALOC: Ministry of Local Government

MININFRA: Ministry of Infrastructure

NISR: National Institute of Statistics of Rwanda

NLC: National Land Centre

NUR: National University of Rwanda

PWS: Public Water Source

UNDP: United Nations Development Programme

UN-HABITAT: United Nations Human Settlements Programme

UNICEF: The United Nations Children's Fund

USAID: United States Agency for International Development

UWS: Unimproved Water Source

USGS: United States Geological Survey

WGS: World Geodetic System

WHO: World Health Organization

WSI: Water Supply Index

1. GENERAL INTRODUCTION

1.1. Introduction

Water is one of the most important necessities for the human life. Without water, life can neither start nor continue (Chaplin, 2001). Access to safe drinking water is therefore a basic need for human beings. The provision of safe drinking water is fundamental to health and well-being improvement and therefore an important component of development (Corinne J. Schuster-Wallace et al., 2008; UN-HABITAT, 2013).

However, access to safe water remains one of the biggest challenges all over the world. Despite continuous improvement in terms of drinking water supply, about 884 million people still do not get drinking water from improved sources all over the world (World Health Organization, 2012). The difference between the number of people in developed and developing countries having access to safe water is increasing (Aiga & Umenai, 2003). Over a third of this unserved people are found in Sub-Saharan Africa, where only 60% of the population have access to safe water (World Health Organization, 2012).

In addition to significant disparities existing between rural and urban areas, spatial inequality in water supply is also prevailing in African cities. Because of high population growth and spatial extension of cities, increase of general households' living conditions, inappropriate planning policies, etc., some neighbourhoods are facing the lack of sufficient infrastructure. The level of water service and infrastructure provision is especially low in informal settlements and/or poor areas (Daniere & Takahashi, 1999; Martínez et al., 2008).

1.2. Background and justification

Urbanization is a main transformation that is taking place all over the World. Today, more than half of the world population live in urban areas (International Federation of Surveyors, 2010). The rapid urban growth in developing countries is mainly accentuated by the natural urban population growth, and rural-urban migration.

Cities of developing countries are nowadays facing the problems related to their rapid spatial development and rapid population growth. The demand for urban services is increasing, and existing infrastructure is unable to provide fully services to the urban population. In addition to low capacity of infrastructure to accommodate such fast growing population, the distribution of infrastructures is not fair.

In Sub-Saharan cities, the problem was also accentuated by the introduction of water services provision operating on commercial basis despite the increase of poor people (Dagdeviren & Robertson, 2011). Thus, people living in slums are not able to pay for services provided.

1.2.1. Urbanization of Kigali

The city of Kigali is the administrative and economic capital of Rwanda. It is nearly situated in the centre of Rwanda. Its landscape is characterized by a contrasting topography marked by the existence of plateaus in the southern part and a range of mountains. Kigali has experienced a high population growth, about 4.0%. During the last decade, the population of Kigali has increased by about 48.4%. It is now populated by about 1, 335,428 persons (Republic of Rwanda, 2013). The administrative boundary of Kigali is quite different from the urbanized area. The later covers 90.24 km^2 (12.5 percent) whereas the whole city occupies 726.83 km^2.

Table 1-1: Expansion of urban space and population growth of Kigali

Year	1962	1984	1999	2005	2010
Population	6,000	164,173	354,273	566,089	1050145
Built-up (km^2)	3	15.9	45.13	65.63	90.24
Population density	2,000	10,325	7,850	8,625	11,637

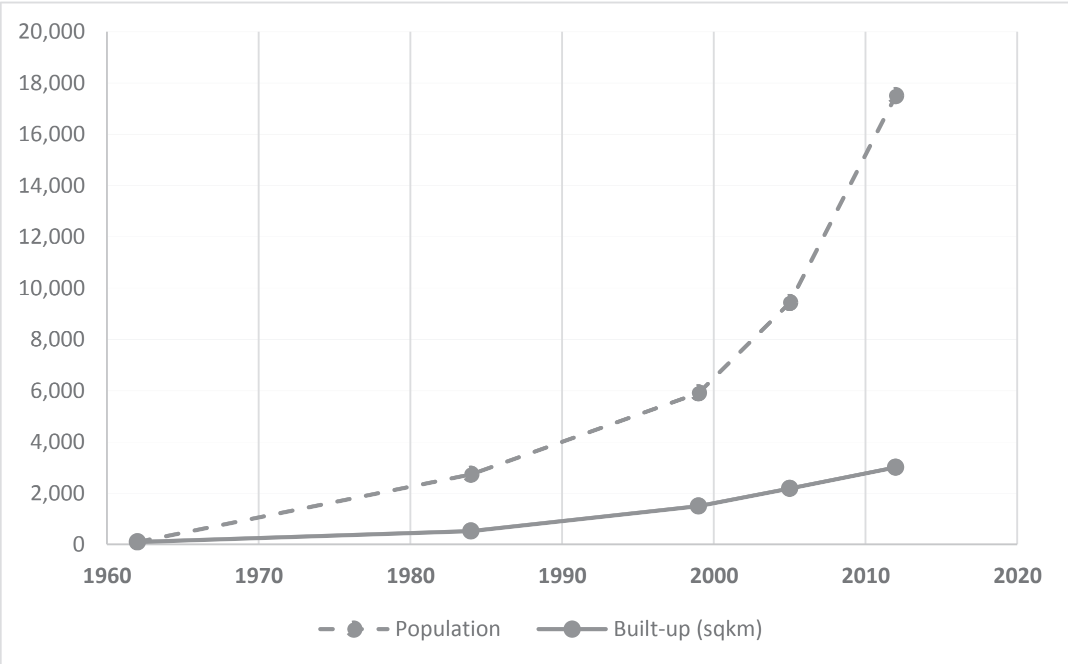


Figure 1-1: Evolution of the population and built-up area of Kigali

As shown by **Figure 1-1**, the evolution of the population is characterized by a high slope compared to the expansion of the urban space. This rapid increase of the population of Kigali has considerably affected the level at which the population is provided with services, especially by urban infrastructure. The most affected population is the one who is living in slums. About 13% of people living in Kigali are under the poverty line (UN-HABITAT, 2008). Many inhabitants who live in slums and peri-urban areas in Kigali City do not have access to adequate infrastructure services, drinking water infrastructure included.

1.2.2. Drinking water supply in Kigali City

The inhabitants of Kigali are supplied with water from three main types of improved drinking-water source systems, namely (1) piped water from the public utility that operates on commercial basis, (2) protected dug-wells, boreholes, hand pumps, and (3) rainwater collection. The piped water supply is the most dominant source of drinking water in urbanized areas of Kigali. The Energy, Water, and Sanitation Authority (EWSA) is a public utility in charge of the provision of piped water all over the country. It delivers drinking water in two forms, namely houses' direct connections, and water kiosks. The city of Kigali is at present divided into seven water service areas, namely Remera, Kanombe, Kacyiru, Nyarugenge, Nyamirambo, and Muhima.

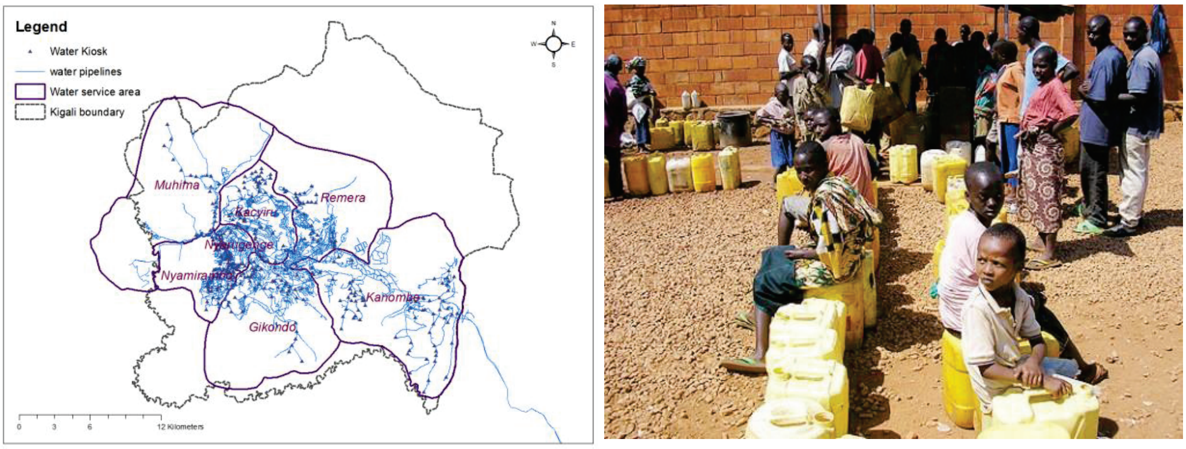


Figure 1-2: Coverage of drinking water infrastructure managed by EWSA in Kigali, and people queuing at water tap

Water Service Areas are defined by the public utility in charge of Energy, Water, and Sanitation Authority (EWSA) in Rwanda. They are not covering the whole administrative Kigali City. Their boundaries are fixed based on the extent of water supply infrastructure. Some peri-urban/rural areas of Kigali are until now excluded in the service areas of the public utility.

This growth has significantly affected water provision. As illustrated by **Figure 1-2**, some areas of the city are therefore struck by the shortage of drinking water, and water is not continuously provided to the whole city (KigaliConnect, 2012). This situation has negatively affected the daily life of many people living in the city, especially children who are mainly supposed to fetch for the water for the family.

The quality of water supplied constitutes an issue as all improved drinking water are not reliable. This is the case of drinking water supplied directly from the boreholes. According to the Ministry of Infrastructure (Republic of Rwanda, 2010), the main target was to provide safe water at affordable cost to the whole urban population (100%) within 200 m of an improved source by 2012. Urban water supply system in Kigali is dominated by a customer-driven service. The population gets water services when they are able to pay for it. Considering this prevailing situation, it is quite possible to find great differences in access to drinking water given that Kigali is also populated by poor people, especially in slums and peri-urban areas.

1.3. Research problem

After the 1994 genocide, Rwanda tried to develop the national economy through different programs. Adequate water supply has been considered by the Rwandan government as one of the important drivers for social and economic development, and good public health. Rwanda has therefore committed itself to reach an ambitious target in access to clean drinking water with the vision, starting from 44% in 2005, to attain 95% by 2015, and 100% service coverage by 2020 (Republic of Rwanda, 2010).

To improve urban water supply in Kigali, different actions have been taken such as reviewing of water tariff to improve operational performance, updating water supply master plan, developing pro-poor programs to serve low-income households by public kiosks and social connections (The World Bank, 2010). Despite all these measures, many authors (Kamuzinzi, 2013; KigaliConnect, 2012; Republic of Rwanda, 2010; The World Bank, 2010) proclaimed that some areas of Kigali City are still experiencing the lack of safe water. Even areas covered by the water supply infrastructure face the problem of water scarcity, and are therefore struck by a high and unexpected increase of water prices (Gideon, 2013). In order to evaluate the level at which the population of Kigali city is supplied with safe drinking water, we need to know if the population of Kigali is continuously provided with reliable, affordable water services, sufficient quantity of drinking water within an acceptable distance.

However, drinking-water supply in Kigali has not been submitted to the assessment that integrates key indicators of drinking-water provision to the population. There is therefore a need to appraise the extent at which drinking water is supplied to the population of Kigali City using Nyamirambo sector as a case study.

1.4. Research objectives and questions

This research aims to assess the adequacy of drinking water supply in Kigali, using Nyamirambo sector as a case study.

Specific objectives and research questions

To achieve the main objective mentioned above, this research focused on specific objectives and research questions given in **Table 1-2**.

Table 1-2: Research specific objectives and questions

Specific objectives	Research questions
To analyse the physical access to drinking water supply infrastructure	What is the coverage of drinking-water supply infrastructure?
	How many households are potentially serviced by drinking water infrastructure?
To examine the availability of drinking water	What is the duration of supply of drinking water?
	What is the quantity of water accessed per capita per day?
To determine the quality of drinking water supplied	What is the quality of drinking water supplied?
To evaluate the affordability for drinking water in the study area	What is the proportion of people affording the cost of drinking-water services provided?
To compare the achievement levels of drinking-water supply indicators	At which extent are indicators of drinking-water supply performing?

1.5. Research design

This section provides an overview of how the research was conducted. It gives an outline of research stages, used methods to collect and analyse the data, and outcomes of each step of the research.

This research was conducted in three main phases: the pre-fieldwork period, fieldwork period and post-field period. The pre-field period consisted of two main activities: development of the research proposal and preparation of the fieldwork. This period was essentially devoted to the identification of the research problem, definition of research objectives and questions, development of a conceptual model, development of a sampling strategy, construction of the questionnaire, and practical preparation of fieldwork.

The fieldwork period consisted of data acquisition. Two main types of data were collected: primary data and secondary data. The primary data were collected through a questionnaire-based household survey, semi-structured interviews, and observation. Secondary data was collected from different official services in charge of water supply or statistics.

The post-fieldwork period was devoted to the preparation of collected data for the analysis, data analysis, results discussion or interpretation, conclusion and recommendations drawings, writing and final editing of the thesis. **Figure 1-3** shows research steps followed, methods or techniques used, and outcomes of each step.

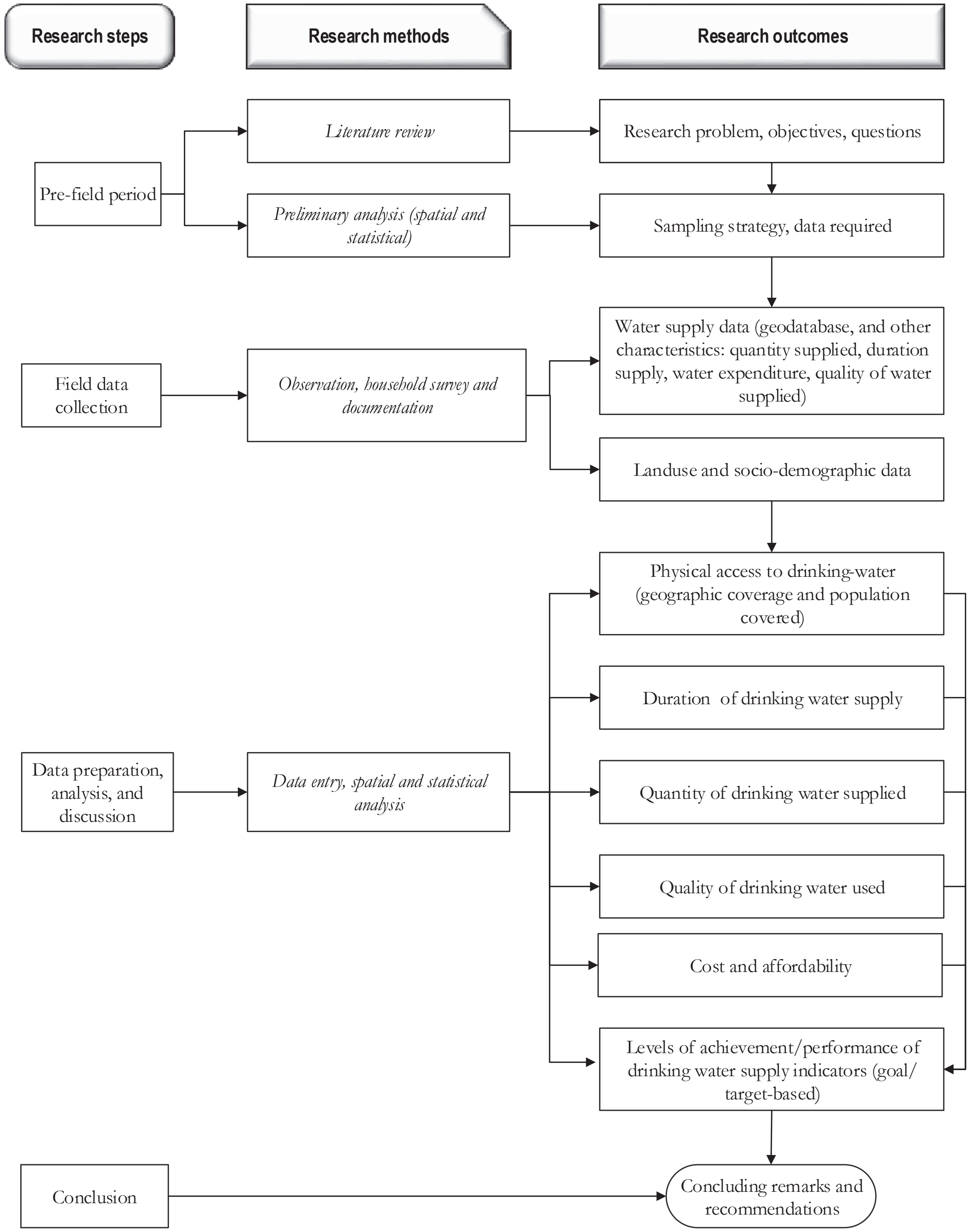


Figure 1-3: Research steps, methods, and outcomes

1.6. Research matrix

The following research matrix (see **Table 1-3**) gives a set of specific research objectives, associated research questions, input data needed, data sources, and applied methods/techniques for the analysis.

Table 1-3: Research matrix

Specific objective	Research question	Input data	Data source	Methods/techniques for data analysis
To analyse the physical access to drinking-water supply infrastructure	What is the coverage of drinking-water supply infrastructure?	Location of households	Extracted from orthophotos of 2009 (NLC), household survey	Proximity analysis with ArcGIS, descriptive statistics, one-way ANOVA and Tukey post-hoc tests
		Water supply infrastructure	EWSA, field observation	
		Administrative map of Rwanda	CGIS-NUR	
	How many households are potentially serviced by drinking water?	Distance to water source	EWSA, field observation	Descriptive statistics, one-way ANOVA and Tukey post-hoc tests
		Population of 2012	NISR	
To examine water availability	What is the duration of water provision per day?	Duration of supply	Questionnaire based-household survey	Descriptive statistics, one-way ANOVA and Tukey post-hoc tests
	What is the quantity of water accessed per capita per day?	Quantity of water accessed	Questionnaire based-household survey	Descriptive statistics, one-way ANOVA and Tukey post-hoc tests
To determine the quality of drinking water supplied	How is the quality of water supplied?	Quality of water supplied	Household survey, semi-structured interviews,	Descriptive statistics, one-way ANOVA and Tukey post-hoc tests
To explore the affordability for drinking water service	What is the proportion of people who are not affording the cost of drinking water?	Level of affordability	Household survey	Standardization, descriptive statistics, one-way ANOVA and Tukey post-hoc tests
To compare the achievement levels of drinking water supply	At which extent are the indicators of drinking water supply performing?	Standardized values of drinking water supply indicators	Outputs related to drinking water supply indicators	Standardization, comparative analysis (spider chart), spatial prediction (interpolation)

1.7. Thesis structure

The thesis consists of six chapters. It is composed of the general introduction, description of the context and concepts of drinking-water supply, description of the study area, the research methodology, the presentation of research results and discussion, the conclusion, and recommendations.

The first chapter gives the background and justification of the research, the research problem, the research objectives and questions, the research design, and the structure of the thesis. The second chapter gives the context of access to drinking water in cities of developing countries, sub-Saharan African cities, and Rwanda. It also gives the definitions of main concepts and description of the conceptual mode of the adequacy of drinking water supply.

The third chapter includes the description of administrative structure, physical environment, socio-economic aspects of the study area, and an overview of drinking water supply in the study area. The fourth chapter deals with the methodology. It describes different steps or procedures followed and methods or techniques used to collect and analyse data, to present and interpret results.

The fifth chapter gives the outcomes of the analysis and the discussion. It provides the detailed information about performance levels of each indicator of drinking-water supply, outputs of comparative and integrated assessment, and the prediction of performance levels of main indicators in the study area. The sixth and last chapter consists of concluding remarks and recommendations.

2. CONTEXT AND CONCEPTS OF DRINKING WATER SUPPLY

2.1. Introduction

This chapter gives definitions and description of main concepts and systems related to the topic. First, it provides definitions of drinking water supply indicators, and the conceptual framework. It furthermore gives the general state of drinking water supply in cities in general, access to drinking water in African cities and in Rwanda.

2.2. Access to drinking water infrastructure services in developing countries

Decent health, economic efficiency and quality of life in a city is a result of adequate access to basic services (Daniere & Takahashi, 1999). Adequate drinking water supply, sanitation, power supply, sufficient transport network, and information technologies are elements that bring the city to its economic progress, and improve the wellbeing of its population. In principle, urban infrastructure services provided to the population have to be efficient, safe, and affordable (Gerlach & Franceys, 2010).

Even if water constitutes one of the most important services to provide to the population, a big number of people lack access to safe water all over the World. The provision of safe drinking water to the population requires the establishment of a water supply system, and the consideration of the population capacity. In urban areas, the rapid urbanization causes an imbalance between services demand and supply. The demand for water has increased faster than the capacity of infrastructure, and many people are still getting water from unimproved sources (United Nations, 2013) despite many efforts deployed by African governments to "*Halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation*" as by the Millennium Development Goals, target 7.C (Dagdeviren & Robertson, 2011)

2.3. Access to safe water in African cities and Rwanda

Improved drinking water infrastructure is still covering a low proportion of the population in sub-Saharan countries. This situation is marked the occurrence of diseases associated with the use of unsafe drinking water, such diarrhoea (Ntouda et al., 2013). In addition to this global low level of water services (Cohen, 2006), the delivery of urban water infrastructure is also characterized by regional disparities. These dissimilarities result from the diversity of levels of economic development levels, the level of urbanization, and the political will. African cities have the lowest level of urban infrastructure provision. Even the statistics show that about 89 per cent of the urban population are supplied in water in African cities, many Sub-African cities are regularly experiencing water scarcities (UN-HABITAT, 2013).

Based on guidelines detailed in National Policy and Strategy for Water Supply and Sanitation Services (Republic of Rwanda, 2010), the physical access to drinking water is acceptable if households are located within 200 meters from an improved source of drinking water in urban areas, and 500 metres in rural areas. Water might be supplied continuously, and the quantity used per capita per day is sufficient when it is at least minimum 80 litres. The price has to affordable for all people without any exclusion. Despite this programme that aims to improve the level of drinking water service, the access to drinking water is still a big challenge in Rwandan cities, Kigali included. Big drinking water supply system is operating on market-oriented basis. The urban population has to pay for all water services provided by the utility. Only a small proportion of households rely on community-run systems, but water services provided are not very reliable.

As mentioned in the next section (chapter 5), community-based water supply system is generally characterized by a low service level in terms of water quality.

2.4. Definitions and performance indicators of drinking water supply

2.4.1. Drinking water and improved water sources

Drinking water must be free from all kinds of matter that could be dangerous to human health. It must be free of suspended particles, bad taste, colour, and smell. Drinking water is considered as safe when its quality is in accordance with WHO guidelines or national standards (Word Health Organization, 2011). Drinking water is called “potable” when is both safe and acceptable (USAID, 2013).

Are considered as improved all drinking water sources that are constructed in such way that any pollution from outside cannot reach its water. This mainly concerns faecal matter that constitutes the most contaminant of drinking water. **Table 2-1** gives a detailed list of improved and unimproved water sources

Table 2-1: List of improved and unimproved water sources

Improved water sources	Unimproved water sources
Piped water into dwelling, plot or yard	Unprotected dug well
Public tap or standpipe	Unprotected spring
Tubewell or borehole	Cart with small tank or drum provided by water vendor
Protected dug well	Surface water (river, dam, lake, pond, stream, canal, irrigation channel
Protected spring	Tanker truck provision water
Rainwater collection	

Source: Word Health Organization (2012a)

2.4.2. Performance indicators for drinking-water supply and variables

There is a set of many indicators used to evaluate the performance of urban water supply. Depending on goals, some indicators are used to assess the level to which drinking-water supply infrastructures are providing services to the population as specified by fixed norms or standards, others are used to know if the system itself is maintained at the highest level of performance.

When analysing the case of access to water in Dar es Salaam, Smiley (2013) took into consideration 4 indicators: the location of water sources, the reliability of the supply, the quality of water and the cost of water. On the other hand, The World Health Organization (2011) recommends the use of five indicators to assess the adequacy of drinking water supply such as accessibility, continuity or duration of supply, quantity of water supplied, quality of water supplied, and affordability. To evaluate these indicators, benchmarks were established (see **Table 2-3**).

2.4.2.1. Accessibility

The accessibility of drinking water or **physical access** to drinking water supply infrastructure is defined in terms of time spent or the distance travelled to get to water sources (Lamichhane & Mangyo, 2011; Word Health Organization, 2011). Physical accessibility is also determined by the proportion of people within acceptable distance or travel time (Cross & Morel, 2005). As shown in **Table 2-2**, The World health Organization has given guidelines defining different service levels based travel time and/or distance. Only households with house connection are considered as the ones who have intermediate and optimum access to water services. Households within one kilometre are considered to have basic service. However, the

World Bank and the Government of Rwanda have a different threshold. Only households within 200 metres from an improved water source are well served (Alexander et al., 2005; Republic of Rwanda, 2010).

2.4.2.2. Water availability

Water availability involves the ***quantity of drinking water supplied per capita per day***, and the ***continuity or duration of supply***. To ensure self-sufficiency for the household, each Rwandese may be supplied with at least 20 litres per day in rural areas, and 80 litres in cities, and the supply might be continuous (Republic of Rwanda, 2010). As detailed in Table 2-2, the World Health Organization does not make any distinction between rural and urban areas in terms of the quantity of drinking water used per capita, but a person is having an optimum access drinking water when he uses between 100 and 200 litres per day (Word Health Organization, 2011). Water availability is generally indicated by the capacity of drinking-water supply infrastructure.

Table 2-2: Service level and quantity of water collected

Service level	Distance/time	Volumes of water
No access	More than 1km/ more than 30 minutes round-trip	very low: 5 litres per capita per day
Basic access	within 1km/within 30 minutes round-trip	approximately 20 litres per capita per day on average
Intermediate access	water provided on-plot through at least one tap (yard level)	approximately 50 litres per capita per day
Optimal access	supply of water through multiple taps within the house	100 – 200 litres per capita per day on average

Source: Word Health Organization (2011)

2.4.2.3. Drinking water quality

The quality of drinking water involves different parameters to be taken into consideration. As mentioned in different study cases (Howard & Bartram, 2005; John et al., 2013), the quality of drinking water is also deteriorated even after the treatment operated by the supplier. In addition, the deterioration within the distribution network, drinking water is also contaminated when it is subjected to households poor storage of water.

a) Drinking Water quality verification

The framework for safe drinking Water suggested by the World Health Organization (2011) propose a regular checking of water to ensure the protection of public health. This action consists of verification of physical, microbiological, and chemical properties of water provided to the population. The assessment is based on or national Water Safety Approved or guidelines established by the World Health Organization (Word Health Organization, 2011). This constitutes an important factor given that water from many improved water sources is also not reliable, and as a result the statistics about people who have access to safe water are expected to be less than those provided officially (United Nations, 2013).

The verification of physical properties of drinking water looks at the turbidity, total dissolved solids, hardness, temperature, pH, dissolved oxygen, taste, odour, and colour. Contrarily to other parameters, there are not health-based values established for temperature, taste, odour, and colour. The detection of taste, colour and odour in drinking water only indicates the presence of unwanted substance (organic or inorganic)in water (John et al., 2013).

The inspection of biological contaminants looks at the potential existence of microorganisms that can negatively affect human health such as bacteria, viruses and protozoa (David Suzuki Foundation, 2006). Most of these pathogens originate from human and animal faeces, and the protection of drinking water from them requires water treatment and good maintenance of water distribution infrastructure (Word Health Organization, 2011).

In addition to microbiological contaminants, drinking water is also submitted to chemical contaminations that are also harmful to human health. Chemical contamination of drinking water comes essentially from naturally occurring chemicals, industrial waste and human dwellings, agricultural activities, water treatment or materials in contact of drinking water, and pesticides used in water for public health. All these motioned chemicals become dangerous when they are excessively concentrated in drinking water (Word Health Organization, 2011) (see Appendix 3 for more detailed information).

b) Drinking water treatment

In most cases, drinking water treatment consists of different approaches used to remove unwanted physical, chemical and biological substances from the water to the levels that cannot cause any infection to humans (Gadgil & Derby, 2003; Gordalla, 2011; Karavoltsos et al., 2008; Word Health Organization, 2011). As it is established by WHO guidelines or national standards. It includes five processes, specifically coagulation, flocculation, sedimentation, filtration, and disinfection.

Coagulation refers to the process of enabling the formation of larger particles suspended in water by adding chemicals such as alum in drinking water, whereas the flocculation consists of mixing small particles suspended in water and bring them into larger ones to allow them to settle out of the water as a sediment. The sedimentation is a physical process consisting of removing suspended solid particles from drinking water. This process only applies to particles whose size is not less than 10 µm.

The filtration involves the removal of all kinds of turbidity in drinking water, but not microbiological contamination (faecal pathogens). It therefore facilitates the disinfection of drinking water. Disinfection consists of removing pathogens that can affect human health. Boiling, chlorination, ultraviolet (UV) disinfection are the most techniques used to disinfect drinking water (Gadgil & Derby, 2003). The use of chlorine is not totally effective for removing all pathogens, especially when the turbidity is high (Word Health Organization, 2011).

2.4.2.4. Affordability

The affordability, according to Fankhauser and Tepic (2005), is more than the willingness to pay or low cost of service provided. Affordability is therefore considered as "the ability of consumers or consumer groups to pay for a minimum level of service" (Fankhauser & Tepic, 2005, p. 4). Because of low income, some consumers could not be able to pay for services at low cost. Affordability for water supply is therefore mostly based on the proportion of water expenses by household income (Gawel et al., 2013). For that reason, the benchmark as an acceptable level of expenditure for basic utility services has been set.

According to Guy Hutton (2012), affordability criterion is economically expressed by an "Affordability Index" which makes comparison between monthly water cost and household income. The affordability implies therefore the ability of consumers to pay water tariffs or connection fees. To determine the level of affordability different thresholds have been established.

The United Nations Development Programme (UNDP) has adopted 3 per cent of the total household income, the Organization for Economic Cooperation and Development has approved 4 per cent, whereas the World Bank and the Asian Development Bank consider 5 per cent (Gawel et al., 2013; Guy Hutton, 2012). However, affordability indices differ from region to another. In Africa, the affordability index generally varies between 2.8 and 7.5 per cent for poor and median households supplied by public water infrastructure, whereas 6 per cent is accepted as an acceptable affordability index in Latin America because it doesn't go beyond 10 (Guy Hutton, 2012).

Table 2-3: List of benchmarks used to measure drinking water supply indicators

Indicator	Benchmarks	Level of service	Organization
Physical access	0-200 metres	Good service	Rwandan Government (2010)
	0-500 meters		WHO (
	500-1000 metres		WHO
Duration of supply	24 hours/day		Rwandan Government and WHO
Quantity of water	80 litres		Rwandan Government
	120 litres	optimum	WHO
Water quality	100%	Absence of pathogens and chemical contamination)	WHO
Affordability	3-5%		World Bank
	3%		UNDP
	5%		ADB

2.5. Conceptual framework

To know if the water supply infrastructure is adequately providing drinking water service to the population within its coverage, one scientific approach is the assessment of a set of relevant water supply indicators. The World Health Organization (2011) and many other authors (Fankhauser & Tepic, 2005; Gawel et al., 2013; Hofmann, 2005; G. Hutton, 2013; Kayser et al., 2013; Nauges & Whittington, 2010; Ntouda et al., 2013; Phansalkar, 2007; Smiley, 2013) have revealed an exhaustive list of benchmarks (**Table 2-3**) to use to assess the level of performance of drinking water supply indicators. As detailed by **Figure 2-1**, the appraisal of adequacy of drinking-water supply takes into account relevant water service features such as accessibility or physical access, water availability, quality of water supplied, and affordability.

The physical accessibility shows at which level the people are covered by water supply infrastructure. It indicates the relation between locations of households and locations of water supply infrastructure (pipelines, private and public taps, etc.). Accessibility considers the level of coverage of direct water supply connections. The concept of the availability of water includes the quantity of water supplied (per capita per day) and the duration or continuity of supply. The affordability looks at the ability of consumers to pay the cost of water supplied. The frequencies of water quality verification, techniques used to measure and treat water supplied are main indicators used to assess the quality of water provided to the population

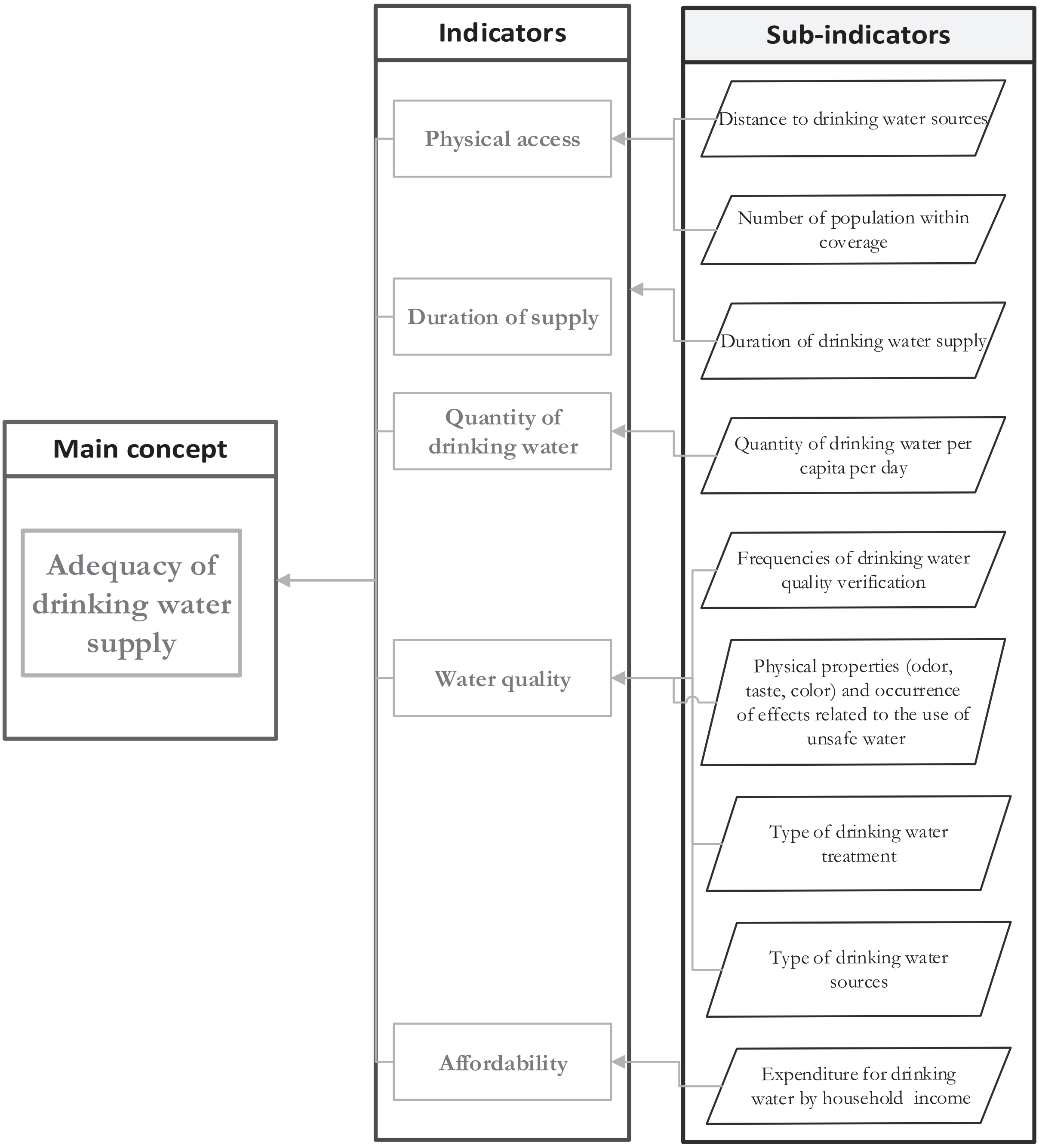


Figure 2-1: Conceptual framework of the adequacy of drinking-water supply

2.6. Concluding remark

Cities of developing countries and sub-African ones particularly, are experiencing very rapid urban growth that is affecting the extent at which the urban infrastructure is providing basic service to the population. This chapter had detailed the context of access to drinking water in urban areas of developing cities, particularly in sub-African cities and Rwanda. It had also explained main drinking water supply indicators such as physical access, duration of supply, quantity used, quality of water and level of affordability. The section ends up giving the conceptual framework that involves all indicators and associated variables, which explain the adequacy of drinking water supply system.

3. DESCRIPTION OF STUDY AREA

3.1. Introduction

This chapter aims to make a detailed description of Nyamirambo as the study area. It gives successively the location of the study area in Nyarugenge District and the whole City of Kigali, its administrative organization and boundaries, exhaustive description of physical conditions, socio-demographic situation, and depiction of drinking water supply system of the study area. Nyamirambo sector was selected as the study area based on its characteristics that reflect main aspects of the City of Kigali as it is fully explained in chapter four.

3.2. Location and administrative structure of the study area

As mentioned above, the City of Kigali is made of three Districts, i.e. Gasabo, Kicukiro and Nyarugenge. Nyamirambo sector is one of 10 sectors composing Nyarugenge District. It is located in the west-central part of the District. It is bounded by six sectors, namely Mageragere, Kigali, Nyakabanda, Rwezamenyo, Nyarugenge, and Kigarama (Kicukiro District). The study area covers about 8.94 km². It is subdivided into four cells, i.e. Cyivugiza, Gasharu, Mumena, and Rugarama. Cells are divided into 33 villages. **Figure 3-1** shows the location of the study area in the City of Kigali and its administrative boundaries.

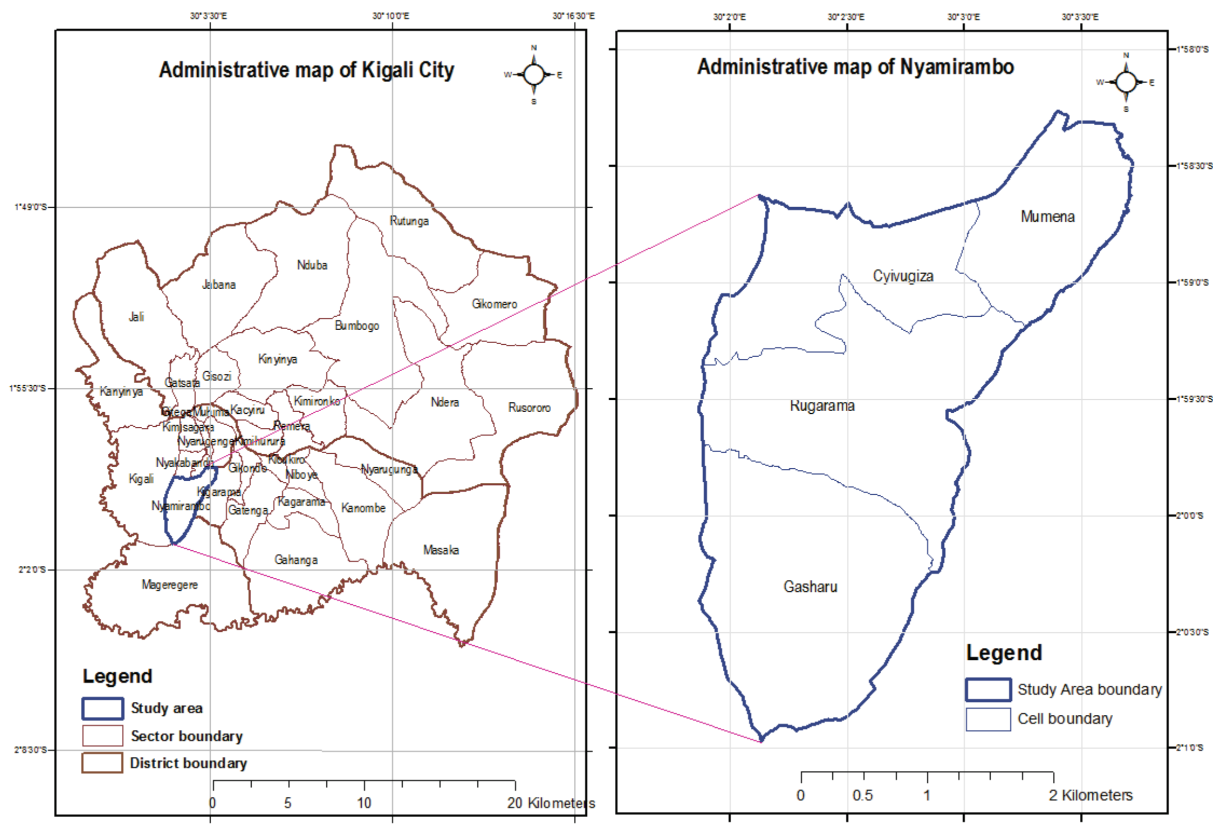


Figure 3-1: Location and administrative boundaries of the Study area in Kigali City

3.3. Physical environment

Nyamirambo sector is located on the eastern side of Kigali mountain range. Its landscape is developed in the quartzitic substratum like its surroundings. Its slope reaches 1575 meters; its altitude varies between 1793 meters and 1369 meters. The talwegs are generally wide and not drained by rivers. They are almost dry, except the part of wetland located in the south-east of the study, which is flooded during the great rainy season. **Figure 3-2** gives elevation features of Kigali City and the study area.

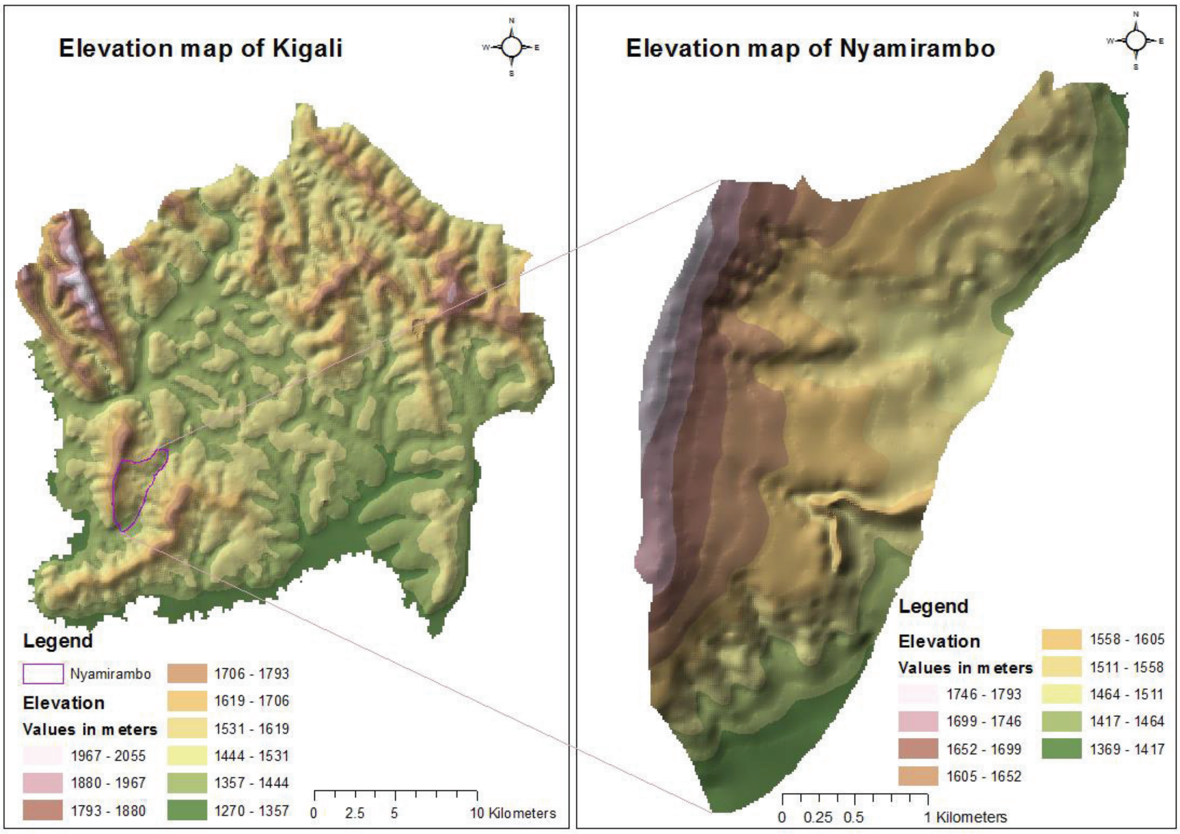


Figure 3-2: Elevation maps of Kigali and Nyamirambo sector.

3.4. Infrastructure and land use

The land use of Nyamirambo is categorized into two main groups: urbanized area and peri-urban area. Based on settlement characteristics, the study area is subdivided into three categories, specifically planned and informal settlements in the urbanized area, and scattered settlement in the peri-urban area. Urban planned and informal areas are characterized by high density of buildings and infrastructure, whereas the peri-urban area is marked by the scattered settlement inside land reserved for agricultural activities.

Given its position in the City of Kigali, Nyamirambo sector is differently covered by urban infrastructure. The later predominantly consists of roads, water supply infrastructure, electricity, schools, trade centres, etc. Road network density is significantly denser in the urbanized area than in the peri-urban area (9.62km/km^2 against 3.53km^2). The study area is also covered by drinking water supply, electricity network, schools, trade centres, etc. Nyamirambo sector itself lodges 7 primary schools, two secondary schools, and one small trade centre. **Figure 3-3** shows the distribution of road network, schools, trade centres and the land use in Nyamirambo sector.

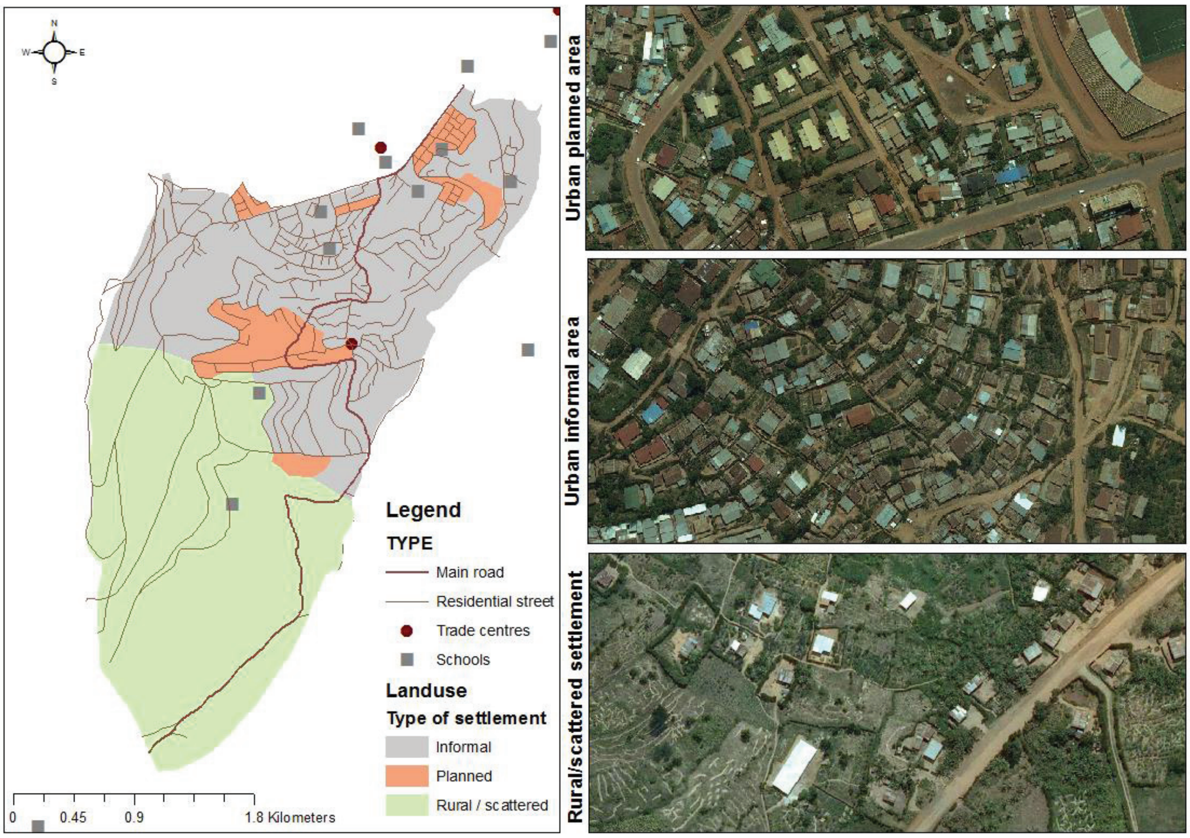


Figure 3-3: Road network and main characteristics of land use and its structures in the study area

3.5. Drinking water supply in Nyamirambo

Drinking water supply infrastructure of Nyamirambo sector belongs to two types of water supply systems, namely the public drinking water supply system managed by the public utility, and open improved water sources under the control other local community and/or the District of Nyarugenge. **Figure 3-4** displays the spatial distribution of main elements of drinking water supply system in Nyamirambo sector and its surroundings.

3.5.1. Distribution of drinking water supply infrastructure and its management

The population is supplied with piped potable water by the public utility in two ways: household and public connections. All water services provided by the utility are customer-based. Private connection service is totally dependent on the purchase power of the customer, while water kiosks are set up where the supplier considers as a place covering customers as many as possible and being at an acceptable distance from the main pipeline. The cost of service is fixed by the utility and only dependent on the distance at which the customer is located. The customer pays the total cost involved in water connection. The utility only covers the cost of repairing and replacing reservoirs, main pipes, and water kiosks.

In addition to piped water supplied by the public utility, there are two hand pumps, one borehole/tubewell, and two water stand taps (kiosks). This type of drinking-water supply was set up by public and/or non-governmental projects, and it is now managed by the local community. Only the water from hand pumps and protected spring are free of charge. **Figure 3-4** shows the distribution of main elements of the drinking water supply infrastructure in Nyamirambo.

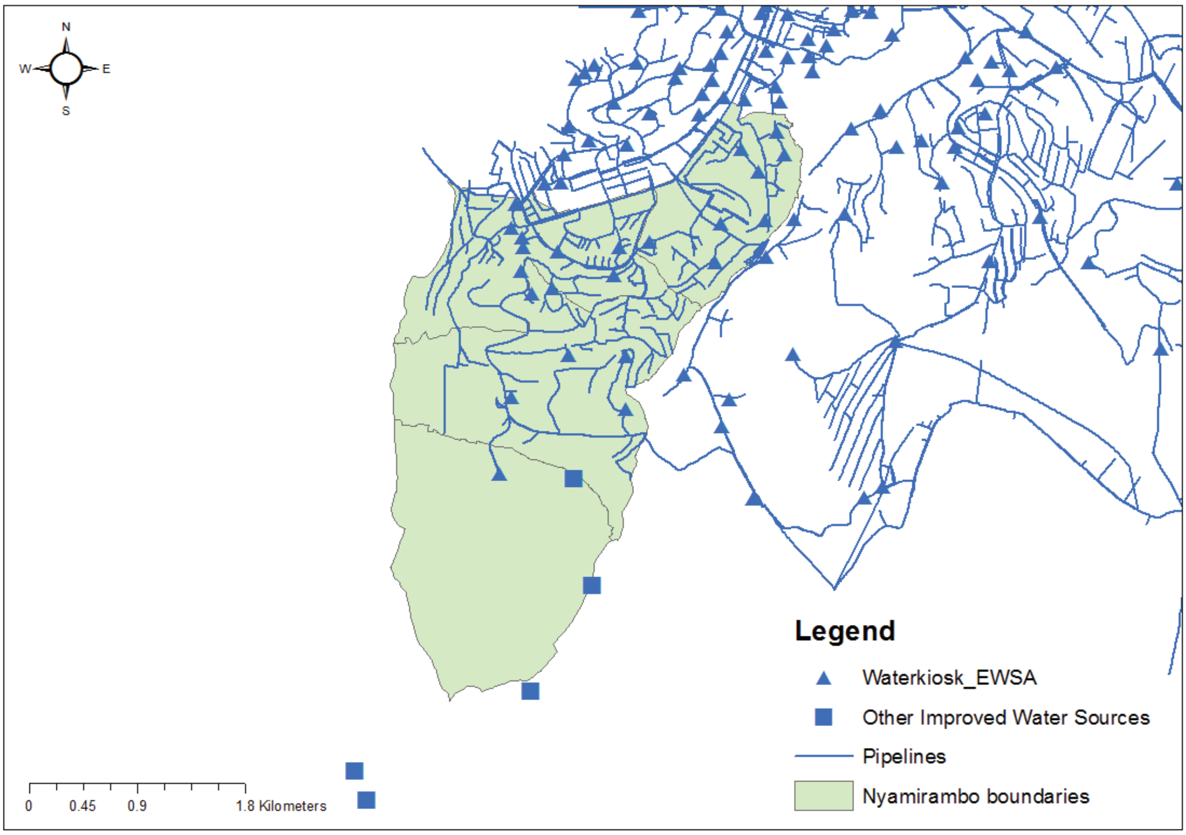


Figure 3-4: Distribution of drinking water infrastructure in Nyamirambo

As shown by **Figure 3-4**, there is a spatial disparity in distribution of drinking water supply infrastructure in the study area. The south-west part is poorly provided in water infrastructure, both the piped water system of the public utility and other improved water sources.

3.5.2. Drinking water treatment, production and quality verification

Before the distribution of drinking water to the population, the supplier might first check and treat water (if required). The treatment of water distributed, and regular checking of water quality is done only by the public Utility.

Drinking water distributed in Kigali by the Public Utility "EWSA" is treated at Kimisagara Plant and its connection units, specifically Karenge Plant and Nzove Plant. Water distributed in Nyamirambo is treated and distributed by Kimisagara Plant (see **Figure 3-4**). Water treatment consists of checking of the quality of raw water and adjusting it to the standards of the World Health Organization (WHO). Four parameters, namely turbidity, pH, hardness, and total coliforms, are taken into consideration during the process of water quality checking. Sulfate, lime, chlorine, sodium, chlorine, and polymer are the main chemicals used to treat water.

At Kimisagara Plant, the treatment of raw water consists of five processes such as coagulation, sedimentation, filtration, disinfection and storage. Coagulation consists of eliminating mud and other elements suspended in raw water. The sedimentation is a process by which suspended elements settle out of the water. Then, cleared water moves through filters, and even smaller elements are taken away. Before being distributed in the network by pumps, water from the filters is decontaminated by adding chlorine to destroy microbes or microorganisms that could possibly be in water, and stored in big reservoirs.

The quality of raw water is constantly verified at the entry of the treatmentplantt. The quality of treated water is verified at the distribution point (pumps) in the plant and in the distribution network. Within the distribution network, the samples for quality verification are taken each day at secondary distribution points and at the last point of water distribution, the standpipe in order to verify if the water supplied was not contaminated along the distribution pathway.

Figure 3-5: Infrastructure of Kimisagara water treatment plant

3.5.3. Population characteristics

According to the most recent census results (Republic of Rwanda, 2013), Nyamirambo sector was populated by 40,388 people in 2012. Females are more representative than male; the sex ratio was evaluated to 102. The average annual growth rate, from 2002 to 2012, is appraised to 4.7 per cent. Based on that, the population of Nyamirambo is now estimated to 42,234 people. Its population shows a high diverse spatial distribution. The population density, people per square kilometre, at village level varies from 647 to 16,908. High population densities are generally observed in more urbanized residential areas, whereas the centre and south are less densely populated.

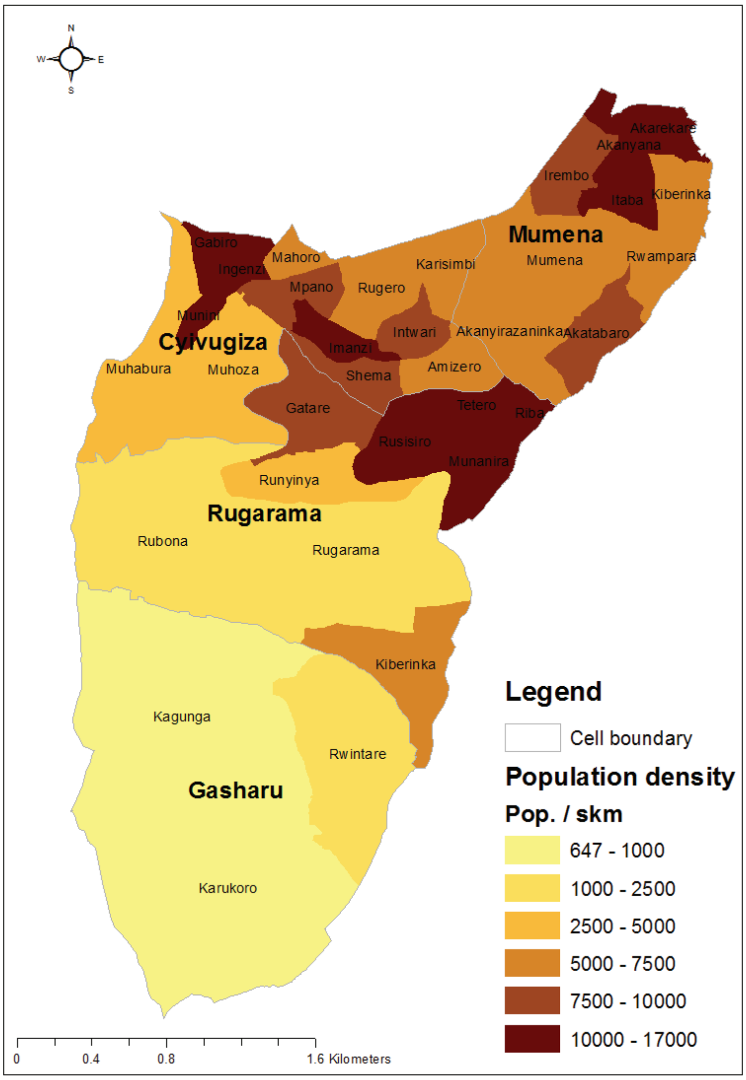


Figure 3-6: Population density in Nyamirambo

As shown by the map above (**Figure 3-6**), a large zone of the peri-urban area registers a low population density. This is the case of two out of three villages of Gasharu Cell which are characterized by a population density less than 1000 people per square kilometres. Despite some disparities, high population densities are observed in all cells of the urbanized areas (planned and informal) of Nyamirambo sector.

3.6. Concluding remark

In addition to institutional organisation, water service also depends on different local factors, specifically the physical environment, social and economic conditions, etc. Thus, the description of Nyamirambo sector as the case study gives better understanding of the local context that explains the performance level of drinking water service. This part consisted of description of elevation features, land use, demographic aspects, and an overview of drinking water supply system. Nyamirambo sector is marked by the spatial diversity of its physical environment; land use, drinking water supply infrastructure and population density.

4. RESEARCH METHODOLOGY

4.1. Introduction

This chapter describes essential methods and techniques used to conduct this research. It contains the procedures used to select the study area within the City of Kigali, techniques and methods used for data collection and analysis, results discussion, and interpretation. Given the time, material means allocated to the research and type of research, there was a need of choosing the small study area that has characteristics reflecting the general situation of the City of Kigali.

4.2. Selection of the study area

The city of Kigali has three administrative districts (Nyarugenge, Kicukiro, and Gasabo), divided into 35 sectors (see Figure 6). The latter is divided into cells and each cell is divided in Imidugudu (villages) as the smallest administrative units. The administrative boundary of Kigali combines urbanized (12.5 percent), and peri-urban zones. The urbanized area consists of zones marked by planned settlements and informal settlements, whereas the peri-urban area is characterized by a scattered settlement.

There is a set of factors to take into consideration when selecting the case study, which can be adequate for applying your methodology in order to answer the particular research questions. In our case, combining numerous physical and socio-economic aspects, the study area selection (a) should be representatives of the whole area characteristics for scientific/statistical comprehensive of research results, at the same time (b) also considering the limitation such as time, money, access, and expertise (Seawright & Gerring, 2008).

Thus, given the characteristics of Kigali City, in terms of physical capital (settlements, infrastructure), related demographic features, types of information to collect, time allocated to the fieldwork and financial means, Nyamirambo Sector was purposively selected. The above-mentioned issues to be considered should be embraced well using Nyamirambo Sector as our case study since:

- It has the typical urban and peri-urban areas of Kigali city,
- It is an illustration of the contrast of population density (700 to 24,000 inhabitants/km^2) and life style of Kigali city is well observed in Nyamirambo Sector,
- It has all categories of settlement encountered in Kigali: the contrast planned/informal, urban and peri-urban is well articulated in the selected area,
- It has a diversity in terms of water supply infrastructure: spatial dissimilarity for the density of water supply infrastructure is well pronounced in Nyamirambo,

It is practicable for time and financial limitations without losing any scientific aspect.

Figure 4-1 shows the location of the study area, its land use and water supply infrastructure under the management of the public Utility – Energy, Water and Sanitation Authority (EWSA).

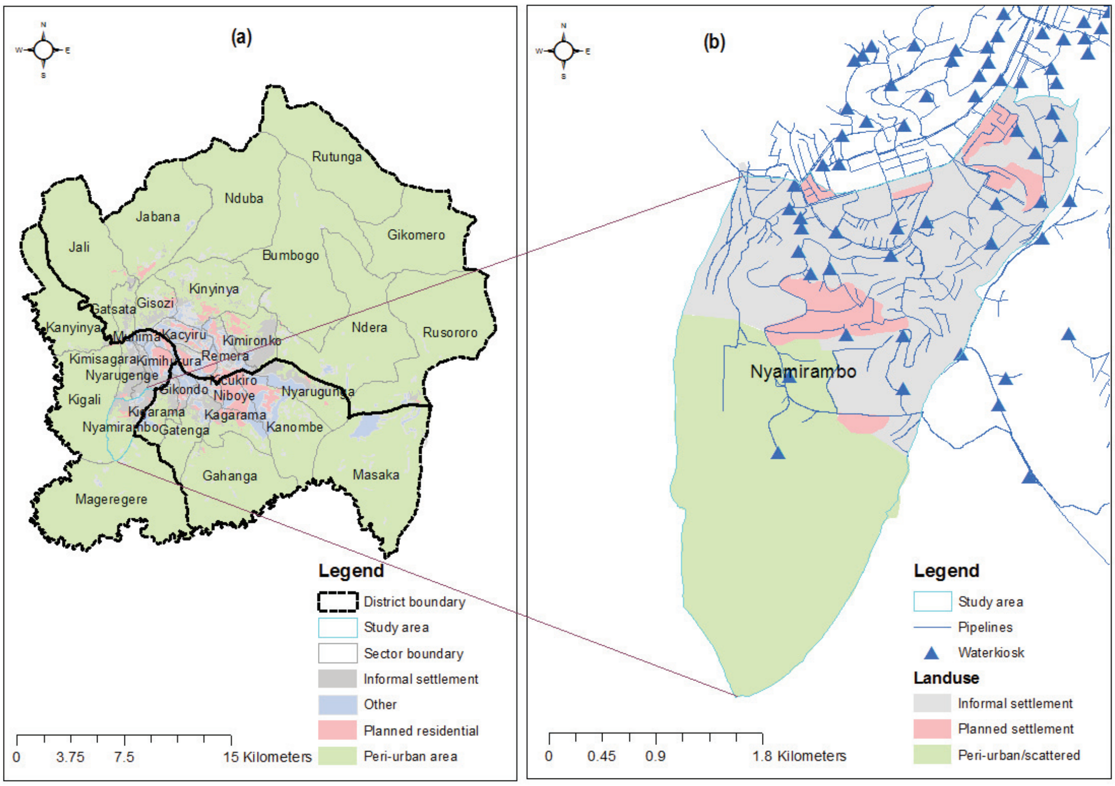


Figure 4-1: Land use in Kigali City (a) and the study area associated with water supply infrastructure of EWSA (b)

4.3. Data collection

The field data collection was preceded by the design of sampling strategy, which intended to determine the population to target for the survey in the study area.

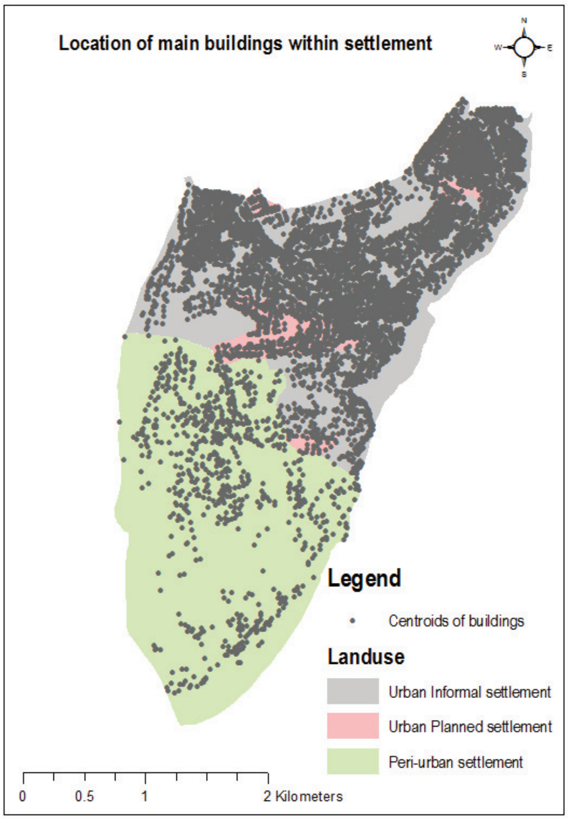
4.3.1. Sampling strategy

A multi-stage sampling (Kuno, 1976) was applied in this case study**.** In the study area, households to receive our questionnaire were selected in different steps:

- Cluster sampling delineated three categories of typical settlements found in Kigali: (1) planned and (2) unplanned zones within an urbanized area and (3) peri-urban area (characterized by scattered settlement) as three different clusters.
- The exact places for the survey were located in urban planned settlement, urban informal settlement, and scattered/peri-urban settlement within the study area.
- The total number of households to be surveyed was equally divided into those categories, not considering the proportion of total households they are representing, in order to allow statistical comparisons during the analysis;
- The households to be surveyed within each category of settlement were randomly selected using SPSS applied to prints (location) of buildings located in sites concerned.
- Identified buildings were visualized on a map having an orthophotograph as background to ease their field identification.

Households to investigate within urbanized areas were targeted in three cells of Nyamirambo sector, namely Cyivugiza, Mumena and Rugarama which are occupied by both planned and informal settlements. And

Gasharu and Rugarama cells comprise the households to investigate in order to depict the aspects of scattered/peri-urban settlements in the study area. Gasharu is totally covered by the scattered/peri-urban settlement and located further away from water supply infrastructure managed by EWSA. **Figure 4-2** displays the location of buildings and households surveyed within settlement in Nyamirambo sector.



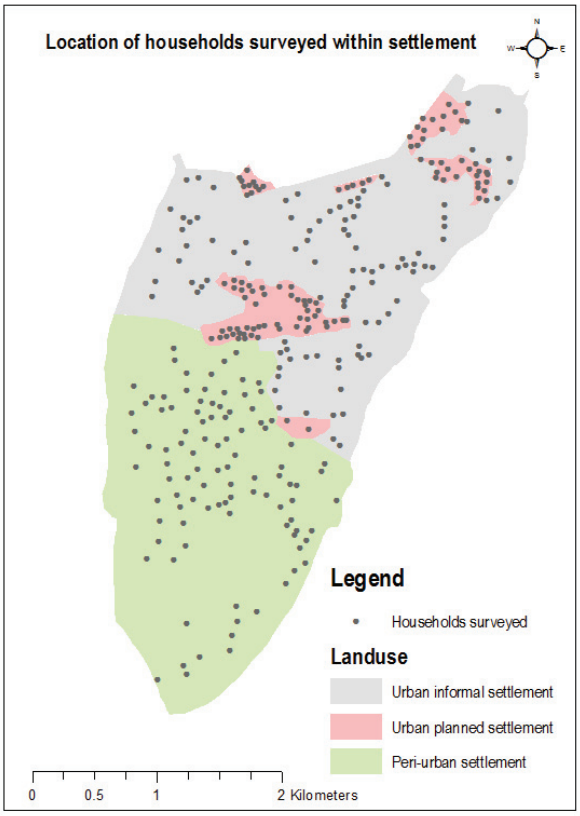


Figure 4-2: Location of buildings and households surveyed, and types of settlement

The selection of households to survey within the study area was done based on the updated data of land use and location (centroids) of buildings extracted from Kigali orthophotos of 2009 (images 25cm resolution).

Considering the scientific research requirements, financial means and time allocated to the field work, the survey targeted 303 households in Nyamirambo. The number of households was almost equally distributed into three different types of settlement to allow statistical analysis, especially statistical comparisons of observed cases.

4.3.2. Construction of the questionnaire and guide for semi-structured interviews

The household survey is made of questions consisting in detecting socio-demographic characteristics of the household, type of water sources used, duration of drinking water supply, quantity of water used, type of water treatment, cost of drinking water, and their perception of the level of service provided (see **Appendix: 1**). The guide for semi-structured interviews with officers in charge of water supply focused on water supply infrastructure, duration of water supply, quantity of water distributed, drinking water treatment and quality checking. The semi-structured interview with local leaders looked at different drinking water sources used by the population.

Types of questions

According to the informants, questions were different. The households were asked about water service they are receiving, and officers of utility and districts in charge of water supply were asked questions related to the water services provided to the population. **Table 4-1** gives an overview of types of questions tested to households and officers in charge of water supply in the study area.

Table 4-1: Major elements of questions of the survey

For a household survey	For a semi-structured interview with officers in charge of water supply
Type of water source used	Number and types of water sources
Duration of supply (hours per day)	Duration of supply (hours per day)
Time spent/distance to the water source (if applicable)	Location of water supply infrastructure
Quantity of drinking water used	Quantity of water provided or produced
Quality of drinking water supplied (reliance)	Techniques used to measure and treat water supplied
Physical properties of drinking water supplied and health problems related to the use of unsafe drinking water (diarrhoea, cholera, typhoid, others)	Frequencies of water quality verification and water treatment

4.3.3. Field/primary data collection

The data collection period involves two main activities. It consisted of primary data collection through different tools mentioned below and secondary data collection. Primary data collection involved four main activities such as training of survey assistants and survey testing, effective household survey, semi-structured interviews, and geographic observation and measurement.

a) Training of survey assistants and survey testing

After being authorized by Nyarugenge District to conduct my research in Nyamirambo sector, three field assistants were trained and a survey testing run. This process revealed that some questions might be reformulated in order to allow the effectiveness of measures and reduce confusion and non-response cases as it was observed during the testing exercise.

b) Effective household survey

The questionnaire-based household survey targeted 303 households located in Nyamirambo sector. As shown in **Table 4-3**, 100 households surveyed are located in the peri-urban area or scattered settlement, 103 in the urban planned area, and 100 in the urban informal area. The household survey focused on some socio-demographic characteristics of the household characteristics, level of access to drinking water (location of households surveyed, quantity of water provided, duration of water supply, cost of water, and appreciation of the population of all these variables.

c) Semi –structured interviews

In addition to the household survey, semi-structured interviews were conducted with local leaders, different officers in charge of drinking-water supply of Energy, Water, and Sanitation Authority (EWSA), and an officer in charge of infrastructure in Nyarugenge District. The dialogue with local leaders (Executive Secretaries of Cells) took place on October 8th, 2013 after the management meeting held by the Executive Secretary of Nyamirambo Sector. The discussion with the professional in charge of infrastructure in Nyarugenge was done on October 11th, 2013. It looked at the information about other improved water sources that are not under control of the public Utility.

The interview with the head of Water Treatment Unit at Kimisagara Plant and the Manager of Nyamirambo Branch focused on water production and treatment, quality checking at the plant and network, and distribution of treated water in the study area. The interview with the Head of Water Treatment Unit took place on October 3rd, and looked at the processes of water production, quality checking in the network, and distribution by the plant. The conversation with the Manager of Nyamirambo Branch was dedicated to water distribution in the zone.

d) Direct observation and measurement

After getting information from and during the household survey and semi-structured interviews, all other improved water sources used by the population of the study area were located using a GPS receiver.

4.3.4. Secondary data Collection

Secondary data collection aimed to get socio-economic characteristics of the population, and water supply data in the study area. In addition to the household survey and direct observation, a set of data was collected from the offices of local government and other institutions reputed to have data linked to water supply in Kigali. The socio-economic data were collected from official services such as Ministry of Local Government, National Institute of Statistics of Rwanda, office of Nyarugenge District, and Nyamirambo Sector. Data related to water supply were collected from the office of the public utility in charge of water supply – EWSA –, and the office in charge of infrastructure in Nyarugenge District. **Table 4-2** gives a detailed information on secondary data collected, year of production and the source of data.

Table 4-2: List of secondary data collected

Category	Type	Item	Year	Spatial extent	Data source
Water supply	Shapefile	Pipelines, water kiosks, water reservoirs, water supply zones, water pumps	2011	Kigali City	EWSA
	Statistics	Number of people having connections within dwellings	2013	Nyamirambo branch	EWSA
		Drinking water production and distribution	2013	Kigali City	EWSA
	Document	Process of water treatment	2013		EWSA
Land use	Shapefile	Land use (planned, informal, other)	2008	Kigali city	ITC
	Image	Orthophotos	2009	Country	NLC
Topography	Shapefile	Elevation contours		Country	CGIS-NUR
		Digital Elevation Model	2010	Country	CGIS-NUR
Road network	Shapefile	Roads	2006	Country	CGIS-NUR
Administrative	Shapefile	Villages, cells, sectors, districts, provinces	2012, 2006	Country	CGIS-NUR
Population	Statistics	Population per sector	2012	Sector	NISR
		Population per village	2010	Country	MINALOC
		Socio-economic classification of households	2012	Kigali City	Kigali City

4.4. Data preparation and analysis

4.4.1. Data preparation

Given the scope of this research, primary and secondary data collected were submitted to a preliminary investigation in order to allow better analysis. Data preparation mainly dealt with the entry of data from household survey, observation and measurement data, digitization of buildings using a single point fixed approximately on the centre of the roof (done before the household survey), and the projection transformation of spatial data. Because we had to use data from different sources, we changed the coordinate system of some spatial data. Vector data projected in ARC1960 and WGS84 were converted into IRTF2005 to make them to be combined with raster data, especially orthophotographs, defined in such coordinate system.

4.4.2. Data analysis

As detailed in **Figure 4-4**, collected data was submitted to two main types of analysis, namely spatial analysis using ArcGIS and statistical analysis using IBM SPSS Statistics. All these analyses were supported by the use of related literature. To detect potential differences regarding the performance of drinking water supply indicators in the study, households surveyed also were clustered into three classes (low-income, middle-income, and high-income) in addition to the existing spatial grouping. And, as recommended by Field (2009), households were therefore gathered into 3 income groups based on equal percentiles to allow statistical comparisons among them.

Table 4-3: Distribution of households surveyed within settlement and income groups

	Type of settlement			Income group			Total
	Peri-urban	Urban planned	Urban informal	Low	Middle	High	
Number of cases	100	103	100	108	100	95	303
Percent	33.0	34.0	33.0	35.6	33.0	31.4	100

a) Assessment of physical access to drinking water

As specified by the conceptual framework (**Figure 2-1**), the evaluation of the level of physical access to drinking water supply infrastructure involves the appraisal of geographical coverage of drinking water supply infrastructure and the estimation of the population covered.

The spatial analysis using ArcGIS software tools focused on the proximity analysis, and spatial prediction of performance levels observed within households surveyed. The geographical coverage of drinking water supply infrastructure was assessed by the proximity analysis and associated statistical calculations. The analysis of drinking water service coverage was explicitly performed with the "proximity analysis" tool - "*Near*". It was performed in order to determine the distance at which each building in Nyamirambo and surveyed households are located from the nearest water sources. It also allowed to estimate the number of people per level of service since the population density varies within one service level.

The latter was completed using "Near" tools applied to "the buildings" of the study area. After the geographical presentation of the level at which the study area is covered by drinking water infrastructure, the number of the population covered was quantified using a combination of GIS tools and statistical computation. As shown by **Figure 4-3**, the output of "Near" was spatially joined to the layer "villages" containing the average household size. After the spatial join, all buildings within each service level or range were selected, and the output table was computed accordingly (sum of HH_size within selected buildings).

The population of 2012 at the village level was estimated based on the statistics published by the Ministry of Local Administration (MINALOC) in 2010. Its calculation was done based on the population growth of Nyamirambo that was estimated by using the following formula:

Equation 1: Calculation of the population growth

Growth rate = *(Population of 2012-Population of 2010)/Population of 2010"*

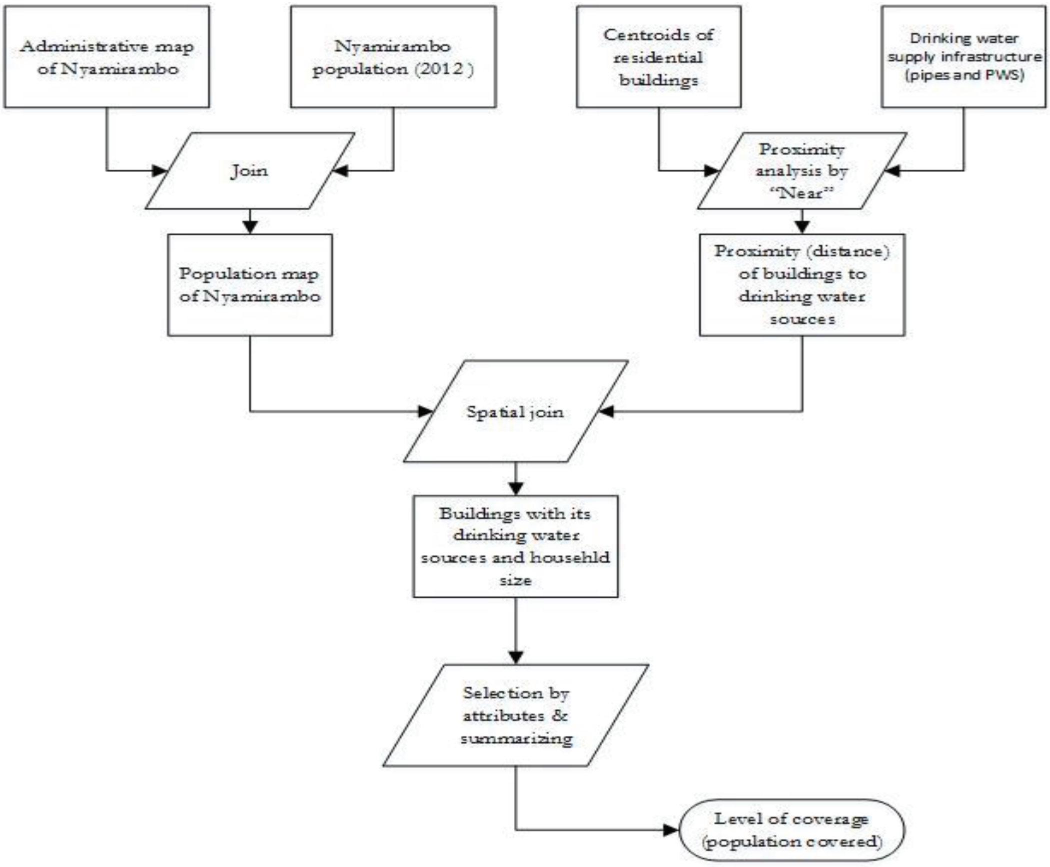


Figure 4-3: Steps for generating geographical coverage

In addition to the results of descriptive analysis (means, graphs, etc.), one-way Analysis of Variance and Tukey post-hoc tests were performed to determine the variation within different groups of households surveyed. One-way ANOVA and Tukey post-hoc tests (Blalock, 1979; Field, 2009) were useful statistical tools to evaluate differences existing in levels of physical access to drinking water within subsets of people living Nyamirambo and/or association existing between the level of service and households characteristics. Thus, one-way ANOVA test, using IBM SPSS Statistics, was performed to test the statistical significance of differences of average distances between different groups of households surveyed as a whole. Through Tukey post-hoc analysis (Multiple Comparisons), we investigated how significant specific average distances pairs are different from one another.

b) Evaluation of duration of supply, quantity of water used, water quality and affordability

Duration of supply, the quantity of drinking water accessed, the quality of water supplied, and level of affordability were assessed through statistical analysis. As mentioned above, descriptive statistics and one-way ANOVA and post hoc tests were performed to reveal the distribution, pattern of scores within surveyed households, and relationships.

Taking into consideration the complexity of drinking water quality, there was a need of developing a water quality index that combines criteria involved. The approach used to develop this composite index consisted of selection of appropriate variables recommended by the guidelines for drinking water quality in Rwanda, and that can be easily investigated using available means (questionnaires, interview, and direct observation) within the timeframe of the fieldwork. The assessment quality of drinking water supplied in Nyamirambo was therefore done based on the analysis of different parameters such as the type of water treatment by the supplier or the user, regular water quality verification, physical properties easily identified by the user (odour, taste, clarity), and occurrence of diseases associated with the use of unsafe water.

Table 4-4: Variables used for developing an Index of drinking water quality

Variable/criteria	Type	Weight
Detection of the odour by the user	Cost	1
Detection of the taste by the user	Cost	1
Detection of the colour	Cost	1
Occurrence of disease associated with the use of unsafe water	Cost	1
Water quality verification	Benefit	1
Water treatment	Benefit	1

Given the nature of the variable (cost or benefit), the score was 1 or 0. One (1) was assigned to the case of positive effect, and zero (0) to the case of negative effect. For water treatment, value 1 was assigned to the type of treatment which contributes to the removal of all unwanted elements (physical, chemical and biological) from water. Above and beyond drinking water provided by the public utility (EWSA) that is submitted to a complete treatment (disinfection of chemical and biological contamination), the treatment of water from other improved sources was assigned 0.5 as the maximum score given that water treatment by the user only removes microorganisms in water. Techniques used by the users cannot remove any chemical contamination at all. To estimate the index of drinking water quality for each household, we used the following formula:

Equation 2: Formula used to calculate drinking water quality index

***WQI**= (score_Odour + score_Taste + score_Colour + score+ Disease_Score_Wqv + score_Wtt+D)/6*

c) Comparison and standardization of drinking water supply indicators

Given that different variables/criteria used were measured in different units and scales, they needed to be transformed into linear scales to allow their comparison, and combination if required. Depending on the type of criteria used, two types of standardization were performed, namely *"maximum standardization"*, and *"goal standardization*". Sharifi et al. (2004, pp. 74, 75, 76) propose formula for these linear transformation methods.

Maximum standardization was used to transform the duration of drinking water supply per day and drinking water quality. The goal standardization was used to transform the distance to water sources, quantity of drinking water used, and expenditure into linear scores. During the process of transformation, distance and expenditure were considered as cost, whereas the duration of supply, quantity, and quality of water were considered of benefit effect.

Equation 3: Maximum standardization formula

- Benefit criteria$= \frac{Score}{highest\ score}$
- Cost criteria $= 1 - \frac{Score - lowest\ score}{highest\ score}$

Equation 4: Goal standardization formula:

Benefit criteria$= \frac{Score - minimum\ value}{Goal\ value - minimum\ value}$

Cost criteria $= 1 - \frac{Score - minimum\ value}{Gosl\ vslue - minimum\ value}$

d) Development of drinking water supply index

We developed a composite index as useful statistical tool to assess the global performance of drinking water supply, and to compare geographical zones and socio-economic groups of the study area, given that this index allow us to know the level of achievement towards the targets or goals (Antony & Visweswara Rao, 2007; De Muro et al., 2011; Martin et al., 2013). Inspired by formula proposed to calculate the Human Development Index (Antony & Visweswara Rao, 2007; Noorbakhsh, 1998; Sagar & Najam, 1998), the calculation of the composite index of drinking water supply was performed using the following formula:

Equation 5: Formula used to develop drinking water supply index

WSI*= (Physical access_scores+Duration of supply_scores+Quantity of water_scores+WQI_scores+Affordability_scores) /5*

e) Spatial prediction of performance levels

In addition to descriptive statistics, we used "*Inverse Distance Weighted*" interpolation as one of deterministic methods available with Geostatistical Analyst (De Smith et al., 2009) to show clearly the spatial pattern of drinking water supply by predicting the level of performance in the whole study area. Respecting Tobler's law (Miller, 2004), IDW method is based on the assumption that the influence of observed cases to predicted area is proportional to its location defined by the distance. The near case has greater influence than the case located far away from it. The equation of Inverse Distance weighting is:

Equation 6: Inverse Distance Weighting formulae

$$Z(s_o) = \sum_{i=1}^{n} \lambda_i Z(s_i)$$

With $d(s_i s_o)$ is the Euclidean distance between s_i and s_o. P is a power

$$\lambda_i = [d(s_i, s_o)]^p / \sum_{i=1}^{n} [d(s_i, s_o)]^p$$

where $Z(s_i)$ is known value at *i*th location; λ_i unknown weight for the measured value at *i*th location; s_0 predicted area or location…., n number of measured values.

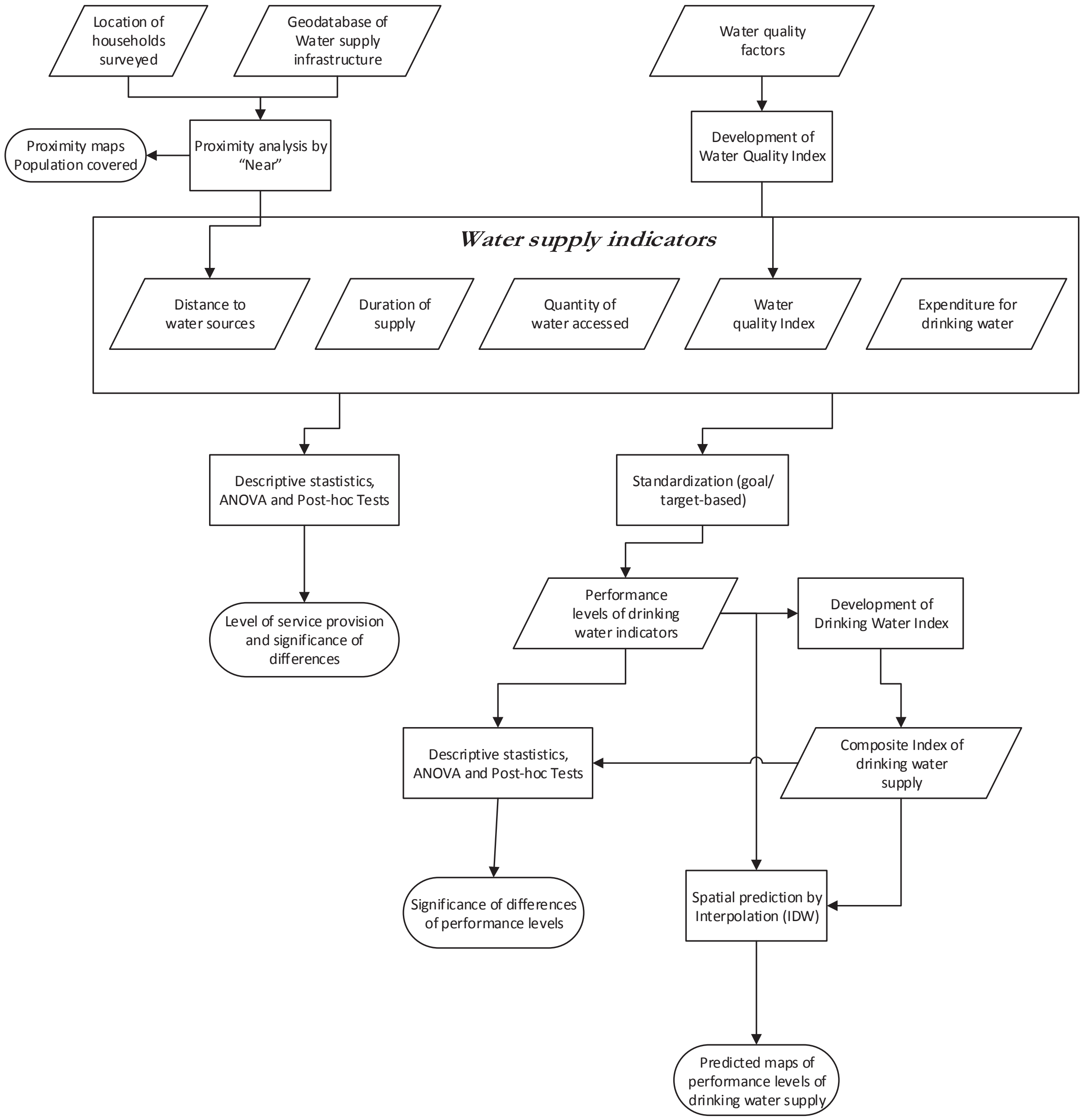


Figure 4-4: Methodological flowchart for data analysis

4.5. Concluding remark

Different methods and techniques were used to assess the performance of drinking water supply in Kigali using the case study of Nyamirambo Sector. The data were collected through questionnaire-based household survey, semi-structured interview with key informants, and direct observation. The analysis of data collected was performed using two main techniques: spatial analysis and statistical analysis. The spatial analysis consisted of the proximity analysis using GIS to determine the level of physical access to drinking water sources, and spatial prediction. The statistical analysis mainly involved the descriptive analysis, and F-test (using one-way ANOVA and Tukey post-hoc) to determine the significance of differences observed in performance levels or association between different groups of households surveyed and levels of performance.

5. PERFORMANCE OF DRINKING WATER SUPPLY

5.1. Introduction

This chapter gives the results of the assessment of a set of indicators selected for the adequacy of drinking-water supply in Nyamirambo. It explicitly gives details on geographical coverage of drinking-water service and related statistics of the population covered, duration of supply, quantity of water accessed, quality of water supplied, level of affordability for water service in the study area, comparative and integrated assessment of all water supply indicators. The level at which each indicator is performing was evaluated based on standards, and inferred to the whole study by visualization based on raster maps. Definitions of these indicators and standards or benchmarks used were given in chapter 2.

5.2. Physical accessibility to drinking water

The distance at which the population to be supplied with service is located constitutes an important factor in assessing the level of service. The geographic coverage of drinking water supply infrastructure is therefore the main element to consider when evaluating the level at which the population is provided with water service. It shows how far the population is from water sources. It also provides an overview of spatial patterns, which is a prerequisite for a better future planning and the reduction of spatial inequities in the water service provision.

5.2.1. Global drinking water service coverage in Nyamirambo

As it is stated in the previous chapter, the population of Nyamirambo sector gets drinking water from three main water supply systems; (1) piped water managed by the Public Utility, (2) water supply system managed by the local community, and (2) rainwater collection. Given that the households are generally connected to water supply infrastructure through a more complex network, and that the study area is characterized by a low dense road network and a disordered pattern of settlement (see **Figure 3-3**), people of Nyamirambo do not get water from public water sources using a well defined network. The Euclidean distance was therefore an effective tool to use to measure the level of physical access to water in Nyamirambo.

As illustrated by **Figure 5-1**, the proximity analysis revealed a clear difference in water service coverage between pipelines and public water sources. Even though the average distance from the public water source (380 m) is greater than the one from the pipelines (306 m), the distance to the furthest building (1282 m) is shorter than the one from the pipelines (1902 m). This is a result of spatial differences in concentration of these two types of infrastructure. The south-western zone of Nyamirambo is the most poorly covered area by public water sources, and the south is poorly covered by the pipelines. The poorly serviced areas are also marked by a low density of built-up space.

Considering the population of Nyamirambo evaluated to 40,338 people in 2012 (Republic of Rwanda, 2013), and 5,840 main residential buildings (generated from orthophotos of Kigali of 2008, 25cmX25cm resolution), the population is differently serviced by drinking water supply infrastructure (see **Figure 5-1**). As shown in **Table 5-1**, only about the half of the population of Nyamirambo (48.3%) is located within 200 meters from public water sources, an adequate distance in urban areas (Republic of Rwanda, 2010). Referring to service levels established by the World Health Organization, most of the population of the Nyamirambo (99.1%) are within a basic water service level, 1km from public water sources (Word Health Organization, 2011). In terms of private connection to piped water, 73.1 percent of the population are located within 50 m from pipelines (satisfactory distance based on average size of a plot in Kigali).

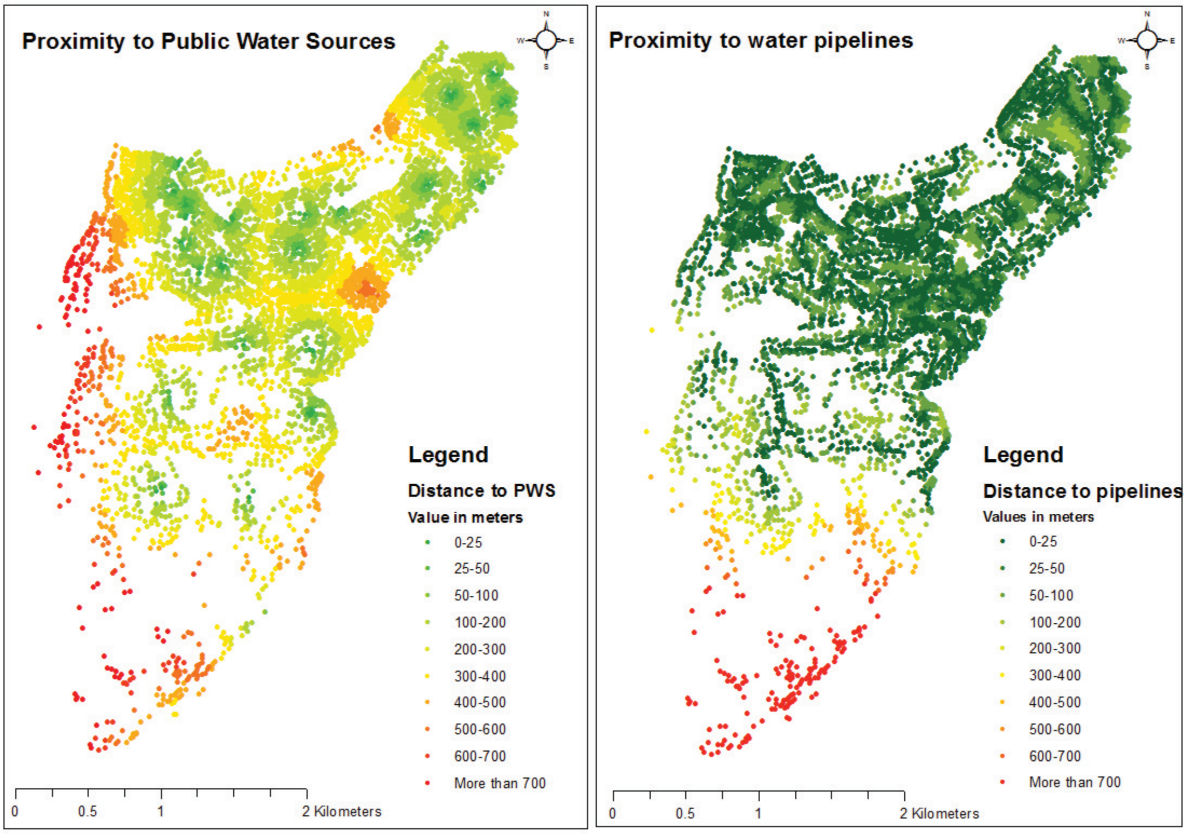


Figure 5-1: Proximity of buildings to drinking water supply infrastructures: (a) public water sources, (b) pipelines

Table 5-1: Distribution of the population of Nyamirambo based on level of coverage of drinking water supply infrastructure

Distance to water sources (metres)	Population covered by PWS	%	Cumulative percent	Population covered by pipelines	%	Cumulative percent
0-25	517	1.3	1.3	17,434	43.2	43.2
25-50	1,499	3.7	5.0	12,071	29.9	**73.1**
50-100	5,025	12.5	17.5	6,873	17.0	90.2
100-200	12,457	30.9	**48.3**	1,871	4.6	94.8
200-300	9,566	23.7	72.0	407	1.0	95.8
300-400	5,710	14.2	86.2	308	0.8	96.6
400-500	3,154	7.8	94.0	312	0.8	97.4
500-750	1,904	4.7	98.7	226	0.6	97.9
750-1000	490	1.2	100.0	89	0.2	98.1
More than 1000	17	0.0	100	747	1.9	100
Total	**40,338**	**100**		**40,338**	**100**	

5.2.2. Physical access to drinking water by households surveyed

The level of physical access to drinking water is function of two main factors: types of drinking water sources and its geographical location in relation to the users' homes.

5.2.2.1. Use of drinking water sources

As detailed in **Table -** and **Figure 5-2**, the population of Nyamirambo gets water from different sources. Private connection is the most predominant water source; it is used by 63% of households surveyed. Tubewells or boreholes come at the second position. They are followed by rainwater collection (32%), water kiosks (22.4%), and hand-pumps (9.2%). The use of water from unimproved sources is insignificant, only 1.3 per cent of households surveyed get drinking water from the stream.

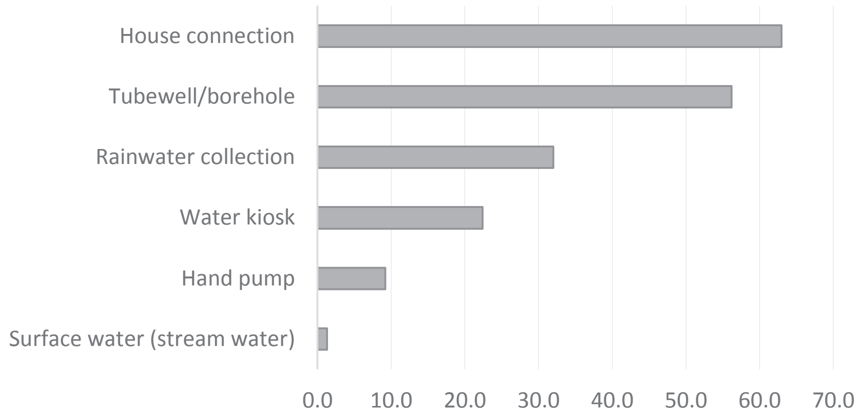


Figure 5-2: Percentages of users of drinking water sources

Within surveyed households, the diversity of use of drinking water sources is more pronounced between peri-urban and urbanized areas, and among income groups. Within households directly connected to piped water (house connections), high proportions are observed in the urbanized area, 89.3% in urban planned area, 86% in urban informal area, and within high-income group (95.8%). High proportions of users of public water sources (water kiosk, tubewell, handpump) are observed in the peri-urban area and within low-income group. **Figure 5-2** shows the proportions (percentages) of households surveyed based on drinking water sources they are using.

Table -2 : Distribution of households surveyed by settlement and income groups based on drinking water sources they are using

Type of water source	Type of settlement			Income groups			Total
	Peri-urban	Planned	Informal	Low	Middle	High	
House connection	13.0	89.3	86.0	21.1	74.0	95.8	**63.0**
Water kiosk	40.0	11.7	16.0	38.9	14.0	12.6	**22.4**
Hand pump	20.0	1.9	6.0	15.7	7.0	4.2	**9.2**
Tubewell/borehole	67.0	45.7	28	71.3	43.0	20.0	**45.9**
Rainwater collection	62.0	16.5	18.0	53.7	23.0	16.8	**32.0**
Surface water (stream water)	1.0	1.9	1.0	**2.8**	**0.0**	**1.1**	**1.3**

5.2.2.2. Pattern of proximity to improved drinking water sources

The analysis of the overall average distance to all drinking water sources in Nyamirambo for all surveyed households has shown a distance of 128.8 m. Nevertheless, this proximity varies within types of settlement and income groups. Urbanized areas (urban planned and informal areas) are therefore better serviced than the peri-urban area. Compared to the peri-urban area, the urbanized area is characterized by short average distance (25.7m and 35.8 m) to all improved water sources and small dispersion (std. dev. = 81.2 and 97.2). The households surveyed in the peri-urban area are located at an average distance of 328 m, and the variation of the distance within this group is very important (std. dev. =222.9). This situation is generally explained by a higher concentration of water supply infrastructure in the urban area than in the peri-urban area (see section 5 of chapter 4). The average distance in the peri-urban area is more than an acceptable distance recommended by the Government of Rwanda and World Health Organization (Republic of Rwanda, 2010; Word Health Organization, 2011). The highest average distance (271.2m) to drinking water sources is observed within low-income groups. The shortest average distance (19.9m) is found within high-income households. Within the middle-income group, the average distance to drinking water sources is evaluated to 78.5m. As illustrated by **Table -**, all households with high income have direct connections (piped water connection within dwellings), whereas households with low income are generally located far from water sources. This situation shows a certain spatial segregation in terms of service provision.

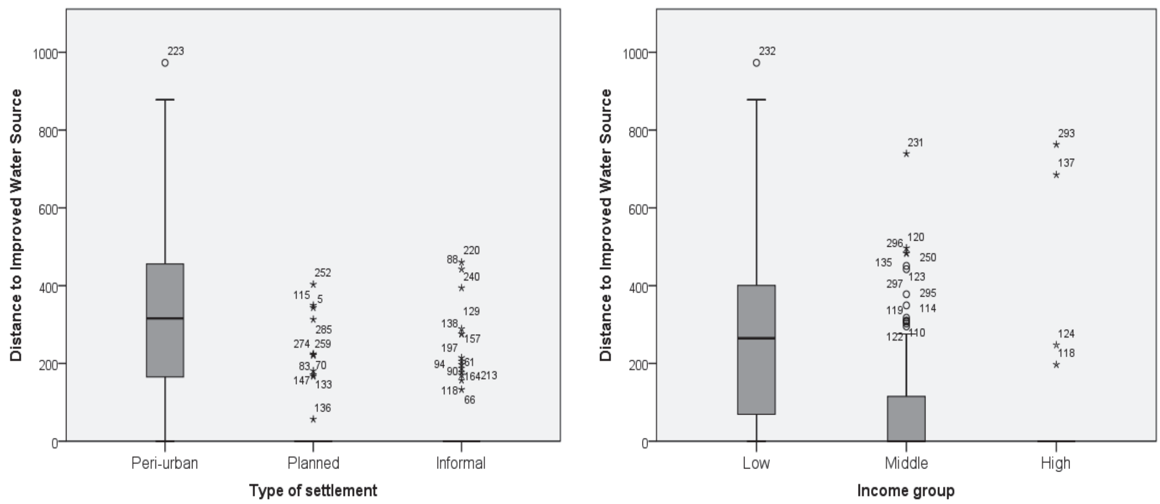


Figure 5-3: Boxplots of distance to drinking water sources within settlements and income groups

The result of one-away ANOVA test has revealed a significant difference of average distances to drinking water supply infrastructure among different types of settlement (F(2,300)=136.2, p=.00). The results of post-hoc tests have shown a significant difference of average distances between the peri-urban are and urban planned/or informal areas (p=.00), but the average distance to water sources in the urban planned settlement is not significantly different from the mean distance observed in the urban informal settlement (p=.88). This show a similar level of physical access to water sources in the whole urbanized area.

In addition to significant differences within types of settlement of Nyamirambo, physical access to drinking water sources is also characterized by a significant difference of average distances within income groups. The outputs of one-way ANOVA has revealed a statistical significant difference of mean distances to drinking water supply infrastructure among surveyed people based on their income level (F(2,300)=60.2, p=.00). As detailed in (**Appendix: 5**), Tukey post-hoc output has revealed a statistical significant difference of average distances to drinking water sources between all pairs of income groups ($p<0.05$). The proximity to drinking water sources there associated to the income level of surveyed household (average distances are significantly different from one income group to another).

Referring to the national standard(0-200m) which also meets international standard in terms of physical access to drinking water (Republic of Rwanda, 2010; Word Health Organization, 2012b), 72.2 per cent of households surveyed are within acceptable distance from improved water sources. Nevertheless, this high level of service goes with significant differences between the peri-urban and the urbanized areas. Only about the fifth (21%) of households living in the peri-urban area are located within 200 meters from public improved water sources, whereas both urban planned and informal areas shelter more than three-quarters of the households located with this acceptable distance.

Table 5-3: Distribution of percentages of households surveyed by settlement and income groups based on distances (metres) to drinking water supply infrastructure

Distance to water sources	Type of settlement			Income group			Total
	Peri-urban	Urban Planned	Urban Informal	Low	Middle	High	
0-50	13.0	89.3	86.0	24.1	74.0	95.8	**63.0**
50-100	3.0	1.0	0.0	3.7	0.0	0.0	**1.3**
100-200	15.0	2.9	6.0	13.9	8.0	1.1	**7.9**
200-300	14.0	2.9	5.0	14.8	5.0	1.1	**7.3**
300-400	23.0	2.9	1.0	18.5	7.0	0.0	**8.9**
400-500	12.0	1.0	2.0	9.3	5.0	0.0	**5.0**
500-750	16.0	0.0	0.0	13.0	1.0	1.1	**5.3**
750-915	4.0	0.0	0.0	2.8	0.0	1.1	**1.3**
Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

5.2.2.3. Situation of proximity to Public Water Sources

However, the analysis of the distance to public water sources (PWS) has exposed a situation different from the previous one and a dissimilar pattern between the peri-urban and urbanized areas. Excluding the households connected to piped water within dwellings in the analysis, the average distance to improved public water sources becomes longer than the global distance. The average distance to public water sources, all groups combined, was estimated to 348.5 metres.

As illustrated by **Figure 5-4**, the high mean distance to water sources is still observed in the peri-urban area (377.1m). The informal area occupies the second position (255.7m), and the average distance to public water sources in the urban planned area was 241m. As mentioned above, the average distances to public water sources do not differ significantly within income groups. High-income households, few as they are, are here located further away (473.1m) from public water sources than low and middle-income groups (357.1m, and 302m).

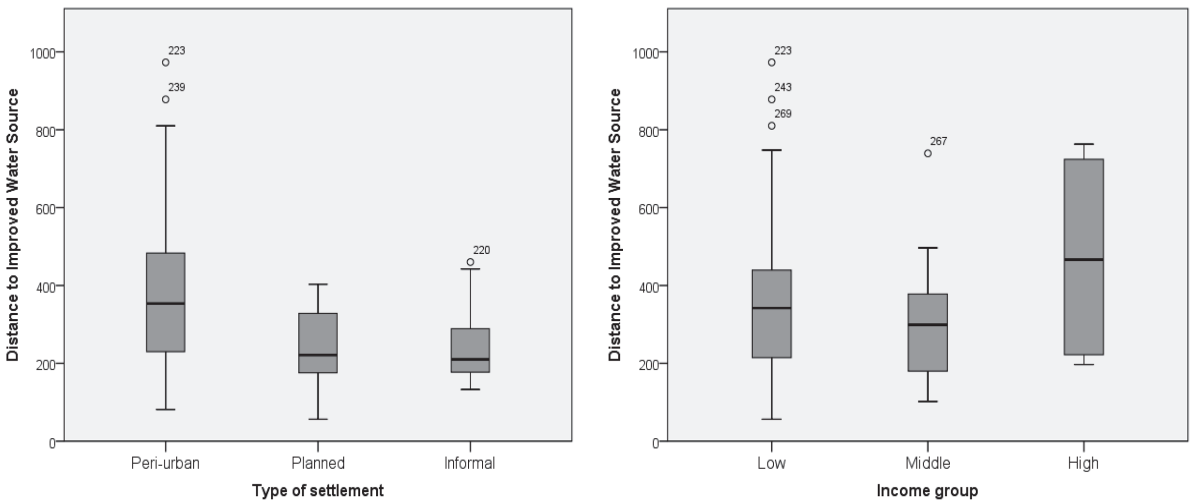


Figure 5-4: Boxplots of distance to PWS within settlements and income groups

The results of One-way ANOVA and Tukey post-hoc (F (2,112) =4.9, p=.01) show a statistical significant difference of mean distances to public water sources within types of settlements as whole, but a lack of any statistical significant difference of means between the peri-urban area and the urban planned or informal areas and vice-versa (p>0.05). However, the result has revealed a lack of statistical significant difference of average distances between income groups as a whole (F (2,112) =1.8, p>.05).

In addition to the increase of the distance to public water sources, the proportion of households using water from public water sources within standards established is now low compared to the overall situation. As shown in **Table 5-4**, only 25% of households surveyed are located within 200 from public water sources in Nyamirambo.

Table 5-4: Distribution of percentages of households surveyed by types of settlement and income groups based on distances (metres) to public water sources

Distance to water sources	Type of settlement			Income group			Total
	Peri-urban	Urban Planned	Urban Informal	Low	Middle	High	
0-100	3.4	9.1	0.0	4.9	0.0	0.0	3.6
100-200	17.2	27.3	42.9	18.3	30.8	25.0	21.4
200-300	16.1	27.3	35.7	19.5	19.2	25.0	19.6
300-400	26.4	27.3	7.1	24.4	26.9	0.0	24.1
400-500	13.8	9.1	14.3	12.2	19.2	0.0	13.4
500-750	18.4	0.0	0.0	17.1	3.8	25.0	14.3
750-915	4.6	0.0	0.0	3.7	0.0	25.0	3.6
Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

5.3. Duration of drinking-water supply

According to The World Health Organization and Rwanda National Policy for water Supply and Sanitation, drinking water have to be supplied 24 hours a day (Republic of Rwanda, 2010; Word Health Organization, 2011) given that water is needed all the time. Drinking water in Nyamirambo sector is on average supplied for about 10 hours a day. The variation of duration of supply is important (std. dev. =9.6). The duration varies between one hour and 24 hours.

5.3.1. Pattern of duration of drinking supply in Nyamirambo

As illustrated by **Figure 5-5**, the long duration of supply is generally observed in the peri-urban area (18 hours) which is submitted to a different type of drinking water supply system. As explained in previous sections, the area has three public water sources operating 24 hours a day (1 borehole and 2 hand pumps) and two water stand taps (kiosks) operating more than 6 hours a day. The average duration supply is very short in the urban informal area (6.5 hours). The mean duration of supply in the urban planned area is 6.2 hours.

Taking consideration of income level, the average duration of supply is high within the low-income group (16.8 hours). The mean duration of drinking water supply is very short within high-income groups (4.9hours/day). The mean duration of supply is 7.9 hours/day with middle-income households.

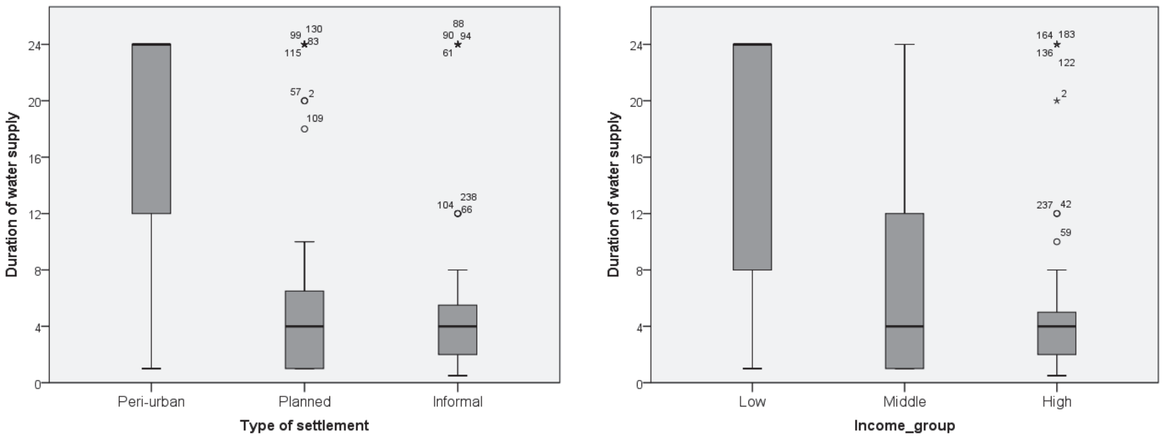


Figure 5-5: Boxplots of duration of drinking-water supply within settlement and income groups

As determined by one-way ANOVA ($F(2,300) = 74.0$, $p=.00$, and $F(2,300) = 59.9$, $p=.00$), there is a statistical significant difference of means of duration of supply as a whole among types of settlement and income groups. Within settlements, The Tukey post-hoc results (see **Appendix: 5**) has shown a statistical significant between the peri-urban area and both urban planned and informal areas ($p=.00$), but a lack of a statistical significant difference of means between the urban planned area and the urban informal area ($p=.97$). Within income groups, all differences obtained are statistically significant ($p<.05$). This shows the association existing between the duration of supply and income level.

As shown in **Table 5-5**, only about the third of households (30%) are supplied 24 hours a day, and more than half of the households surveyed (53.1%) are supplied with drinking water for less than 5 hours a day. The majority of households well supplied in drinking water, referring to the standard (24 hours/day) are located in the peri-urban area (66.0%) and within low-income groups (61.1%). Few households living in the urbanized area are experiencing a low level of water service in terms of duration of supply. High and middle households surveyed are poorly serviced in terms of duration of supply.

Table 5-5: Percentages of households at different level of duration of drinking water supply within settlement and income groups

Duration (hours/day)	Type of settlement			Income group			Total
	Peri-urban	Urban planned	Urban informal	Low	Middle	High	
0-5	15.0	68.9	75.0	21.3	63.0	78.9	**53.1**
5-10	8.0	17.5	8.0	10.2	17.5	8.0	**11.2**
10-15	11.0	0.0	3.0	7.4	0.0	3.0	**4.6**
15-20	0.0	2.9	0.0	0.0	2.9	0.0	**1.0**
20-23	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
24	66.0	10.7	14.0	61.1	20.0	5.3	**30.0**
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100.0**

5.3.2. Level of satisfaction for the duration of supply

Taking consideration of the diversity of the study area, levels of satisfaction differ from one area to another and within income groups. As illustrated by **Figure 5-6**, the high levels of satisfaction were found in the peri-urban area and low-income group, whereas the high levels of dissatisfaction are observed the urban planned area and both middle and high-income groups. Seventy-three per cent of households living in the peri-urban area and 69.9 per cent of low-income households are satisfied with the duration of drinking water supply. About 70 per cent of people living in planned, 48.5 per cent of middle income and 48.4 of high-income households are dissatisfied with the duration of supply.

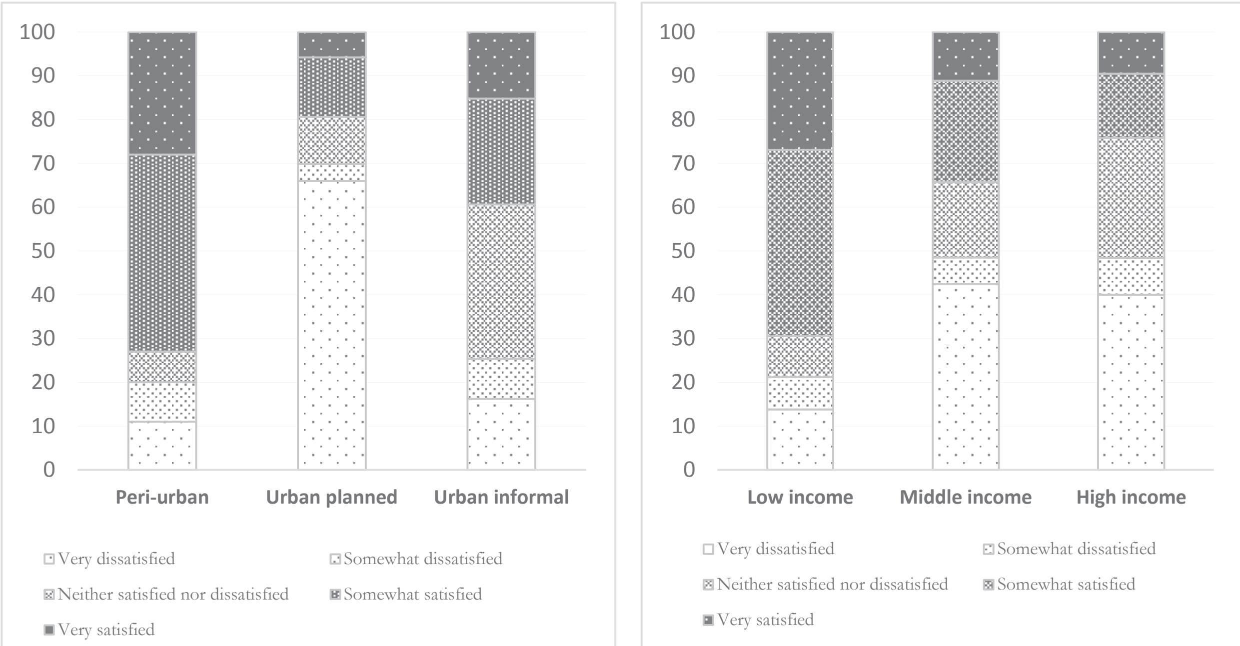


Figure 5-6: Distribution of percentages of households based on the level of satisfaction for the duration of drinking water supply

An overview of households' perception of the duration of supply indicates that the level of satisfaction is higher than the level of dissatisfaction, 43.7% against 38.8%. Through one-way ANOVA test ($F (4,297) = 109.4$, $p=00$) and Tukey post-hoc test (see **Appendix: 10**), it has been revealed that the level of satisfaction for duration of supply is associated with the level of performance of duration of supply despite of the lack of significant differences in terms of duration of supply between some pairs of satisfaction levels.

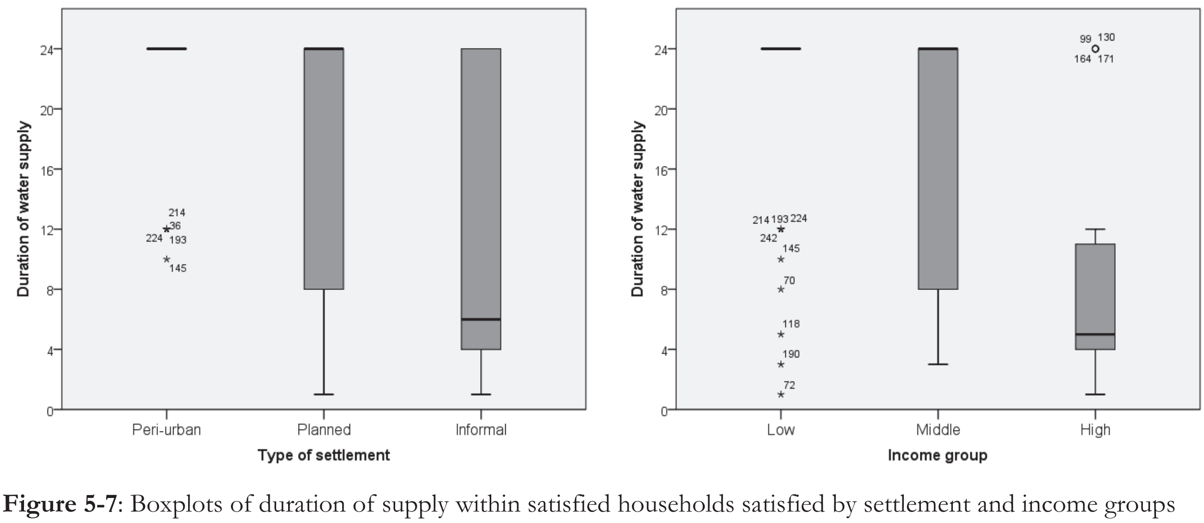


Figure 5-7: Boxplots of duration of supply within satisfied households satisfied by settlement and income groups

Considering the case of those households who appreciate positively the duration of supply (132 households), the average duration of supply becomes high in all settlements and income-groups. As shown by **Figure 5-7**, the average duration of supply is considerably high for the households who appreciate positively the duration of supply (132 households) compared to the global average duration of drinking water supply observed in the study area. Contrary to the previous situation, planned settlement records here a high average duration of supply (17.2 hours/day), and the intra-group variation becomes low in the peri-urban area (std. dev. =4.2), almost the half of the situation observed in the urban planned and informal areas (std. dev. =8.8 and 9.4). The duration of supply within satisfied households has become 17.5 hours for middle-income groups and 9.3 hours for high-income groups (against 7.9 and 4.9 hours observed previously).

5.4. Quantity of drinking water

5.4.1. Variation of the quantity of drinking water used per capita per day

The Government of Rwanda has a target of providing 80 litres of drinking water per capita per day in cities (Republic of Rwanda, 2010), whereas the Word Health Organization (2011) considers 100-200 litres as an optimum quantity to be accessed in urban areas. The mean quantity of drinking water used per capita per day in Nyamirambo is too below the acceptable minimum/target suggested by the Rwandan Government, and the optimum quantity proposed and the World Health Organization. Only 0.6 per cent of surveyed households are meeting the goal established. Within surveyed households, the mean quantity of water used per capita per day is estimated to 22.4 litres. It varies between 0.75 and 120 litres.

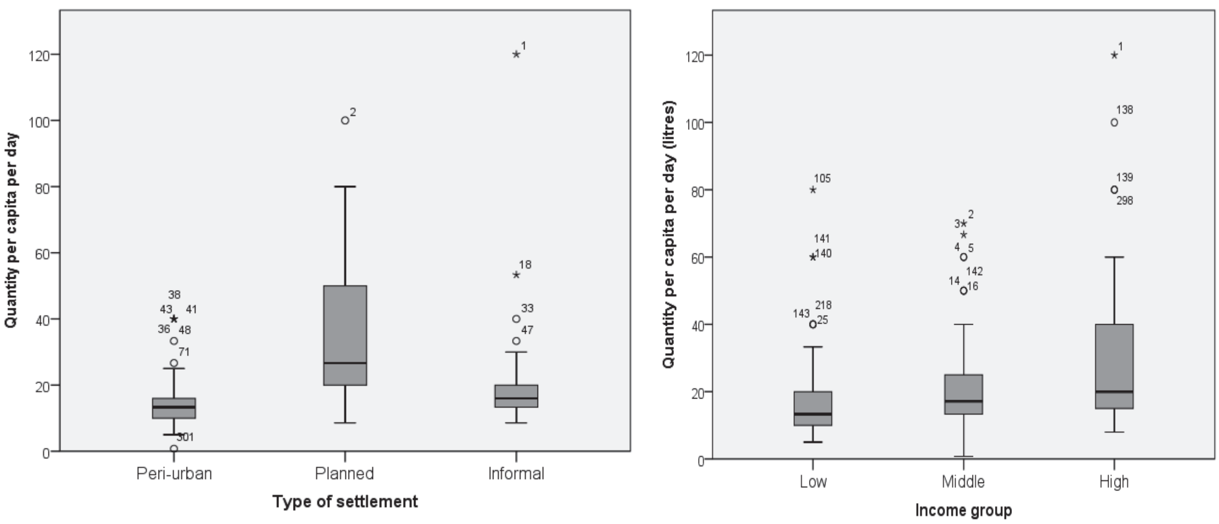


Figure 5-8: Boxplots of quantity of drinking water used within settlement and income groups

In addition to global low level of use of drinking water by the households surveyed in Nyamirambo, the average quantity of drinking water used per capita per day is marked by differences within settlements and income groups. Within settlement, the analysis of drinking water used has shown that the high mean quantity of drinking water used per capita per day (33.4 litres) is observed in the urban planned area, even though it is associated with high intra-group variation (std. dev.=18.8). The informal area takes the second position, with the mean quantity of drinking water used of 19.0 litres, and a standard deviation of 12.2. Despite the long duration of supply, the peri-urban area is the most deprived zone. As shown in **Table 5-6**, about 90 per cent of surveyed households use drinking water quantity smaller than 20 litres per capita per day. Inside the peri-urban area, the average quantity of drinking water used is 14.38 litres per person per day, but the variation within it is lower (std. dev. = 7.5) than the ones observed in the urban planned and informal areas.

The mean quantity of drinking water used increases by income level. Households of high income groups use on average high quantity of drinking water, but the variation within it is very high (std. dev.=20.4) compared to the situation prevailing with low and middle income groups (std. dev. =13.1 within low-income group and std. dev.=11.2 within middle-income group). The average quantity of drinking water used is estimated to 21.6 litres within middle-income households and 17.2 litres within low income.

By settlements, one-way ANOVA results (F (2,300) =53, p<.05) show statistical significant differences of means of quantity of drinking water used between types of settlement as a whole. Outputs of Tukey post-hoc (**Appendix: 3**) have revealed that the average quantity of drinking water used within households living in the peri-urban area is significantly different from the average quantity of water used within households living in the urban planned area or the urban informal area and vice versa. For income groups, one-way ANOVA products (F (2,300) =16. 2, p<. 05) also show statistical significant differences of means of quantity drinking water used between income groups combined. However, Tukey post-hoc results ((see **Appendix: 5**) have revealed only a statistically significant difference of means between the low-income group and high-income group (p=. 00), and between the middle-income group and the high-income group (p=. 00). Any statistical significant difference of means was not observed between the low-income group and the middle-income group (p=.09).

As shown in **Table 5-6**, households are therefore differently distributed within different levels of service (quantity of drinking water used) based on types of settlements or income level.

Table 5-6: Distribution of percentages of households by types of settlement and income level based on the level of the quantity of drinking water used

Quantity of water	Type of settlement			Income group			Total
(in litres)	Peri-urban	Urban planned	Urban informal	Low	Middle	High	
0-20	89.0	35.9	80.6	82.4	66.7	53.2	**68.1**
20-40	11.0	35.9	17.3	14.8	26.3	24.5	**21.6**
40-60	0.0	22.3	1.1	1.9	5.1	18.1	**8.0**
60-80	0.0	4.9	0.0	0.9	2.0	2.1	**1.7**
80-100	0.0	1.0	0.0	0.0	0.0	1.1	**0.3**
More than 100	0.0	0.0	1.0	0.0	0.0	1.1	**0.3**
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100.0**

5.4.2. Level of satisfaction for the quantity of water used

In general, about the third of surveyed households are satisfied (34.3%) with the quantity of water used, but about the same proportion (33%) is not satisfied. As illustrated by **Figure 5-9**, high level of satisfaction is observed in the urban informal area and in the urban informal area (68.1%) and within the high-income group (47.3%). The high level of dissatisfaction for the quantity of drinking water used, on the other hand, is found in the urban planned area (40.4%), the peri-urban area (40%), the low-income group (37.9%), and the middle-income group (35.3%). A high proportion of households of mixed feelings is also observed in the peri-urban area (44%) and within the low-income group (39.8%).

The output of one-way ANOVA test (F (4,294) =3.7, p=01) has revealed that the level of satisfaction for quantity of drinking water used is also associated with the amount of drinking water used. However, Tukey post-hoc test (see **Appendix: 11**) has revealed the non-existence of significant differences of performance levels between many pairs of levels of satisfaction. Within households satisfied with the quantity of drinking water provided, the average quantity of drinking is close to the global average (20 litres). Households living in the urban planned area are the ones who use high quantities of drinking water (31 litres). Peri-urban and urban informal areas have close mean scores (16 and 17 litres). Within income groups, the variation is not important. High mean quantity of water is observed within the high-income group (21.5 litres). Small mean quantity is observed in the low-income group (18 litres).

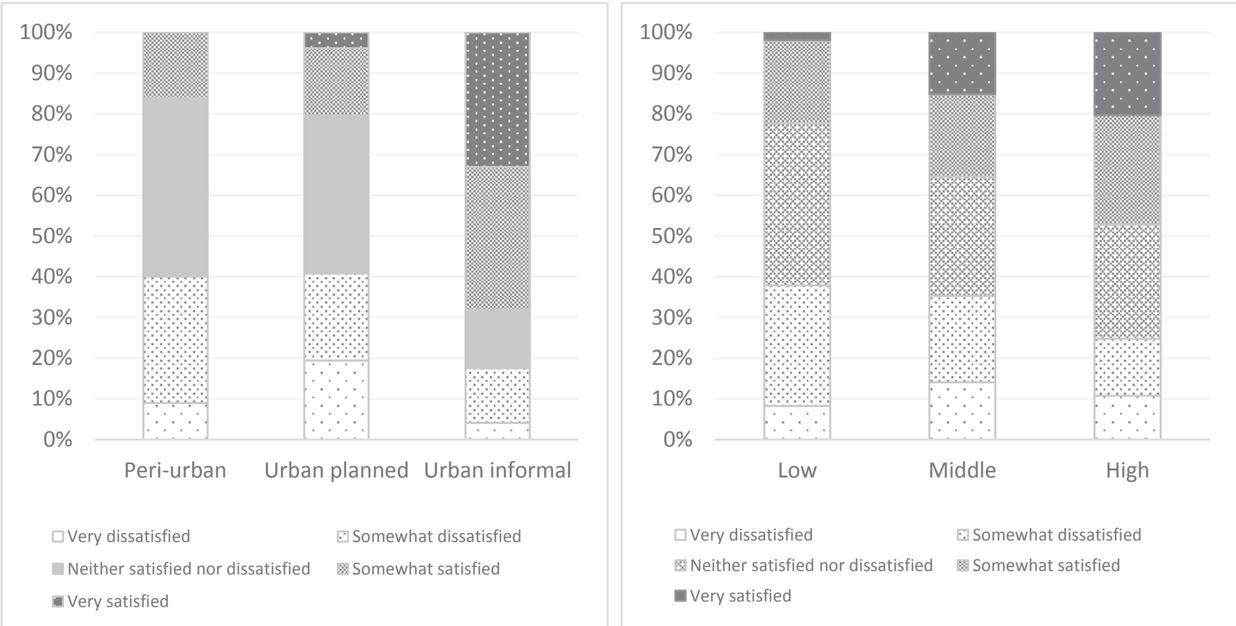


Figure 5-9: Distribution of percentages of households based on the level of satisfaction for the quantity of drinking water used

5.5. Quality of drinking water in Nyamirambo sector

One common practice for appraising the quality of drinking water is to investigate its physical and bacteriological parameters (Karavoltsos et al., 2008). To evaluate the quality of drinking water supplied in Nyamirambo Sector, we used the information provided by Kimisagara Water Treatment Plant, and questionnaire data.

Figure 5-10: Distribution of households surveyed based the state of drinking water quality verification

The questionnaire-based survey has provided the information related to physical properties that can be recognized by our respondents such as odour, taste, clarity (colour), and effects associated with the use of unsafe water, mainly diseases. Even if some used variables (odour, taste, colour) might not have any direct health effects, they indicate that water used may be safe or not (Rickwood & Carr, 2009).

5.5.1. Drinking water quality checking and treatment in Nyamirambo

A high proportion of households surveyed living in Nyamirambo (81.2%) generally use drinking water whose quality is regularly verified and treated by proficient services (provider) before the distribution. Drinking water supplied in Nyamirambo by the public utility is treated at Kimisagara Treatment Plant. Despite this high level of service, there is a variation of proportions of households receiving it within settlement and income groups. As shown by **Figure 5-12Figure 5-10**, a high proportions of households using drinking water treated by the supplier and whose the quality is frequently checked is identified in the urban planned and the informal area (93.2% and 96%), and among middle and high-income groups (86% and 97.9%). A high proportion of households using drinking water whose quality is not being checked was observed in the peri-urban area (54.0%), and among low-income groups (38%).

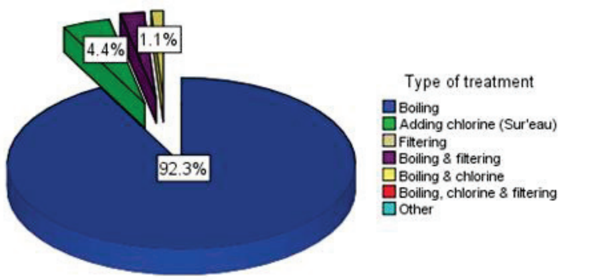


Figure 5-11: Distribution households (%) by types of drinking water treatment

In addition to water treatment and water quality checking by the supplier, especially EWSA, the population of the study area proceeds by different types of water treatment. Water boiling is the most predominant technique used by households surveyed. About 95 percent of the respondents confirmed to boil drinking water provided. The second position is taken by the use of chlorine “Sur'eau”. Cleaning drinking water by filtering is weakly practiced in Nyamirambo Sector (0.4%).

Based on types of settlement and income levels, boiling as type of drinking water treatment is largely practiced in the urban informal area (96.7%) and within the high-income group (96.6%), whereas the use of chlorine is mainly observed within households living in the peri-urban area (5.5%) and low-income people (7.6%). Despite its low frequency, filtering was observed within middle-income households living in the urban informal area.

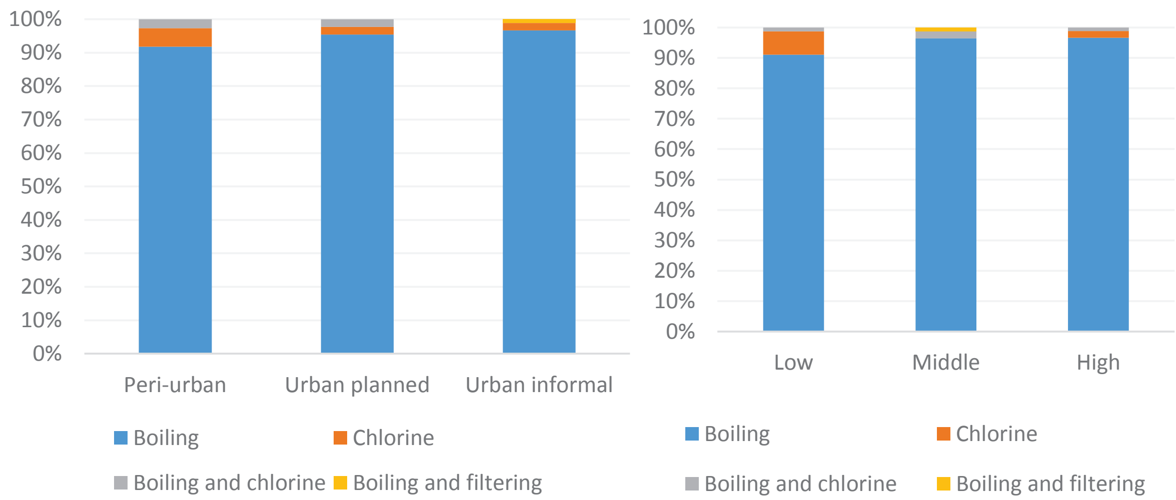


Figure 5-12: Distribution of percentages of households, within settlement and income groups, based on types of water treatment

5.5.2. Odour, taste, clarity, disease occurrence

Odour, taste, colour, and occurrence of diseases associated with the use of unsafe water also constitute a set of variables used to depict the level of drinking water within the population of Nyamirambo. The analysis has shown that water quality is not a significant issue. Taste, odour, colour, and diseases were detected only within a small proportion of the population. All cases occurred in less than 6 per cent of surveyed households.

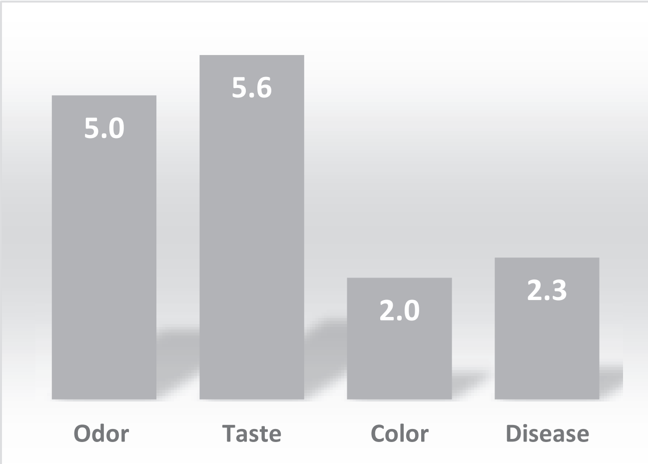


Figure 5-13: Occurrence of parameters associated with the use of unsafe water

In addition to the global information provided by **Figure 5-13** regarding the percentages of occurrence of aspects associated with the use of unsafe water, the incidence of these parameters used shows a certain pattern. 93.3% of odour occurrence in drinking water was detected in the peri-urban area, 53.3% within the low-income group. The taste was, however, detected only in the peri-urban area. 64.7% of taste occurrence were observed within the low-income group. The lack of clarity or colour was almost equally distributed within settlements and income groups; 32.7% of occurrence are observed in the peri-urban area, 34.3% in the urban planned area, 33% in the urban informal area, 36% within the low-income group, 32.7% within the middle-income group, and 31.3% within the high-income group. The incidence of diseases (diarrhoea, typhoid) associated with the use of unsafe drinking water was highly detected the peri-urban area and within the low-income group. 85.7% of diseases occurrence were observed in the peri-urban area, and 43% within the low-income group.

5.5.3. Drinking Water Quality Index

To have an easy understanding and to evaluate the situation of drinking water quality in the study area, there was a need of developing an index that combines indicators of drinking water quality. We have therefore combined water treatment and checking, detection of odour, taste, and colour, occurrence of disease associated with the use of unsafe water, and the type of water source. The combination of all these variables gave a global water quality index of .91 and the standard deviation is .11. This index shows that the quality of drinking water is not generally an issue in the study area.

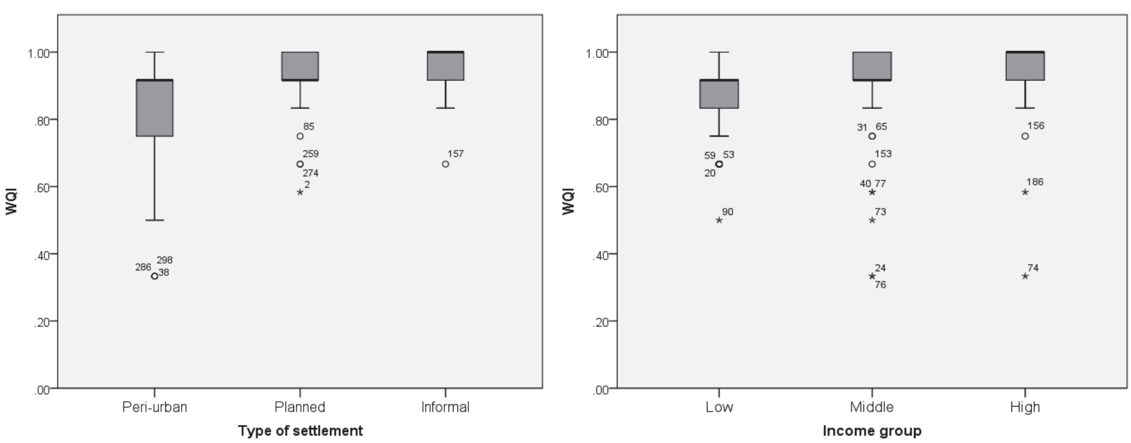


Figure 5-14: Boxplots of index drinking water quality within settlement and income groups

Despite this high overall score, there is a variation of water quality index within types of settlement and income groups. The results of One-way ANOVA ($F (2,300) = 37.8$, $p=.00$) have revealed that the average indices of water quality are different between different types of settlement combined. However, the output of post-hoc test has only shown that the statistical significant difference of average index values is only prevailing between the peri-urban area and urban planned and informal areas and vice versa. The average index value of water quality observed in the urban informal area is not statistically different from the one observed in the urban planned area ($p=.510$). On the contrary, one-way ANOVA and post-hoc tests (see **Appendix: 5**) have shown that the difference of mean values of water quality index is statistically significant between income groups combined ($F (2,300) = 17.4$, $p=.00$) and within all income groups ($p<.05$). Within settlement, the high mean value of drinking water quality index is observed in the urban informal area (0.96). The urban planned area comes at the second position (0.94). The peri-urban area has an average index value of 0.84. Referring to income level, the high mean value of the index is found within the high-income group (0.95). Within the middle-income group, the mean value of the index is 0.91, and the low-income group has registered the index value of 0.87.

5.5.4. Level of satisfaction for the quality of drinking water

Regardless of the high value of drinking water, a low proportion of households surveyed (38.5%) is satisfied with the quality of drinking water provided. About half of surveyed people (48%) have mixed feelings about the quality of water supplied. Through one-way ANOVA test ($F (4,291) = 10.9$, $p=00$) it has been revealed that the level of satisfaction for the quality of drinking water used is associated with the level of performance of water quality. Nevertheless, the output of Tukey post-hoc test (see **Appendix: 12**) has shown the lack of significant differences in terms of drinking water quality between some pairs of levels of satisfaction.

Considering different types of settlement and income level, there are high proportions of cases of satisfaction in the peri-urban area (53.6%) and low-income group (40.5%). Cases of dissatisfaction are also important in the peri-urban area (23.7%), within the low-income group (16.4%), and the middle-income group (13.2%). Mixed feelings (indecision) for the quality of drinking water are mainly observed in the urban planned area (64.1%), urban informal area (56.3%), middle-income group (45.9%), and high-income group (67%). **Figure 5-15** displays detailed information about the perception of the population for drinking water quality.

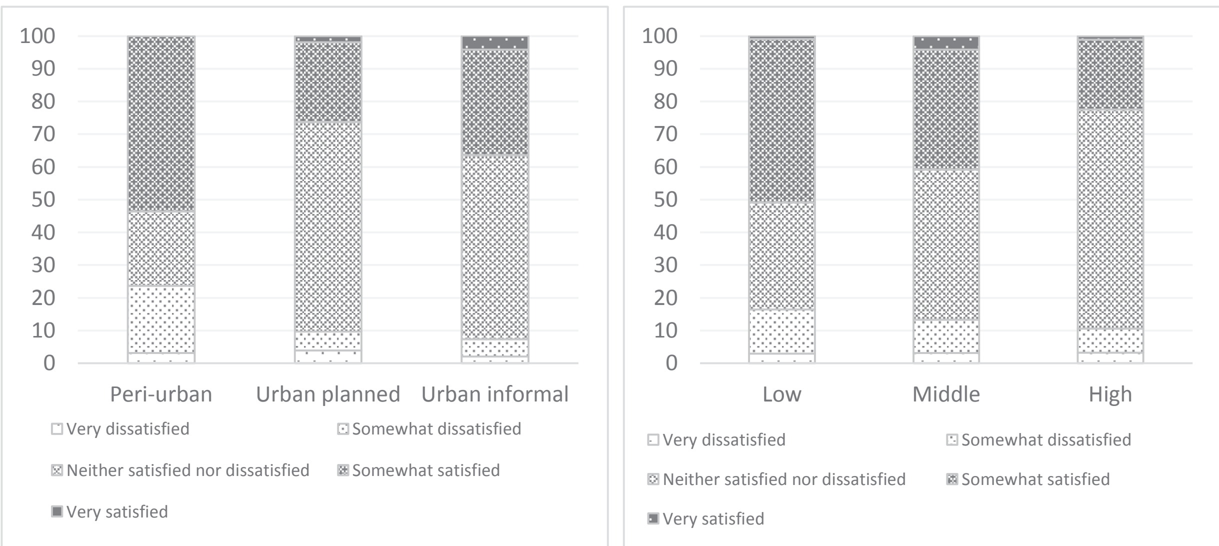


Figure 5-15: Distribution of percentages of households (within settlement and income groups) based on the level of satisfaction for the quality of drinking water

5.6. Level of affordability for drinking-water in Nyamirambo

The level at which a service is affordable is determined by its price in relation to the ability of the user to pay (Gawel et al., 2013). To evaluate the level of affordability to drinking water supply in Nyamirambo, there was a need of comparing monthly average cost of drinking water and household income. According to Guy Hutton (2012), the amount of money spent by average household income is the tool predominantly used to appraise the extent to which water service is affordable in many countries.

5.6.1. Expenditure for drinking water

The analysis of affordability based on the cost of drinking water used by the average monthly income of households surveyed has revealed that the average expenditure for drinking water in Nyamirambo is around 7%. Nevertheless, the expenditure fluctuates within settlements and among income groups.

The cost of drinking water constitutes an issue for households living in the peri-urban area and within the low-income group. The average expenditure in the peri-urban area is evaluated to 13 per cent, and 15.5 per cent within the low-income group. The expenditure is low for households living in the urban planned and informal areas, middle and high-income groups.

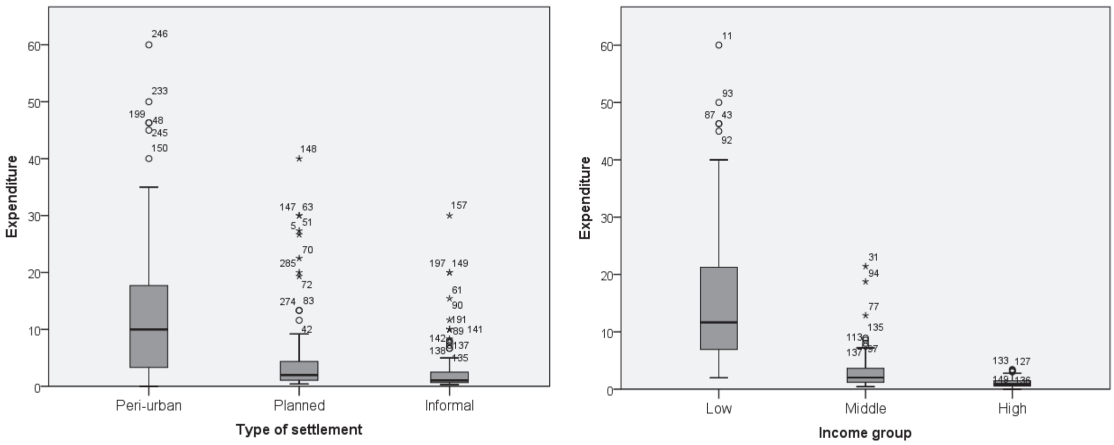


Figure 5-16: Boxplots of expenditure for drinking water by settlement and income group

The results of One-way ANOVA (F (2,300) =38.5, p=0.00) have revealed the existence of significant differences of mean expenditure for drinking water between types of settlements as a whole. Based on the results of Tukey post-hoc test , the average expenditure for drinking water in Nyamirambo is only significantly different between the peri-urban area and the urban planned area or urban informal area, and vice versa (p<.05). The difference of mean expenditure is not significant between the urban planned area and the informal area (p>.05).

Considering the level of income, one-way ANOVA result (F (2,300) =111.9, p=.00) has shown that the average expenditures are significantly different between income groups combined. In addition, Tukey post-hoc output has revealed that the average expenditure for drinking water provided within the low-income group is significantly different from the one observed within the middle and high-income groups (p<.05). However, the mean expenditure for drinking water of the middle-income group is not significantly different from the one observed within the high-income group and vice-versa (p>.05).

Referring to the benchmark established by the World Bank (Fankhauser & Tepic, 2005; Gawel et al., 2013; G. Hutton, 2013; Kayser et al., 2013), 5 per cent of household income, only 66 per cent of households surveyed are affording the cost of drinking water in Nyamirambo. As shown in **Table 5-7**, about 78 % of households living in urban planned area, 85% in the urban informal area and all high-income families spend less than 5% of their income for drinking water.

Table 5-7: Percentages of households within settlement and income groups by expenditure for drinking water

Expenditure	Type of settlement			Income group			Total
	Peri-urban	Planned	Informal	Low	Middle	High	
0-5	35.0	77.7	85.0	18.5	85.0	100.0	66.0
5-10	20.0	11.7	10.0	27.8	12.0	0.0	13.9
10-15	12.0	2.9	1.0	13.9	1.0	0.0	5.3
15-20	12.0	1.9	3.0	14.8	1.0	0.0	5.6
20-30	12.0	4.9	1.0	15.7	1.0	0.0	5.9
More than 30	9.0	1.0	0.0	9.3	0.0	0.0	3.3
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**

5.6.2. Perception for the cost of drinking water

The cost of drinking water is perceived differently in Nyamirambo. About 64 percent of households surveyed consider the cost of drinking water delivered expensive. Only 22.6 percent consider drinking water as low-priced. Within settlement, the peri-urban area records a high proportion of households considering very high the cost of drinking water provided (69.4%). Many households living in the informal area consider the cost as moderate. Based on income level, a high percentage of households considering high the cost of drinking water are observed within the low-income group. **Figure 5-17** shows the details of level of perceptions for the cost of drinking water within settlements and income groups.

Through one-way ANOVA test (F (4,263) =16, p=00) and Tukey post-hoc test (see **Appendix: 13**), it has been revealed that the level of satisfaction for the cost of drinking water is associated with the level of expenditure spent despite of the lack of significant differences between some pairs of perception levels.

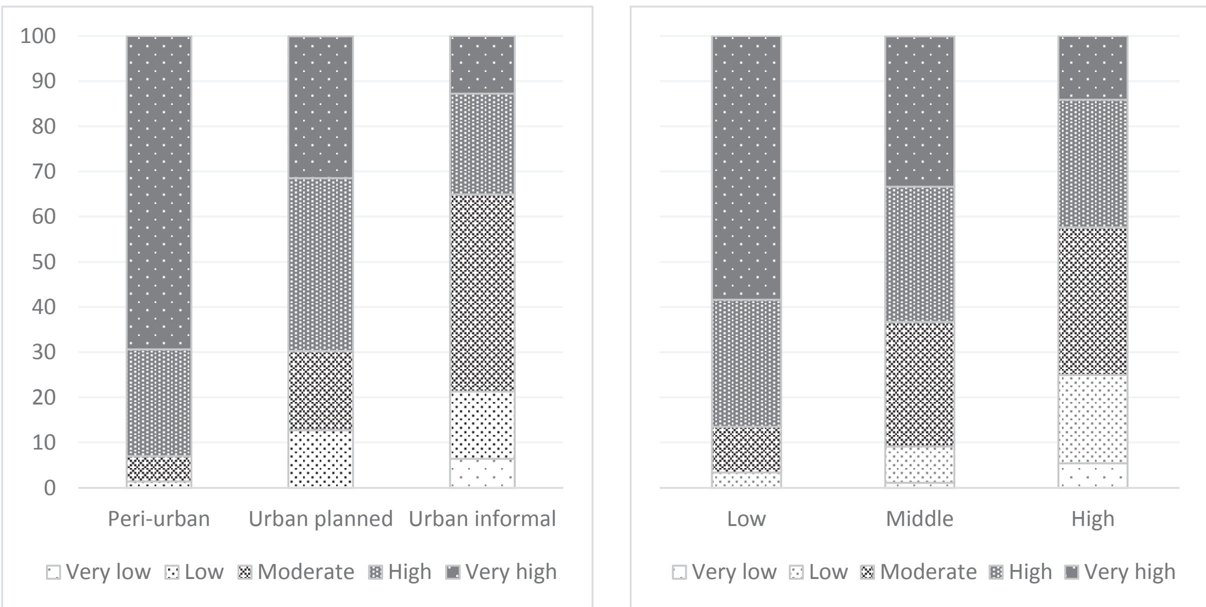


Figure 5-17: Distribution of percentages of households (within settlement and income groups) based on the level of perceptions for the cost of drinking water

5.7. Comparison and integrated assessment of drinking water supply indicators

To get a holistic understanding of drinking water supply in Nyamirambo, there was a need of making an integrated assessment of its main indicators such as physical access, duration of supply, quantity of water used, water quality, and expenditure for drinking water. Integrated assessment has allowed comparing different levels of achievement in terms of drinking water supply themselves and within different categories of water service beneficiaries.

5.7.1. Normalised indicators and levels of performance

To compare the levels of achievement or performance of drinking water supply indicators, it was needed to standardize these indicators given that they have different measurement units. As it is mentioned above (in chapter 3), all concerned indicators were normalized based on standards or targets established by the Government of Rwanda or World Health Organization. Physical access (distance to water sources) was standardized based on a range of 0-200 metres as an acceptable distance in urban areas. The duration of supply was standardised using 24 hours as the maximum duration of supply per day. For the quantity of drinking water per capita per day, the target is 80 litres. In terms of drinking water quality, the maximum is an index value of 1 given that drinking water must be without colour, taste, odour, and any contamination (microbiological) which is removed by treatment. For the affordability, the expenditure for drinking water was normalised based on a benchmark suggested by the World Bank (5%).

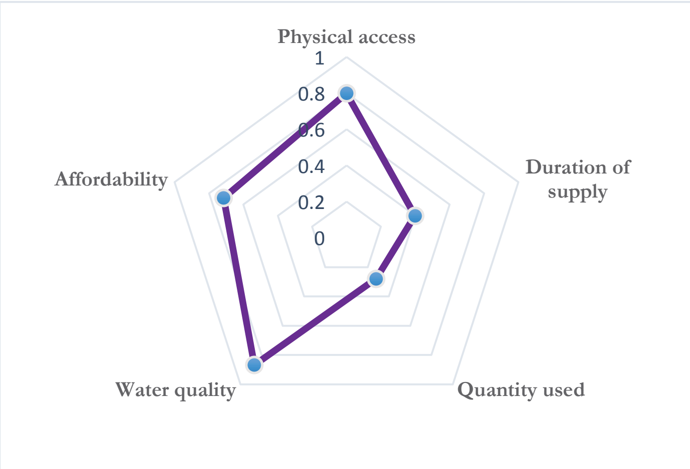


Figure 5-18: Performance levels of drinking water supply indicators

In general, the indicators of drinking water supply in Nyamirambo are not at the same level of achievement towards goals or targets established. Through the comparison of achievement levels of drinking water supply indicators using the spider chart (**Figure 5-18**); water quality is generally the indicator that is performing better than others are. At the second position comes the physical access to drinking water infrastructure. Conversely, the quantity of drinking water used constitutes the indicator that is very poorly performing. It is followed by the duration of supply and affordability.

Based on types of water sources, the performance levels are characterized by a specific pattern. The analysis looked at the situation of three main groups of water sources, specifically house connections, water kioks and other improved water sources, specifically tubewell, and handpumps, and rainwater collection. The outputs of descriptive statistics have revealed that households with private connection, in addition to its highest accessibility, are well serviced in terms of water quality (0.93), affordability (0.88), and quantity of water used per capita (0.33). They are, however, the most poorly serviced group in terms of duration of supply (0.14). As shown by **Figure 5-19**, there is not a large difference of performance levels between households using water kiosks and other improved water sources. The lowest levels of performance for the physical access to water (0.62), and affordability (0.52) were observed within households who get water from kiosks. The highest level of performance for the duration of supply (0.55) was found within households using tubewell, handpumps, and rainwater collection. This group had the lowest performance levels in terms of quantity of drinking water used (0.23), and water quality (0.78).

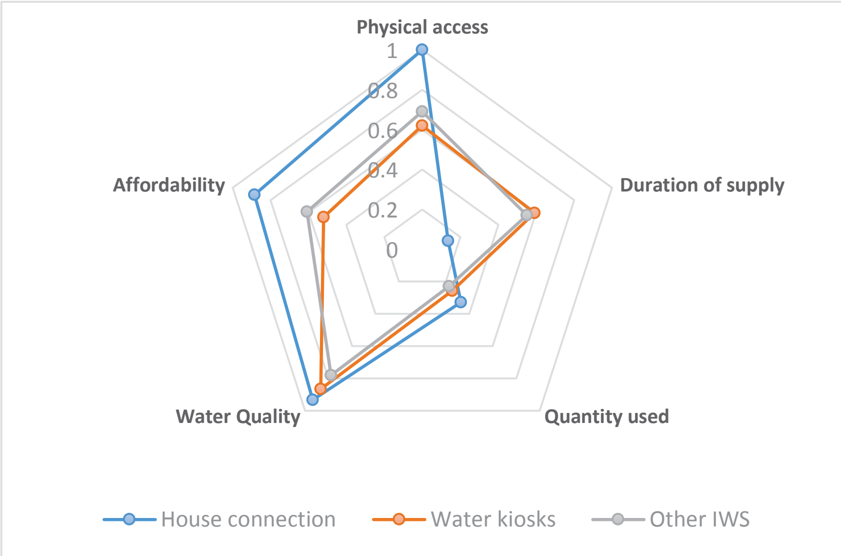


Figure 5-19: Achievement levels of drinking water supply based on types of water sources

In addition to the overall performance of drinking water supply indicators, the comparison of means applied to performance scores, as shown by **Figure 5-20**, has revealed different levels of performance. For the physical access, the high level of performance is experienced in the urban planned area (0.97) and high-income group (0.98). The lowest level of performance is prevalent in the peri-urban area (.47) and low-income group (.57) that are characterized by high variances within scores (std. dev. =.34 and .42). In terms of duration of supply, the level of performance is very high in the peri-urban area (0.74) and within low-income group (0.69). These two groups are also marked by high variances within scores; the standard deviation equals .39 in the peri-urban area and .42 within the low-income group. The lowest level of performance for the duration of supply is observed in the urban planned area (0.22) and high-income group (0.23).

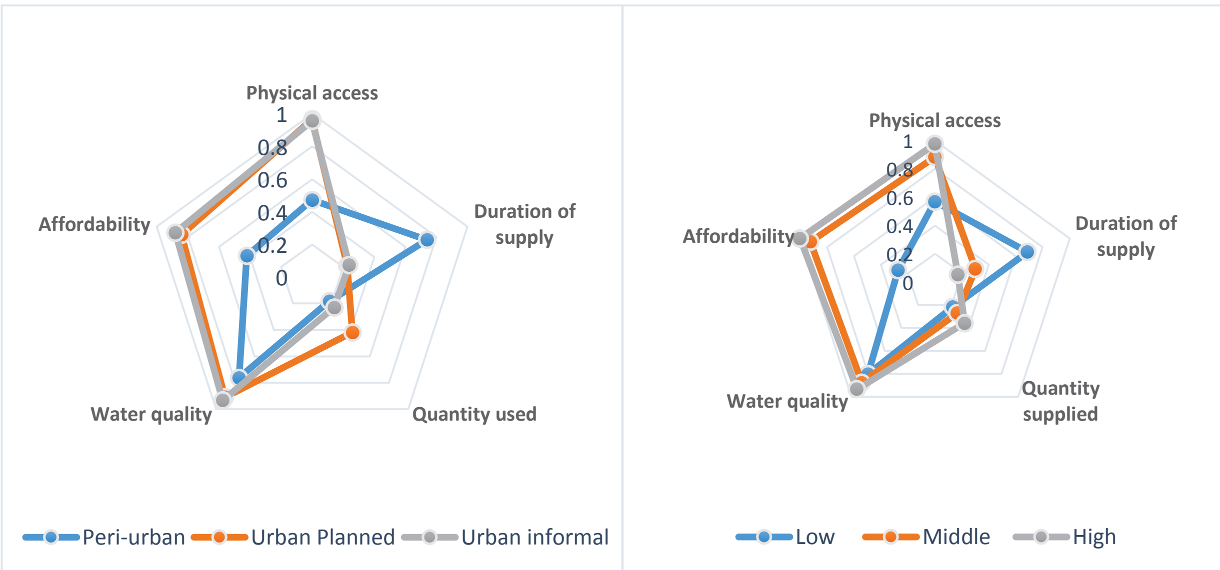


Figure 5-20: Achievement levels of drinking water supply within settlements and income groups

The achievement level for the quantity of drinking water used per capita per day is also high in the urban planned area (0.42) and high-income group (0.36). High variances of scores are also prevalent within these two groups; the standard deviation equals about .23 within observations from both urban planned area and high-income group. The peri-urban area and the low-income group are experiencing a low performance level (.18 and .22). In case of drinking water quality, high performance level (0.93) is found in the urban informal area and within the middle-income households. High variances of scores exist within the peri-urban area and in middle-income group. The low level of performance for water quality is predominant in the peri-urban area (0.76) and low-income group (0.80). In terms of affordability, high level of performance occurs in the urban planned area (0.84), informal area (0.88) and within the high-income group (1.00). The most disadvantaged in terms of affordability is the peri-urban area with an average score of 0.42 and the low-income group that has a score of 0.27.

Based on type of settlements and income groups, the achievement levels change significantly within them. As detailed by **Appendix: 6**, **Appendix: 7**, **Appendix: 8**, and **Appendix: 9**, the results of one-way ANOVA have revealed statistical significant differences between the achievement levels of five indicators separately (distance to water sources, duration of supply, water quantity, water quality, and affordability) between different types of settlements, and income groups.

On the contrary, the outputs of Tukey post-hoc (Multiple comparisons) have revealed the lack of significant difference of levels of achievement between some types of settlements and income groups. For the physical access, there is only no statistical significant difference of the achievement level between the urban planned and the informal areas (p=.71). In terms of duration of supply, the analysis has discovered the lack of statistical significant difference between urban planned and informal areas (p=.97). The level of performance of the peri-urban area in terms of the quantity of drinking water used is not significantly different from the one observed in the urban informal area (p=.08). The similar situation exists between the low-income group and the middle-income group (p=. 09). Regarding the quality of drinking water used, the difference in performance is statistically insignificant between the urban informal area and planned area (p=.51). In terms affordability for drinking water supplied, the levels of achievement differ significantly from one group to another (p<.05).

5.7.2. Index of drinking water supply

The average index value of drinking water supply developed from a combination of standardized values of all used indicators is around 0.63. As shown by **Figure 5-21**, this index varies within different types of settlement and income groups. High overall performance of drinking water supply is on average found in the urban planned area (0.69) and informal area (0.70), and high-income group (0.75). The peri-urban area and low-income group experience low performance (index values are 0.50 and 0.51).

Within settlements, the results of one-way ANOVA (see **Appendix: 7** and **Appendix: 9**) have revealed that the levels of achievement are statistically different between types of settlement combined (F (2,300) =130.4, p=.00). The outputs of Tukey post-hoc (Multiple Comparisons) have revealed a significant difference in levels of performance only between the peri-urban area and the urban planned area, the peri-urban area and the urban informal and vice versa (p<.05), while there is not any significant difference of performance levels between the urban planned area and the informal area (p=.96). Drinking Water Supply Index is, however, characterized by a significant difference of performance levels between income groups combined (F (2,300) =160.9, p=.00), and between all pairs (p<.00).

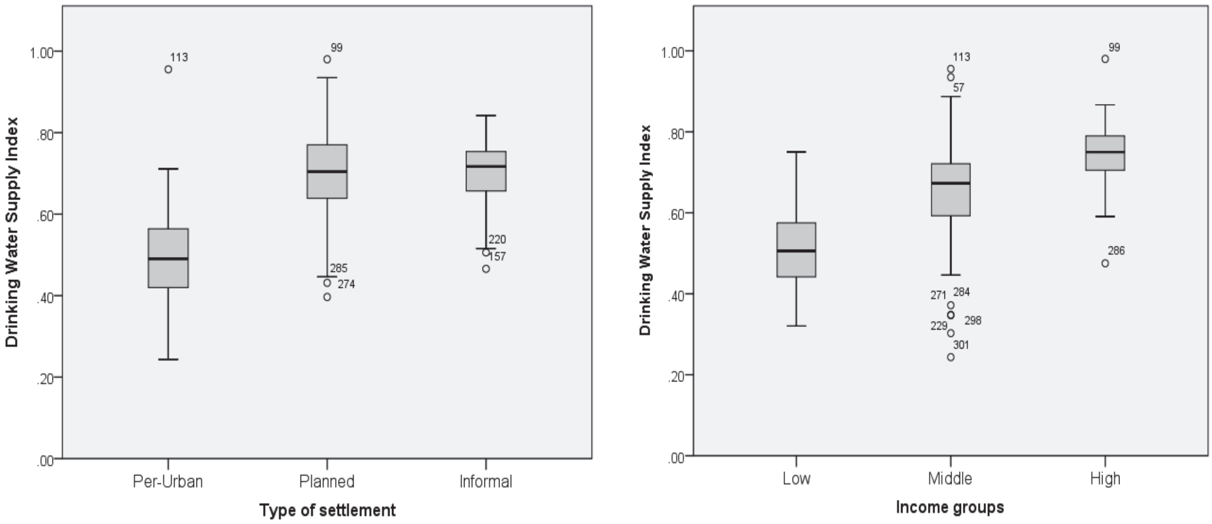


Figure 5-21: Boxplots of drinking Water Supply Index values by settlement and income groups

5.7.3. Spatial prediction of performance levels of drinking water supply indicators in Nyamirambo

The aim of this section was to display the spatial pattern of performance levels of drinking water supply indicators in the study area based on location of 303 surveyed households. The outputs of spatial interpolation, by "*Inverse Distance Weighting",* applied to performance levels of surveyed households in terms of drinking water have revealed spatial dissimilarities inside the study area. As demonstrated in the previous sections and displayed by **Figure 5-22**, the urbanized area (urban planned and informal areas) is generally well served than the peri-urban area. Urban areas have important high scores in terms of physical access, water quality and affordability level. The peri-urban area, specifically the south-western zone, is generally the worst serviced area, except in terms of duration of supply.

5.8. Concluding remark

The assessment of the performance of drinking water supply has taken into consideration five indicators, specifically physical access, duration of supply, quantity of water accessed, water quality and affordability. Each indicator was evaluated based on standard or goal established by either the Government of Rwanda, the World Health Organization, or the World Bank. Compared to each other, water quality is an indicator that is performing better than others are. The physical comes at the second position. Contrariwise, the quantity of water used is the indicator that is performing very poorly before the duration of supply and affordability. Applying statistical tests (one-way ANOVA and Tukey post-hoc) and spatial prediction (interpolation), the levels of performance are generally different between types settlements and income groups. The outputs have revealed that households surveyed living in urban areas and/or high-income groups are generally well serviced than those living in the peri-urban area, and/or the low-income groups.

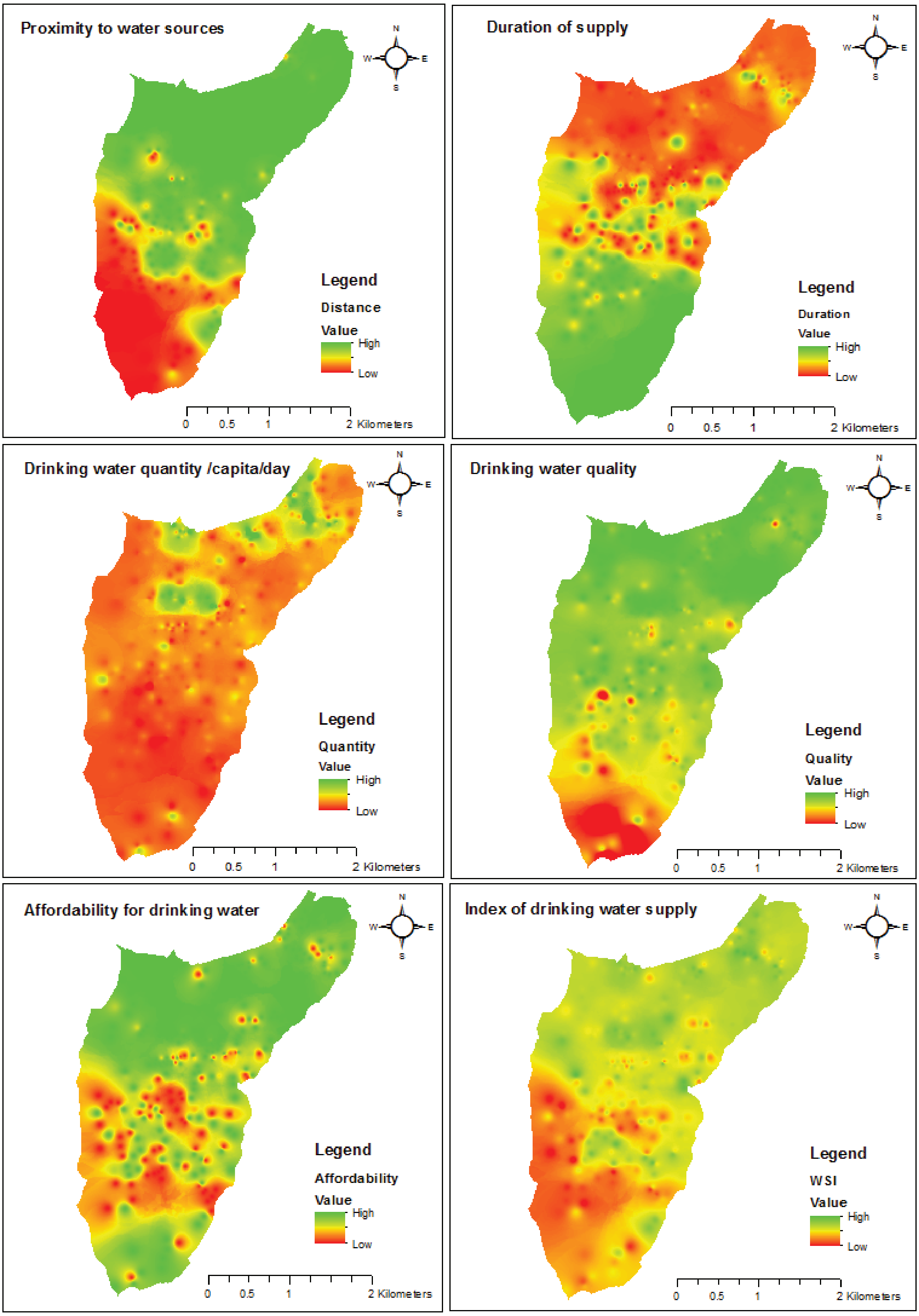


Figure 5-22: Predicted maps of performance levels of drinking water supply in Nyamirambo sector

6. CONCLUSION AND RECOMMENDATIONS

This section includes two main elements. The first comprises concluding remarks which intend to recapture the purpose of the research conducted, main concerns covered, and to give comments upon the results of research, and implications of results. The second part of this chapter involves the recommendations to solve the current problems related drinking water supply, and guidelines for future studies related to the topic or filling in the gaps with today understanding.

6.1. Conclusion

The goal of my research was to investigate the adequacy of drinking water supply in Kigali using a case study of Nyamirambo. Using some geospatial and statistical tools, we investigated the performance levels of main five indicators of drinking water supply towards standards or goals established by the Rwandan Government, the World Health Organization, and the World Bank.

Making use of data collected through household-based survey, direct observation, interviews, and documentation, several procedures were executed to determine the achievement levels in terms of physical access, duration of supply, and the quantity used per capita, quality and affordability for drinking water. For each step of the analysis, the diversity of the study area was taken into consideration. In addition to the overall presentation of scores, we looked at possible patterns existing within the population investigated. 303 households surveyed were somewhat equally distributed in three types of settlement (peri-urban, urban planned and informal), and three income groups.

To detect such patterns in drinking water supply indicators, one-way analysis of variance (ANOVA) and Tukey post-hoc tests were performed. One-way ANOVA was applied to examine the significance level of differences of means observed among above-mentioned groups, and of course the relationships. In addition to one-way ANOVA, Tukey post-hoc tests were performed to investigate if existing differences within groups as a whole also are significant for individual comparison. Proximity analysis based on Euclidean distance and spatial prediction of performance scores were used to illustrate the spatial pattern of drinking water supply.

Through the assessment of physical access (accessibility) to drinking water infrastructure, around 72 per cent of the households of Nyamirambo are well served. The average distance to water sources was estimated to 129 metres, a value that is defined within national requirement. In addition to significant differences between the peri-urban area and urbanized areas, and among income groups, the level of physical access to public water sources is, however, considerably reduced. Only 25% of households using water from public water sources are within 200 metres.

In general, the average duration of supply is too short (10 hours). Only 30% of households living in the study area use drinking water sources with a duration of supply of 24 hours a day, and many of them live in the peri-urban area and defined as low-income groups. The poor performance of duration of supply is significantly dominant in urban areas, which are supplied with water by the public utility – EWSA, whereas high level of performance is prevalent in the peri-urban area that is dominated by water sources managed by local authorities or communities.

Studying the variation of the quantity of drinking water used per capita, we find out that a very low percentage of households have reached the target suggested. Only 0.6% of households surveyed use drinking water equals or more than 80 litres per capita per day. All of them are detected in an the urban planned area, and within the high-income group. The mean quantity of drinking water used per capita per day was estimated to 22.4 litres. Despite this low level of performance, the third of the households are however satisfied with the quantity of drinking water used. Within households satisfied, the average quantity of drinking water used is too low, only 20 litres.

The quality of drinking water is not a great matter in Nyamirambo. A high proportion of households (85%) get water from a piped system whose the quality of the water is checked every day by proficient services. The index of drinking water quality developed using related parameters has shown a high performance (0.91) in general. This situation is a result of the use of improved water sources by most of the households and water treatment performed by either drinking water supplier or the user, and/or both.

Evaluating the expenditure of the households on drinking water based on the benchmark established by the World Bank (Fankhauser & Tepic, 2005), 66% of households are affording drinking water costs. The level of affordability is consistently low in the peri-urban area despite the existence of free open improved sources, and within low-income group. Only 35% of households living in the peri-urban area, and 18% of low-income households spend less than 5 per cent of their income for drinking water, whereas 82 of households living in the urban areas and 100% of high-income households are affording the cost of drinking water.

Through a comparative assessment of all indicators of drinking water supply towards goals established, Nyamirambo is generally marked by poor performance in terms of quantity of drinking water used and the duration of supply. Physical access and water quality occupy respectively high levels of performance. However, the analysis of performance levels approached based on types of settlement and income groups has revealed low performance levels prevailing in the peri-urban area and within the low-income group for three-quarters of drinking water supply indicators, namely affordability, physical access, and water quality.

Based on the results of an integrated assessment, the study has revealed a clear pattern in performance of drinking water supply in Nyamirambo. Households living in the peri-urban area and/or low-income group are more deprived than others are. This situation constitutes an indication of possible social and spatial segregation in terms of drinking water supply in the study area, which can be deeply investigated during future studies.

6.2. Recommendations

Thus, our research has shown the extent to which the study area is being supplied with drinking water towards standards and goals established, and the pattern of performance levels among different groups of people living Nyamirambo based on the type of neighbourhoods they are living in and their economic situation.

Given that the provision of drinking water might also respect the principle of equity (Guy Hutton, 2012), we recommend that all authorities and organizations involved take appropriate measures to reduce such disparities. Based on observed differences, there is a need of prioritizing area/group-based interventions, which should effectively target more deprived areas and groups in the study area.

Given that the households surveyed were randomly selected based only on the type of settlement they are living in, the study could not have sufficiently detected all possible patterns prevailing in drinking water supply in the study area. The future investigation of performance of drinking water supply would be based on high prior knowledge of the population to investigate, specifically its socio-economic situation and types of drinking water sources they are using. Taking proportional sample sizes will allow the analysis to come up with the results more statistically relevant in all circumstances.

As our research has only used standards or goals established to evaluate the level of performance of drinking water supply, the future assessment would also approach the same topic in a way that will systematically compare the levels of achievement towards both standards and specific water demand of the population.

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APPENDICES

Appendix: 1: Questionnaire addressed to households of Nyamirambo, Kigali

This research mainly concerns the assessment of adequacy of drinking-water supply using geo-spatial and statistical methods. We highly appreciates your support in answering the following questions, and guarantee you that the information provided will only be utilized for the research objectives and not for any other purpose, and be treated with full confidentiality. Besides, we will make proper acknowledgement of your contribution in the final document.

If you have any queries about this questionnaire, please contact me on (+250) 7 88 46 76 97 or t.barifashe@student.utwente.nl

Village: ………………………………………..

Cell: ……………………………………………

Names of Surveyor: ………………

GPS coordinates : Waypoint : ……….

X-coordinate: …………………..

Y-coordinate: ……………………

Type of settlement: Peri-urban ☐ Planned ☐ Informal ☐

A. **Household details**

1. Position in the family (respondent):
   - Husband ☐ - Wife ☐ - Other (specify): ………………
2. What is the education level of the family:

	Pre-primary	Primary	Post-primary	Secondary	University
Wife					
Husband					

3. Number of persons in a household: ………..
4. Number of bedrooms/house: …………
5. Construction Material:

1	baked bricks	
2	adobe bricks	
3	wood (ibiti)	
4	concrete blocks	
5	other (specify)	

6. Is the house the property of the family? Yes ☐ No ☐
7. Phones: mobile phones………….. Landline phones ………..
8. Ownership of vehicles: car …….. Motorcycle ……..bicycle …………… other ….

9. What is the average monthly income of the family (Rwandan francs) ………….

B. Water service provision and access

This section intends to detect the level at which the population living in Nyamirambo sector gets access to drinking-water using different indicators.

B.1. Type of drinking-water sources (all surveyed households).

1. Which source of water does the households get drinking water? (can be more than one)

Household connection		Unprotected dug well	
Water kiosk		Unprotected spring	
Hand pump		Container provided by water vendor	
Tube well or borehole		Surface water (river, dam, lake, pond, stream, canal, irrigation channel)	
Protected dug well		Bottled water	
Rainwater collection		Tanker truck provision of water	
Other (specify) :		Other (specify): ………….	

B.2. Questions only reserved for people having household connections

1. How many hours per day water is supplied (hours/day)? ……………
2. How many times per day water is supplied to the households? ……………….
3. How are you satisfied with the duration of drinking-water supply?

1	Very dissatisfied	
2	Somewhat dissatisfied	
3	neither satisfied nor dissatisfied	
4	Somewhat satisfied	
5	Very satisfied	

4. When is drinking water supplied? Day …… Night …… Both …….
5. How are you satisfied with the time of drinking-water supply?

1	Very dissatisfied	
2	Somewhat dissatisfied	
3	neither satisfied nor dissatisfied	
4	Somewhat satisfied	
5	Very satisfied	

6. Is the water availability varies along months? Yes No
7. Which months are marked by scarcity of drinking-water?

- January May September
- February June October
- March July November
- April August December

8. What is the average quantity of water (jerycans of 20 liters) per day does the family use? ……
9. How are satisfied with the quantity of drinking-water supplied?

1	Very dissatisfied	
2	Somewhat dissatisfied	
3	neither satisfied nor dissatisfied	
4	Somewhat satisfied	
5	Very satisfied	

10. How is the quality of water supplied?
    - ODOR: Smell No smell
    - TASTE: tasteful No taste
    - Clarity: Clear Not clear
11. Is there any family member who suffered of the following diseases in last three months?:
    - Diarrhea
    - Cholera
    - Typhoid
12. Do you treat yourself drinking-water supplied? Yes …. No…….
13. If yes, how do you proceed?
    - by boiling it
    - by using "Sur'eau"
    - filtering
    - Other (specify): ……………….
14. How are satisfied with the quality of drinking-water supply?

1	Very dissatisfied	
2	Somewhat dissatisfied	
3	neither satisfied nor dissatisfied	
4	Somewhat satisfied	
5	Very satisfied	

15. How much money do you spend for drinking water supplied per month? : ……….. (frw)
16. How do you consider the cost of drinking-water supply?

1	Very low	
2	Low	
3	Moderate	
4	High	
5	Very high	

B.2. Questions only reserved for people using water from public water sources (water kiosks, hand pumps, boreholes…)

1. Who is responsible of getting water from the source? : Husband ……… wife …….. Children ……..houseboy/girl …..
2. Who is the provider of the drinking water used by the family?
    - EWSA ……

- NGO …….
- Local community organization..…..
- Free/open water source…..

3. How many hours per day water is supplied/available (hours/day)? ……………
4. How are satisfied with the duration of drinking-water supply?

1	Very dissatisfied	
2	Somewhat dissatisfied	
3	neither satisfied nor dissatisfied	
4	Somewhat satisfied	
5	Very satisfied	

5. When is drinking water supplied? Day ……Night ……Both ……….
6. How are you satisfied with the time of drinking-water supply?

1	Very dissatisfied	
2	Somewhat dissatisfied	
3	neither satisfied nor dissatisfied	
4	Somewhat satisfied	
5	Very satisfied	

7. Is the water availability varies along months? Yes ………. No ………
8. Which months are marked by scarcity of drinking-water?

- January May September
- February June October
- March July November
- April August December

9. What is the average quantity of water (jerycans of 20 liters) per day does the family use?
10. How are you satisfied with the quantity of drinking-water supplied/used?

1	Very dissatisfied	
2	Somewhat dissatisfied	
3	neither satisfied nor dissatisfied	
4	Somewhat satisfied	
5	Very satisfied	

11. Where exactly do you get drinking-water (specify the name of the place or facility)? ………..
12. Is it the nearest water source? Yes …… No ……
13. If not, why?

1	high water price	
2	low discharge	
3	short duration of supply	
4	Inappropriate time of supply	
5	Other (specify): ………..	

14. How long does it take to get drinking-water from the source (one way-walking time/minutes): ………..

15. How long do you wait on the tap or other source of drinking-water (waiting time)? (Minutes) ……….
16. How do you find the time spent for fetching water?

1	very long	
2	long	
3	Moderate	
4	short	
5	Very short	

17. How is the quality of water supplied?
    - ODOR: Smell No smell
    - TASTE: tasteful No taste
    - Clarity: Clear Not clear
18. Is there any family member who suffered of the following diseases in last three months?
    - Diarrhea
    - Cholera
    - Typhoid
19. Do you treat yourself drinking-water supplied? Yes ………… No ……….
20. If yes, how do you proceed?
    - by boiling it
    - by using "Sur'eau"
    - filtering
    - Other (specify): ……………….
21. How are satisfied with the quality of drinking-water supply?

1	Very dissatisfied	
2	Somewhat dissatisfied	
3	Neither satisfied nor dissatisfied	
4	Somewhat satisfied	
5	Very satisfied	

22. How much money do you spend for drinking water supplied per month? : ……….. (frw)
23. How do you consider the cost of drinking-water supply?

1	Very low	
2	Low	
3	Moderate	
4	High	
5	Very high	

Appendix: 2: Outputs of one-way ANOVA test for drinking water supply indicators by settlement

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Distance to Improved Water Source	Between Groups	5929487.596	2	2964743.798	136.279	.000
	Within Groups	6526493.625	300	21754.979		
	Total	12455981.221	302			
Duration of water supply	Between Groups	9146.871	2	4573.436	74.003	.000
	Within Groups	18540.292	300	61.801		
	Total	27687.163	302			
Quantity_capita	Between Groups	20079.575	2	10039.788	53.202	.000
	Within Groups	56235.797	298	188.711		
	Total	76315.373	300			
WQI	Between Groups	.768	2	.384	37.764	.000
	Within Groups	3.052	300	.010		
	Total	3.820	302			
Expenditure	Between Groups	5903.039	2	2951.519	38.527	.000
	Within Groups	22982.722	300	76.609		
	Total	28885.761	302			

Appendix: 3: Outputs of Post Hoc test for drinking water supply indicators by settlement

Multiple Comparisons

Tukey HSD

Dependent Variable	(I) Type of settlement	(J) Type of settlement	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Distance to Water Source	Peri-urban	Planned	302.32080*	20.70660	.000	253.5484	351.0932
		Informal	292.26623*	20.85904	.000	243.1347	341.3977
	Planned	Peri-urban	-302.32080*	20.70660	.000	-351.0932	-253.5484
		Informal	-10.05457	20.70660	.878	-58.8270	38.7179
	Informal	Peri-urban	-292.26623*	20.85904	.000	-341.3977	-243.1347
		Planned	10.05457	20.70660	.878	-38.7179	58.8270
Duration of water supply	Peri-urban	Planned	11.815*	1.104	.000	9.22	14.41
		Informal	11.545*	1.112	.000	8.93	14.16
	Planned	Peri-urban	-11.815*	1.104	.000	-14.41	-9.22
		Informal	-.270	1.104	.967	-2.87	2.33
	Informal	Peri-urban	-11.545*	1.112	.000	-14.16	-8.93
		Planned	.270	1.104	.967	-2.33	2.87
Quantity_capita	Peri-urban	Planned	-19.04726*	1.92854	.000	-23.5899	-14.5046
		Informal	-4.63530*	1.95262	.048	-9.2347	-.0359
	Planned	Peri-urban	19.04726*	1.92854	.000	14.5046	23.5899
		Informal	14.41196*	1.93849	.000	9.8459	18.9781
	Informal	Peri-urban	4.63530*	1.95262	.048	.0359	9.2347
		Planned	-14.41196*	1.93849	.000	-18.9781	-9.8459
WQI	Peri-urban	Planned	-.09849*	.01416	.000	-.1318	-.0651
		Informal	-.11417*	.01426	.000	-.1478	-.0806
	Planned	Peri-urban	.09849*	.01416	.000	.0651	.1318
		Informal	-.01568	.01416	.510	-.0490	.0177
	Informal	Peri-urban	.11417*	.01426	.000	.0806	.1478
		Planned	.01568	.01416	.510	-.0177	.0490
Expenditure	Peri-urban	Planned	8.36137*	1.22877	.000	5.4671	11.2556
		Informal	10.17225*	1.23781	.000	7.2567	13.0878
	Planned	Peri-urban	-8.36137*	1.22877	.000	-11.2556	-5.4671
		Informal	1.81088	1.22877	.305	-1.0834	4.7051
	Informal	Peri-urban	-10.17225*	1.23781	.000	-13.0878	-7.2567
		Planned	-1.81088	1.22877	.305	-4.7051	1.0834

*. The mean difference is significant at the 0.05 level.

Appendix: 4: Outputs of one-way ANOVA test for drinking water supply indicators by income groups

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Distance to Improved Water Source	Between Groups	3569310.283	2	1784655.142	60.247	.000
	Within Groups	8886670.937	300	29622.236		
	Total	12455981.221	302			
Duration of water supply	Between Groups	7903.848	2	3951.924	59.928	.000
	Within Groups	19783.315	300	65.944		
	Total	27687.163	302			
Quantity_capita	Between Groups	7501.152	2	3750.576	16.242	.000
	Within Groups	68814.220	298	230.920		
	Total	76315.373	300			
WQI	Between Groups	.397	2	.198	17.383	.000
	Within Groups	3.423	300	.011		
	Total	3.820	302			
Expenditure	Between Groups	12650.921	2	6325.461	116.887	.000
	Within Groups	16234.840	300	54.116		
	Total	28885.761	302			
	Total	5.492	300			

Appendix: 5: Outputs of Post Hoc test for drinking water supply indicators by income groups

Multiple Comparisons

Tukey HSD

Dependent Variable	(I) Income_reclassified	(J) Income_reclassified	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Distance to Improved Water Source	Low	Middle	192.68271*	23.88519	.000	136.4234	248.9420
		High	251.29286*	24.20936	.000	194.2700	308.3157
	Middle	Low	-192.68271*	23.88519	.000	-248.9420	-136.4234
		High	58.61014*	24.65837	.047	.5297	116.6906
	High	Low	-251.29286*	24.20936	.000	-308.3157	-194.2700
		Middle	-58.61014*	24.65837	.047	-116.6906	-.5297
Duration of water supply	Low	Middle	8.903*	1.127	.000	6.25	11.56
		High	11.902*	1.142	.000	9.21	14.59
	Middle	Low	-8.903*	1.127	.000	-11.56	-6.25
		High	2.998*	1.163	.028	.26	5.74
	High	Low	-11.902*	1.142	.000	-14.59	-9.21
		Middle	-2.998*	1.163	.028	-5.74	-.26
Quantity_capita	Low	Middle	-4.42670	2.11440	.093	-9.4071	.5537
		High	-12.13608*	2.14354	.000	-17.1851	-7.0870
	Middle	Low	4.42670	2.11440	.093	-.5537	9.4071
		High	-7.70938*	2.18841	.001	-12.8641	-2.5546
	High	Low	12.13608*	2.14354	.000	7.0870	17.1851
		Middle	7.70938*	2.18841	.001	2.5546	12.8641
WQI	Low	Middle	-.04944*	.01482	.003	-.0844	-.0145
		High	-.08808*	.01503	.000	-.1235	-.0527
	Middle	Low	.04944*	.01482	.003	.0145	.0844
		High	-.03864*	.01530	.032	-.0747	-.0026
	High	Low	.08808*	.01503	.000	.0527	.1235
		Middle	.03864*	.01530	.032	.0026	.0747
Expenditure	Low	Middle	12.42323*	1.02090	.000	10.0186	14.8279
		High	14.40528*	1.03476	.000	11.9680	16.8425
	Middle	Low	-12.42323*	1.02090	.000	-14.8279	-10.0186
		High	1.98205	1.05395	.146	-.5004	4.4645
	High	Low	-14.40528*	1.03476	.000	-16.8425	-11.9680
		Middle	-1.98205	1.05395	.146	-4.4645	.5004
		Middle	.09541*	.01356	.000	.0635	.1273

*. The mean difference is significant at the 0.05 level.

Appendix: 6: One-way ANOVA outputs of standardized indicators by settlement

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Distance_std	Between Groups	16.114	2	8.057	100.794	.000
	Within Groups	23.980	300	.080		
	Total	40.094	302			
Duration_std	Between Groups	17.284	2	8.642	73.995	.000
	Within Groups	35.037	300	.117		
	Total	52.321	302			
Quantity_std	Between Groups	3.210	2	1.605	63.281	.000
	Within Groups	7.608	300	.025		
	Total	10.818	302			
WQI_std	Between Groups	1.711	2	.856	37.764	.000
	Within Groups	6.798	300	.023		
	Total	8.509	302			
Affordability_std	Between Groups	13.009	2	6.505	46.168	.000
	Within Groups	42.267	300	.141		
	Total	55.276	302			
WSI	Between Groups	2.563	2	1.281	130.364	.000
	Within Groups	2.929	298	.010		
	Total	5.492	300			

Appendix: 7: Outputs of Post Hoc Tests of standardized indicators by settlement

Multiple Comparisons
Tukey HSD

Dependent Variable	(I) Type of settlement	(J) Type of settlement	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Distance_std	Peri-urban	Planned	-.49532*	.03969	.000	-.5888	-.4018
		Informal	-.48522*	.03998	.000	-.5794	-.3910
	Planned	Peri-urban	.49532*	.03969	.000	.4018	.5888
		Informal	.01009	.03969	.965	-.0834	.1036
	Informal	Peri-urban	.48522*	.03998	.000	.3910	.5794
		Planned	-.01009	.03969	.965	-.1036	.0834
Duration_std	Peri-urban	Planned	.51371*	.04798	.000	.4007	.6267
		Informal	.50174*	.04833	.000	.3879	.6156
	Planned	Peri-urban	-.51371*	.04798	.000	-.6267	-.4007
		Informal	-.01197	.04798	.966	-.1250	.1010
	Informal	Peri-urban	-.50174*	.04833	.000	-.6156	-.3879
		Planned	.01197	.04798	.966	-.1010	.1250
Quantity_std	Peri-urban	Planned	-.23753*	.02236	.000	-.2902	-.1849
		Informal	-.04855	.02252	.081	-.1016	.0045
	Planned	Peri-urban	.23753*	.02236	.000	.1849	.2902
		Informal	.18898*	.02236	.000	.1363	.2416
	Informal	Peri-urban	.04855	.02252	.081	-.0045	.1016
		Planned	-.18898*	.02236	.000	-.2416	-.1363
WQI_std	Peri-urban	Planned	-.14700*	.02113	.000	-.1968	-.0972
		Informal	-.17040*	.02129	.000	-.2205	-.1203
	Planned	Peri-urban	.14700*	.02113	.000	.0972	.1968
		Informal	-.02340	.02113	.510	-.0732	.0264
	Informal	Peri-urban	.17040*	.02129	.000	.1203	.2205
		Planned	.02340	.02113	.510	-.0264	.0732
Affordability_std	Peri-urban	Planned	-.41935*	.05269	.000	-.5435	-.2952
		Informal	-.45974*	.05308	.000	-.5848	-.3347
	Planned	Peri-urban	.41935*	.05269	.000	.2952	.5435
		Informal	-.04039	.05269	.724	-.1645	.0837
	Informal	Peri-urban	.45974*	.05308	.000	.3347	.5848
		Planned	.04039	.05269	.724	-.0837	.1645

WSI	Peri-urban	Planned	-.19409*	.01392	.000	-.2269	-.1613
		Informal	-.19776*	.01409	.000	-.2310	-.1646
	Planned	Peri-urban	.19409*	.01392	.000	.1613	.2269
		Informal	-.00367	.01399	.963	-.0366	.0293
	Informal	Peri-urban	.19776*	.01409	.000	.1646	.2310
		Planned	.00367	.01399	.963	-.0293	.0366

*. The mean difference is significant at the 0.05 level.

Appendix: 8: One-way ANOVA outputs of standardized indicators by income group

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Distance_std	Between Groups	9.432	2	4.716	46.144	.000
	Within Groups	30.662	300	.102		
	Total	40.094	302			
Duration_std	Between Groups	14.931	2	7.466	59.901	.000
	Within Groups	37.390	300	.125		
	Total	52.321	302			
Quantity_std	Between Groups	1.015	2	.508	15.535	.000
	Within Groups	9.803	300	.033		
	Total	10.818	302			
WQI_std	Between Groups	.884	2	.442	17.383	.000
	Within Groups	7.625	300	.025		
	Total	8.509	302			
Affordability_std	Between Groups	33.177	2	16.589	225.205	.000
	Within Groups	22.098	300	.074		
	Total	55.276	302			
WSI	Between Groups	2.852	2	1.426	160.944	.000
	Within Groups	2.640	298	.009		
	Total	5.492	300			

Appendix: 9: Outputs of Post Hoc Tests of standardized indicators by income groups

Multiple Comparisons
Tukey HSD

Dependent Variable	(I) Income_reclassified	(J) Income_reclassified	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Distance_std	Low	Middle	-.31493*	.04437	.000	-.4194	-.2104
		High	-.40767*	.04497	.000	-.5136	-.3017
	Middle	Low	.31493*	.04437	.000	.2104	.4194
		High	-.09274	.04580	.108	-.2006	.0151
	High	Low	.40767*	.04497	.000	.3017	.5136
		Middle	.09274	.04580	.108	-.0151	.2006
Duration_std	Low	Middle	.38710*	.04899	.000	.2717	.5025
		High	.51724*	.04966	.000	.4003	.6342
	Middle	Low	-.38710*	.04899	.000	-.5025	-.2717
		High	.13014*	.05058	.028	.0110	.2493
	High	Low	-.51724*	.04966	.000	-.6342	-.4003
		Middle	-.13014*	.05058	.028	-.2493	-.0110
Quantity_std	Low	Middle	-.05322	.02509	.087	-.1123	.0059
		High	-.14096*	.02543	.000	-.2009	-.0811
	Middle	Low	.05322	.02509	.087	-.0059	.1123
		High	-.08774*	.02590	.002	-.1487	-.0267
	High	Low	.14096*	.02543	.000	.0811	.2009

		Middle	.08774*	.02590	.002	.0267	.1487
WQI_std	Low	Middle	-.07380*	.02213	.003	-.1259	-.0217
		High	-.13147*	.02243	.000	-.1843	-.0786
	Middle	Low	.07380*	.02213	.003	.0217	.1259
		High	-.05767*	.02284	.032	-.1115	-.0039
	High	Low	.13147*	.02243	.000	.0786	.1843
		Middle	.05767*	.02284	.032	.0039	.1115
Affordability_std	Low	Middle	-.65028*	.03766	.000	-.7390	-.5616
		High	-.72744*	.03818	.000	-.8174	-.6375
	Middle	Low	.65028*	.03766	.000	.5616	.7390
		High	-.07716	.03888	.118	-.1687	.0144
	High	Low	.72744*	.03818	.000	.6375	.8174
		Middle	.07716	.03888	.118	-.0144	.1687
WSI	Low	Middle	-.14020*	.01310	.000	-.1710	-.1093
		High	-.23560*	.01328	.000	-.2669	-.2043
	Middle	Low	.14020*	.01310	.000	.1093	.1710
		High	-.09541*	.01356	.000	-.1273	-.0635
	High	Low	.23560*	.01328	.000	.2043	.2669
		Middle	.09541*	.01356	.000	.0635	.1273

*. The mean difference is significant at the 0.05 level.

Appendix: 10: Outputs of Tukey Post-hoc test of duration of supply and level of satisfaction, and means plot

Multiple Comparisons

Dependent Variable: Duration of water supply

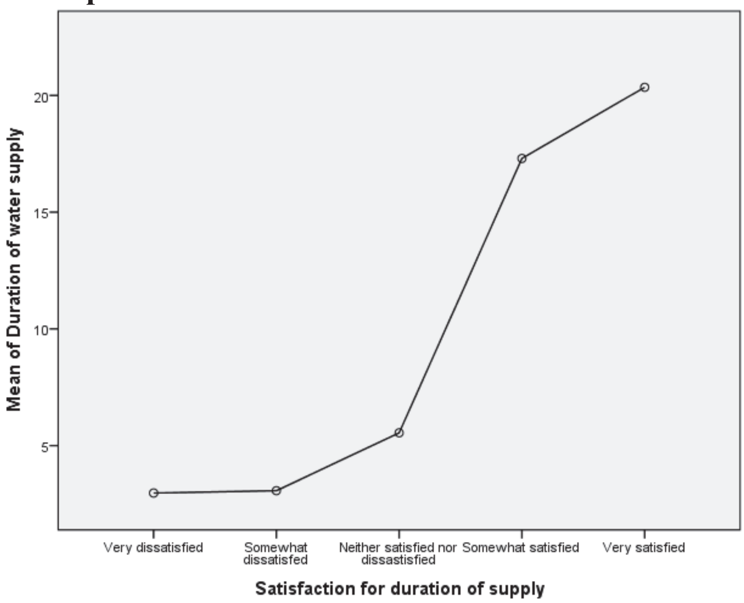
Tukey HSD

(I) Satisfaction for duration of supply	(J) Satisfaction for duration of supply	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Very dissatisfied	Somewhat dissatisfed	-.100	1.451	1.000	-4.08	3.88
	Neither satisfied nor dissastisfied	-2.579	1.051	.105	-5.46	.31
	Somewhat satisfied	-14.333*	.921	.000	-16.86	-11.80
	Very satisfied	-17.379*	1.079	.000	-20.34	-14.42
Somewhat dissatisfed	Very dissatisfied	.100	1.451	1.000	-3.88	4.08
	Neither satisfied nor dissastisfied	-2.479	1.555	.503	-6.75	1.79
	Somewhat satisfied	-14.233*	1.471	.000	-18.27	-10.20
	Very satisfied	-17.279*	1.574	.000	-21.60	-12.96
Neither satisfied nor dissastisfied	Very dissatisfied	2.579	1.051	.105	-.31	5.46
	Somewhat dissatisfed	2.479	1.555	.503	-1.79	6.75
	Somewhat satisfied	-11.754*	1.078	.000	-14.71	-8.79
	Very satisfied	-14.800*	1.215	.000	-18.14	-11.46
Somewhat satisfied	Very dissatisfied	14.333*	.921	.000	11.80	16.86
	Somewhat dissatisfed	14.233*	1.471	.000	10.20	18.27

	Neither satisfied nor dissastisfied	11.754*	1.078	.000	8.79	14.71
	Very satisfied	-3.046*	1.105	.048	-6.08	-.01
Very satisfied	Very dissatisfied	17.379*	1.079	.000	14.42	20.34
	Somewhat dissatisfed	17.279*	1.574	.000	12.96	21.60
	Neither satisfied nor dissastisfied	14.800*	1.215	.000	11.46	18.14
	Somewhat satisfied	3.046*	1.105	.048	.01	6.08

*. The mean difference is significant at the 0.05 level.

Means plot



Appendix: 11: Outputs of Tukey post-hoc test for the quantity of drinking water accessed and level of satisfaction

Multiple Comparisons

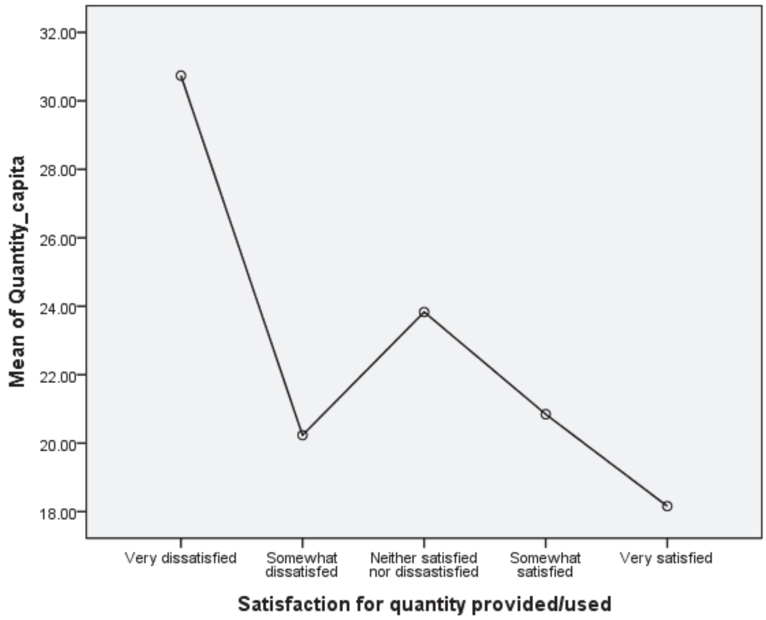
Dependent Variable: Quantity_capita
Tukey HSD

(I) Satisfaction for quantity provided/used	(J) Satisfaction for quantity provided/used	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Very dissatisfied	Somewhat dissatisfed	10.50380*	3.35129	.016	1.3053	19.7024
	Neither satisfied nor dissastisfied	6.90641	3.16776	.190	-1.7884	15.6012
	Somewhat satisfied	9.89266*	3.34294	.027	.7170	19.0683
	Very satisfied	12.57900*	3.78825	.009	2.1811	22.9769
Somewhat dissatisfed	Very dissatisfied	-10.50380*	3.35129	.016	-19.7024	-1.3053
	Neither satisfied nor dissastisfied	-3.59739	2.50818	.606	-10.4818	3.2870
	Somewhat satisfied	-.61115	2.72608	.999	-8.0937	6.8714
	Very satisfied	2.07520	3.25686	.969	-6.8642	11.0146
Neither satisfied nor dissastisfied	Very dissatisfied	-6.90641	3.16776	.190	-15.6012	1.7884
	Somewhat dissatisfed	3.59739	2.50818	.606	-3.2870	10.4818

	Somewhat satisfied	2.98625	2.49702	.754	-3.8675	9.8400
	Very satisfied	5.67259	3.06769	.347	-2.7475	14.0927
Somewhat satisfied	Very dissatisfied	-9.89266*	3.34294	.027	-19.0683	-.7170
	Somewhat dissatisfed	.61115	2.72608	.999	-6.8714	8.0937
	Neither satisfied nor dissastisfied	-2.98625	2.49702	.754	-9.8400	3.8675
	Very satisfied	2.68635	3.24828	.922	-6.2295	11.6022
Very satisfied	Very dissatisfied	-12.57900*	3.78825	.009	-22.9769	-2.1811
	Somewhat dissatisfed	-2.07520	3.25686	.969	-11.0146	6.8642
	Neither satisfied nor dissastisfied	-5.67259	3.06769	.347	-14.0927	2.7475
	Somewhat satisfied	-2.68635	3.24828	.922	-11.6022	6.2295

*. The mean difference is significant at the 0.05 level.

Means plot



Appendix: 12: Outputs of Tukey post-hoc of Water quality index and levels of satisfaction

Multiple Comparisons

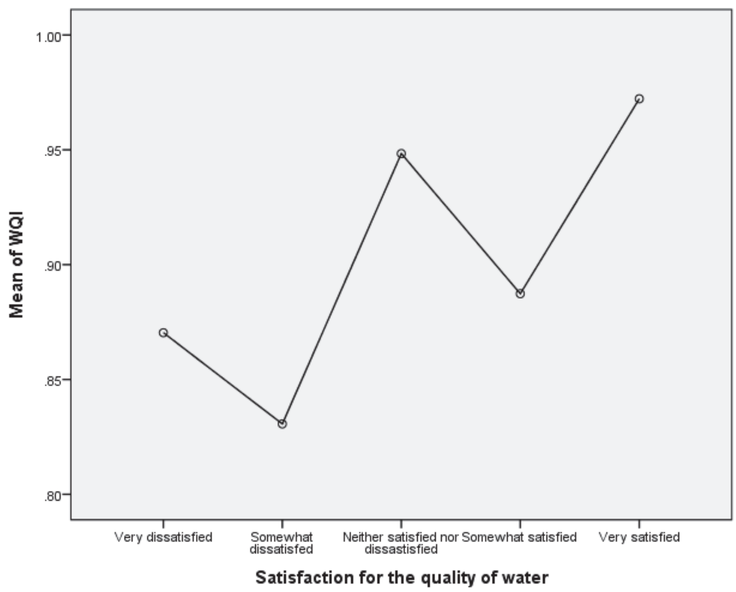
Dependent Variable: WQI
Tukey HSD

(I) Satisfaction for the quality of water	(J) Satisfaction for the quality of water	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Very dissatisfied	Somewhat dissatisfed	.03973	.04030	.862	-.0709	.1503
	Neither satisfied nor dissastisfied	-.07799	.03658	.209	-.1784	.0224
	Somewhat satisfied	-.01698	.03692	.991	-.1183	.0844
	Very satisfied	-.10185	.05609	.366	-.2558	.0521
Somewhat dissatisfed	Very dissatisfied	-.03973	.04030	.862	-.1503	.0709
	Neither satisfied nor dissastisfied	-.11771*	.02110	.000	-.1756	-.0598
	Somewhat satisfied	-.05670	.02168	.070	-.1162	.0028
	Very satisfied	-.14158*	.04747	.026	-.2719	-.0113
Neither satisfied nor dissastisfied	Very dissatisfied	.07799	.03658	.209	-.0224	.1784
	Somewhat dissatisfed	.11771*	.02110	.000	.0598	.1756
	Somewhat satisfied	.06101*	.01359	.000	.0237	.0983

	Very satisfied	-.02387	.04436	.983	-.1456	.0979
Somewhat satisfied	Very dissatisfied	.01698	.03692	.991	-.0844	.1183
	Somewhat dissatisfed	.05670	.02168	.070	-.0028	.1162
	Neither satisfied nor dissastisfied	-.06101*	.01359	.000	-.0983	-.0237
	Very satisfied	-.08488	.04464	.319	-.2074	.0377
Very satisfied	Very dissatisfied	.10185	.05609	.366	-.0521	.2558
	Somewhat dissatisfed	.14158*	.04747	.026	.0113	.2719
	Neither satisfied nor dissastisfied	.02387	.04436	.983	-.0979	.1456
	Somewhat satisfied	.08488	.04464	.319	-.0377	.2074

*. The mean difference is significant at the 0.05 level.

Means plot



Appendix: 13: Outputs of Tukey post-hoc for the perceptions of the cost of drinking water

Multiple Comparisons

Dependent Variable: Expenditure

Tukey HSD

(I) Satisfaction for drinking water cost	(J) Satisfaction for drinking water cost	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Very low	Low	-.96679	3.83803	.999	-11.5091	9.5755
	Moderate	-1.57441	3.64504	.993	-11.5866	8.4378
	High	-4.65494	3.61611	.699	-14.5877	5.2778
	Very high	-11.05096*	3.59239	.019	-20.9185	-1.1834
Low	Very low	.96679	3.83803	.999	-9.5755	11.5091
	Moderate	-.60762	1.93774	.998	-5.9302	4.7149
	High	-3.68815	1.88275	.289	-8.8597	1.4834
	Very high	-10.08417*	1.83679	.000	-15.1295	-5.0389

Moderate	Very low	1.57441	3.64504	.993	-8.4378	11.5866
	Low	.60762	1.93774	.998	-4.7149	5.9302
	High	-3.08053	1.44934	.212	-7.0616	.9005
	Very high	-9.47655*	1.38912	.000	-13.2922	-5.6609
High	Very low	4.65494	3.61611	.699	-5.2778	14.5877
	Low	3.68815	1.88275	.289	-1.4834	8.8597
	Moderate	3.08053	1.44934	.212	-.9005	7.0616
	Very high	-6.39602*	1.31133	.000	-9.9980	-2.7941
Very high	Very low	11.05096*	3.59239	.019	1.1834	20.9185
	Low	10.08417*	1.83679	.000	5.0389	15.1295
	Moderate	9.47655*	1.38912	.000	5.6609	13.2922
	High	6.39602*	1.31133	.000	2.7941	9.9980

*. The mean difference is significant at the 0.05 level.

Means plot