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Presented by

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ASSESSING THE SUSTAINABILITY OF DECENTRALIZED WASTEWATER TREATMENT SYSTEMS (DWWTS's) IN THE CITIES OF DEVELOPING COUNTRIES;

Case Study: Kigali City, Rwanda

Defended on 04th September, 2018 In front of the Following Committee:

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DECLARATION

I **Amos SHYAKA KAZORA**, hereby declare that this thesis represents my personal work, realized to the best of my knowledge. I also declare that all information, material and results from other works that are presented here, have been fully cited and referenced in accordance with the academic rules and ethics.

Amos SHYAKA KAZORA

Supervisor

This thesis has been submitted for the fulfilment of the requirements of the Master of Science, Water Policy track from Pan African University, Institute of Water and Energy Sciences.

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ABSTRACT

PREAMBLE

Lack of scientific knowledge in wastewater treatment systems together with imperfect sanitation legal instruments are considered, among others, the key constraints to sustainable wastewater management systems in the cities of developing countries including Kigali city. Kigali city has increasingly shown failures of such wastewater treatment systems strictly in decentralized wastewater treatment systems. Densely populated cities of poor resourced countries like Kigali largely rely on decentralized wastewater management systems due to the absence of central sewerage systems and limited finances for the development of safe and sustainable sanitation infrastructures. Decentralized wastewater treatment systems reveals on-site sanitation systems either at individual or collective levels. This study aims to assess the sustainability of the existing collective semi-centralized wastewater treatment plants in the estates of Kigali city that are said to be in operation. The research used field observation, questionnaires, structured interviews, and laboratory tests of the analyzed parameters methods in order to protect the ecosystem and safeguard community health. The study also reviewed the influence of national ruling sanitation legal instruments in addressing development, operation and management of such decentralized wastewater treatment plants. The results of this study showed sustainability level of technical dimension at 3.77 with less sustainable status, environmental quality at 5.75 with fairly sustainable status, socio-economic status dimension at 3.53 with less sustainable status, and finally institutional and legal dimension at 3.98 with also less sustainable status.

Therefore, all the weight dimensions rated the sustainability level of collective public semi-centralized wastewater treatment systems of Kigali city as Less Sustainable with 4.26 aggregate. In conclusion, the research highlighted that improved sanitation coverage doesn't mean coverage in terms of sewerage connection proportions for wastewater collection, and the sewerage connections also does not imply wastewater treatment before being discharged.

Keywords: Discharge, Effluent, Legal instruments, Semi-centralized sewerage system, Sewage treatment plant, and Wastewater quality.

DEDICATION

To My Only One Lovely, Odeth MUHONGERWA.

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LIST OF ACRONYMS & ABBREVIATIONS

AIT: Asian Institute of Technology.

BOD: Biochemical Oxygen Demand.

CAPEX: Capital expenditures.

COD: Chemical Oxygen Demand.

CoK: City of Kigali.

DO: Dissolved Oxygen.

DWM: Decentralized Wastewater Management.

DWWTSs: Decentralized Wastewater Treatment Systems.

DWWTPs: Decentralized Wastewater Treatment Plants.

EICV: Enquête Intégrale sur les Conditions de Vie des ménages.

EPA: Environmental Protection Agency.

FAO: Food and Agriculture Organizations of the United Nation

FSTP: Faecal Sludge Treatment Plant.

IHLCS: Integrated Household Living Conditions Survey.

Ltd: Limited.

MININFRA: Ministry of Infrastructures.

MoH: Ministry of Health.

NISR: National Institute of Statistics Rwanda.

NSPS: National Sanitation Policy and Strategy.

OPEX: Operation Expenditures.

REMA: Rwanda Environmental Management Authority.

RSB: Rwanda Standards Board.

RURA: Rwanda Utilities Regulatory Authority.

SBRs: Sequencing Batch Reactors.

SCWWTPs: Semi-Centralized Wastewater Treatment Plants.

SCSSs: Semi-Centralized Sewerage Systems.

STP: Sewage Treatment Plant.

TDS: Total Dissolved Solids.

TS: Total Solids.

TSS: Total Suspended Solids.

UN: United Nations.

UNESCAP: United Nations Economic and Social Commission for Asia and the Pacific.

UNESCO: United Nations Educational, Scientific and Cultural Organization.

VSS: Volatile Suspended Solids.

WASAC: Water and Sanitation Corporation.

WWC: World Water Council.

WW: Wastewater.

WWT: Wastewater Treatment.

WWTP: Wastewater Treatment Plant.

WWTU: Wastewater Treatment Unit.

WWF: World Water Forum.

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DEFINITION OF OPERATIONAL TERMS

Sustainability: This is an intergenerational equity of environmental, financial (social economic), and technical deliberations that meets the needs of the present generation without compromising the ability of future generations to meet their own needs (Erik et al., 2013). Water sustainability simply means long-lasting benefits attained through the practices of continuous enjoyment of water supply, sanitation and hygiene services (WaterAid, 2011).

Decentralized wastewater treatment systems (DWWTS): These systems are used for the collection, treatment, and disposal/reuse of wastewaters from individual homes, clusters of homes (estates), isolated communities (that are relatively located close to each other), industries, or institutional facilities, at or near the point of waste generation (Humble M. Sibooli, 2013; Kiernan et al., 2012). This research will study/investigate the wastewater produced from individual homes constructed as clusters of homes hereinafter called estates.

These systems can either involve aerobic or anaerobic wastewater treatment systems or both of them, but this research will focus on the aerobic wastewater treatment system since it is the one installed and used in the wastewater treatment units of Kigali city estates;

Aerobic wastewater treatment system: Is a microbial reactions system that takes place in the presence of molecular / free oxygen and the reaction products are carbon dioxide, water and excess biomass (Arun et al., 2011).

There are commonly high technologies used in aerobic wastewater treatment system, which include activated sludge, trickling filters, bio-filters, oxidation ditches, rotating biological contactors (RBC), sequencing batch reactor (SBR) and lagoons. A combination of two of these technologies in series (e.g., activated sludge followed by bio-filter) can be used depending on the contamination level of the wastewater (FAO, 2017). The existing semi-centralized wastewater treatment plants of Kigali city estates to be assessed in this study, use either activated sludge processes or sequencing batch reactor (SBR) though the disinfection part may use different technologies.

CHAPTER ONE: INTRODUCTION

1.1 Background

1.1.1 Theoretical background

In general, sanitation is one of the critical infrastructure sectors and essential to well-being of humans and environmental health for sustainable development (E Bahar et al. 2017). The lack of sanitation and wastewater management practices in the developing countries have led to fresh water deterioration, which in its turn increase diseases and death and also affects the ecosystems. 80-90% of all generated wastewaters in developing countries are discharged directly into surface water bodies without any treatment (UNESCAP, 2015).

Management of wastewater has been proven to be among the problems that the world is facing mainly due to increasing population density, great urbanized cities, and expansive industrialization but in most industrialized countries, safe water is supplied to population and wastewater pollution control has been progressively considered. (McCasland et al., 2008) as cited by (Akpor, et al 2011).

One of the extreme challenges in the development of the growing cities of low-income countries like Rwanda, is providing people with access to sanitation (Tayler. T, 2010) and this have relevant relation towards economic performance of any developing country, on the other hand considerably it's impacts results mostly from inadequate and incomplete sanitation infrastructures (Humble M. Sibooli, 2013).

Deficiency access to safe and adequate sanitation in urban low and moderate income households is due to the absence of infrastructures that can meet the increasing demand. Out of over billion people in Sub-Saharan Africa, 695 million people are lacking access to basic sanitation (UN WWAP Report, 2017) and this number increased from 565 million people in 2006 according to (UNDP, 2006) report of that time.

In the low and middle-income countries, the situation is worse mainly where there is lower coverage of sanitation services; the water-borne diseases persist extensively due to the dependence on contaminated surface water with an estimation of 842,000 deaths in 2012 triggered by contaminated drinking water and inadequate sanitation services (WHO, 2014).

Therefore, most developing cities lack adequate wastewater management due to the absent or inadequate sewerage infrastructures (World water council, 2012) and all 62% of urban population in Sub-Saharan Africa, dispose uncollected wastewater without proper treatment to surface water drainage channels, trenches and waterways with high levels of toxicity to the public health and environment due to lack of sanitation drainage and infrastructures (UN WWAP Report, 2017).

In the 1990s, an international network of agencies and NGOs drew conclusions about the deficiencies of existing infrastructure development and produced the so-called "decentralized wastewater treatment systems approach". Decentralized wastewater treatment systems are designed to be an element of comprehensive wastewater strategies: not only the technical requirements for the efficient treatment of wastewater at a given location, but also the specific socioeconomic conditions were taken into consideration (Bernd Gutterer et al, 2009).

The majority of under-resourced developing countries has made investment in social infrastructures to wane the investment in the construction, operation, and management of wastewater treatment systems (Nurudeen et al, 2016). Consequently, the danger naturally leads to unsafe wastewater and poor sewage disposal thus poor sanitation abounded. This tragic scenario was also richly captured by a World Bank report thus: ‘‘microbial diseases—costing billions of dollars in lost lives and unhealthy workers—are endemic in the poorest parts of most cities of the developing world. In these areas, water resources are contaminated and sanitation facilities are negligible or non-existent. Unfortunately, this same scenario persists in most parts of the under-resourced regions of the world until the "present-day" (Nurudeen et al, 2016).

Despite the fact that Rwanda as a country achieved MDG targets on improved sanitation, it is easy to ensure that there are still unsafe and unreliable decentralized wastewater treatment practices for wastewater before discharging into the environment. Largely, wastewater treatment is failing as a result, the majority of wastewaters, septage and feacal sludge are discharged into the environment without any form of treatment spreading disease to humans and damaging key ecosystems (UN-Water Brief, 2015).

The present Sustainable Development Goal no. 6 goes beyond drinking water, to sanitation and hygiene for all in order to address the quality and sustainability of water resources thereby ensuring availability and sustainable management of water and sanitation for all

(UN, 2016). However, there is a significant lack of scientific knowledge on decentralized wastewater treatment systems (Ashok et al, 2012). In addition, there is also a great need for good implementation strategies that are well addressed in the sanitation legal instruments as the country's wastewater management systems cannot be accredited from only the presence of policy or other guidelines like regulations or acts but also from the sustainability of standing sanitation legal instruments in terms of informed practices to ensure sustainable wastewater treatment systems (Akpor, 2011).

The sanitation technologies used in developing cities particularly in the most of populated areas are onsite methods on a large scale such as septic tanks, though ventilated improved pit latrines are also used on a small scale but still people's hygiene and health (wellbeing) is at risk due to the poor wastewater and faecal treatment, management and disposal practices for both individual and collective on-site sanitation.

In the existing estates of Kigali City; the wastewater treatment units for the present semi-centralized wastewater treatment plants use aerobic system in two different technologies: Activated Sludge System (ASS) and Sequencing Batch Reactor (SBR) but there are other technologies that have been tried to be used before namely lagoons though they have completely failed to operate and forgotten where they are no longer in use or exist (REMA, 2016).

Consequently, the assessment focuses on the sustainability of treating wastewater generated from collective small communities using decentralized wastewater treatment systems also known as sewerage systems in a way of providing safe and sustainable on-site sanitation to small collective community areas in the cities of developing countries including Kigali city.

Therefore, in addition laboratory tests done, this study aims to have stakeholder's overview on sanitation sector starting from end users to all responsible and interested institutions specifically on semi-centralized sewerage systems and their treatment units via a designed questionnaire form. The goal for this is aims to identify the appropriate technological solutions for effective management of the existing semi-centralized wastewater treatment plants harmonized with the ruling legal sanitation related instruments as means of providing sustainable sanitation to the densely populated areas in cities of developing countries taking Kigali city as a case study. The semi-centralized wastewater treatment plants will be assessed for their designed system efficiency in relation to the quality of wastewater generated and effluent produced after treatment. Different related research papers and sanitation related policies, laws and regulations will be reviewed for their effectiveness in addressing decentralized wastewater management and monitoring issues before disposal.

The results will be helpful in making well-informed decisions on which collective decentralized wastewater treatment technologies can be adopted in densely populated areas of developing countries as well as sustainable legal sanitation instrumentation changes for sustainable municipal wastewater treatment systems and development.

1.1.2 Conceptual background

In this study, the dependent variable is sustainable development and this has an intergenerational equity of environmental, financial (social economic), and technical sustainability that meets the needs of the present generation without compromising the ability of future generations to meet their own needs (Erik et al., 2013).

The independent variable will be decentralized wastewater treatment systems where these wastewater treatment systems are mainly for collection, conveyance, treatment, and disposal of wastewater from individual homes constructed in clusters of home estates (Kiernan et al., 2012). In this case, the estates assessed are all located in two of the three districts that form Kigali City (Gasabo and Kicukiro districts)

1.1.3 Contextual background

This study took place in the estates of Gasabo and Kicukiro districts of CoK. There are around 20 semi-centralized wastewater treatment plants installed by estates developers which are not functioning properly in these districts. Those assumed to be in operation, the standard quality of their operational conditions do not meet the international and national standards for wastewater discharge (WASAC, 2017).

These systems show irregular operations and inactive frequently due to the lack of scientific knowledge on wastewater treatment systems by both engineers and systems owners, unsuitable design, poor management, and half-finished infrastructures. The residents of these estates showed the will to pay charges for the reliable and sustainable treatment service provided (WASAC, Oct 2017). The consequences of this situation increased diseases, water pollution, and degradation of the ecosystem., which highlighted the need for assessing these

DWWTS's that are not in desired operation as initially designed, an issue that is progressively increasing the environmental and public health threats.

1.2 Problem Statement

The world is faced with problems related to the management of wastewater due to the extensive industrialization, increasing population density and high urbanized societies (Mc Casland et al., 2008; EPA, 1993).

Urban wastewater management systems in developing countries increasingly show failures and significant lack of scientific knowledge in the technology selection, sustainable systems design, and management especially when it comes to decentralized wastewater treatment systems (Nurudeen et al, 2016). In addition, the lack of sanitation infrastructures in fast growing cities and emerging urban and peri-urban areas has greatly increased environmental impacts through the contamination of water resources and the entire ecosystem.

In the City of Kigali, it is common that the few existing decentralized wastewater treatment units, known as semi-centralized wastewater treatment plants, do not function appropriately as initially designed. Furthermore, the inadequate and worthless public sanitation facilities especially sewage network has increased open defecation in the city. Residents use septic tanks and ventilated improved pit latrines for management their wastewater as well as faecal. Public areas like hotels, hospitals, and big commercial buildings are obligatory required to install private semi-centralized wastewater treatment plants for treatment of their wastewater before being discharged into the environment although the standards for wastewater quality discharged is not trusted to meet the standards in most systems due to poor or no monitoring by the concerned utilities with most likely no legal instruments for specific semi-centralized sewerage systems (Baptiste, A.J et, al. 2017). When such septic tanks or improved pit latrines are full, they are emptied and the sewage is just treated by the crude dumping at the Nduba Landfill site. This site is also exposed to open environment and this also affects both people's health and environment since there are no any further treatments done after (Baptiste, A.J et, al. 2017; Jan Spit et, al. 2016). The government is working hard to improve the situation by implementing Kigali centralized sewerage system (KCSS) in the only central business district (CBD) part of Kigali city (EIB, 2017) and a permanent Kigali Faecal Sludge Treatment Plant (FSTP) for unreached parts of Kigali where the sludge collected from pit latrines and septic tanks of the city will be treated to replace the crude dumping (Jan Spit et, al. 2016). There is still discussion on which system to be adopted countrywide between semi-centralized wastewater treatment plants and FSTP. The choice of which system that is economically efficient and can be combined or integrated with planned central sewerage systems of the cities to be constructed is important to have a clear, proper and sustainable sewerage system not only in Kigali city but also in the satellite cities of the country. According to EICV4 (or the English acronym IHLCS) thematic report utilities and amenities approved in March 2016, 81.6% of the improved Sanitation in Rwanda used pit latrines with solid slab and this demonstrated the absence of sewage system/network in the country (NISR, 2016 / EICV4).

The City of Kigali is growing very fast which increasingly affects the environment and the human health due to the absence of sewerage systems and poor operation of already installed wastewater treatment units. This is further compounded by its high altitude topography above the sea level that accelerates water pollution (Ground and surface water contamination), spreading of waterborne diseases down streams and degrading the ecosystem. The topography of Kigali city in relation with poor and old urban resettlement makes the development of centralized sewerage systems more difficult and increases the unreached parts for faecal sludge collection and treatment. In addition, the limited finances from the government to develop different planned immense sanitation projects such as centralized sewerage systems increases wastewater complexities.

1.3 Aim and Objectives

1.3.1 Aim

The main aim of this study is to assess the sustainability of existing semi-centralized wastewater treatment plants of Kigali estates.

1.3.2 General objective

The general objective of this research study is to identify the sustainable technological solutions for efficient management of the existing semi-centralized wastewater treatment plants and to propose the management framework of the decentralized wastewater treatment systems of Kigali city for sustainable development.

1.3.3 Specific objectives:

1. To assess the operation and management practices of the existing semi-centralized wastewater treatment plants in Kigali city estates for their technical and socio-economic sustainability.
2. To evaluate the environmental sustainability of existing semi-centralized wastewater treatment plants in Kigali estates.
3. To propose wastewater management framework for the decentralized systems.

1.4 Research Questions

- Does the technological solutions used lead to the sustainable management of the existing decentralized technologies in terms of operation and Maintenance?

- Do the existing wastewater treatment infrastructures meet the quality standard during the construction works?

- Does the effluent meet the acceptable wastewater quality standards for discharging into the environment and how often testing and monitoring are carried out?

- Do the existing sanitation legal instruments help to address the comprehensive decentralized wastewater management practices such as treatment efficiency and social satisfaction for environmental sustainability?

1.5 Significance of the study

Properly managing wastewater is an issue of increasing importance in sustainable development and design due to growing populations and recent scarcity of freshwater resources (Kiernan et al, 2012). There is no doubt that the safe improved sanitation is critical to public health and the ecosystem. It will be good if several authoritative options can be addressed to tackle the existing sanitation challenges for the developing cities (Sibooli, 2013).

Recently available decentralized technologies have witnessed a great development. However, several obstacles exit, which have hampered their implementation. One of the such barriers is the lack of guidance in what to consider while choosing a system to use.

This study will provide guidance on the management of such existing system technologies, suggest the most suitable technological ways and justify the choice in order to understand when and where to install it, and thus facilitate the use of decentralized wastewater treatment systems

The study is also relevance because it aims at providing environmentally friendly technical and management framework of semi-centralized wastewater treatment plants in the densely populated cities and the emerging urban areas of the developing countries. The framework will encourage the need for community participation in operation, maintenance, and management of wastewater treatment systems in the city of which will support the sustainability of the already installed semi-centralized wastewater treatment plants and other planned sanitation facilities to be developed.

The findings of this study will be useful and beneficial to the Ministry of Infrastructures (MININFRA), Ministry of Natural Resources (MINERENA), Rwanda Utilities Regulation Authority (RURA), city municipality and finally water and sanitation corporation (WASAC) Ltd, a government institution with a mandate to provide and manage water and sanitation services and it will as well serve as a reference to future researchers.

1.6 Scope of the study

The study will be carried out in the City of Kigali, Rwanda and will focus on assessing the design, operation, maintenance, and management frameworks of decentralized wastewater treatment systems (semi-centralized sewerage systems) in collective residential areas of Kigali estates. The study will be limited to the urban cities of developing countries taking the City of Kigali, Rwanda as a case study, which has not given any attention before regarding the installed decentralized wastewater treatment systems.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter will provide a representative image about the universal sustainability of decentralized wastewater treatment particularly, the global overview of sanitation and wastewater management systems in developing countries as well as the status of decentralized wastewater treatment practices in Kigali city, Rwanda.

In this chapter, the extent of wastewater treatment in general will be discussed with a focus on the developing countries and the comparison between centralized and decentralized wastewater treatment systems will also be provided. The experimental review of where related researches has been studied will also be discussed under this section.

Furthermore, many factors that needs to be considered when choosing and installing a wastewater treatment system will also be discussed on mainly including; the types of technologies or technics that can be applied, wastewater characteristics and extent of treatment desired, human health considerations, environmental preservation, level of management, and the standards to be met.

This research is limited to the treatment of residential or domestic wastewater for Kigali city estates in two of the three districts of Kigali city namely, Gasabo and Kicukiro districts. In additional to the definition of the operational terms provided, the following definitions will also be adopted in this chapter:

- **Wastewater:** The water that contains undesirable and potentially unsafe chemical and biological contaminants generated from specific use such as residential, commercial, or industrial processes (Kiernan et, al. 2012; Tsinda et, al. 2013).
- **Centralized Wastewater Treatment System:** A managed system that consists of a collection of sewers and a single treatment plant, which is used to collect and treat wastewater from an entire service area. Traditionally, these systems are referred to as publicly owned treatment works (U.S. EPA Water, 2012), although not all of these systems will be publicly owned.

2.2 Sanitation and Wastewater Management Systems in Developing Countries

Before 1800s, the majority of population were using open defecation while few others were using privy outdoor to dispose their excreta. After diverse scientists and experts showed that many infectious diseases are as result of faecal microorganisms (bacteria), sewage treatment systems were introduced in cities (Niraj et, al. 2015 as well reflected by M. Henze, 1983). Wastewater management systems were revealed after the human health problems became unbearable and the capacity of receiving waterbodies to conform or adapt was exceeded and also as populations increased, the amount of wastewater produced rose rapidly hence self-purification of rivers, streams, and water bodies exceeded their capacity to stabilize the quality of this huge quantity of wastewater generated (Niraj et. al, 2015 and Peace Amoatey et al, 2011).

During late1800s and early 1900s, numerous options counting in today's processes were tried until 1920 and their design was on the other hand experimental until mid-century. By that time, centralized wastewater treatment systems were planned, well designed and encouraged. The cost for wastewater treatment services were borne by communities draining the treatment plant. (Peace Amoatey et al., 2011).

Recently later, the minimum level of treatment to be achieved was set before discharge permits are granted irrespective of the receiving water bodies and streams capacity (Peavy, Rowe and Tchobanoglous, 1985). Currently, the attention is altering from centralized systems to more sustainable decentralized wastewater treatment systems predominantly for developing countries, for instance in Ghana where wastewater infrastructure is deprived and management of central conventional methods is a challenge (Adu-Ahyia and Anku, 2010).

According to the global assessment report on wastewater management systems, local authorities in collaboration with other mandated service providers at different levels are the responsible bodies for wastewater management services, but the problem remains with the institutional capacities or weakness to deliver quality services especially in the high populated areas (Sibooli, 2013).

Some studies showed that public service providers were not allowed to provide such services to the slums and the increase number of population in the cities of the developing world, like Dakar, the most densely populated city in India. (Parkinson and Quader, 2008).

2.3 Theoretical Review

2.3.1 Wastewater Treatment and Management

Historically, wastewater treatment facilities have been designed to treat and remove suspended solids, biodegradable organics, and pathogenic organisms (Metcalf and Eddy, 2003). In order to assess the sustainability of different technologies applied in treatment of wastewater, it’s good to describe the type and characteristics of wastewater to be treated, the levels required in wastewater treatment and the objectives or intentions for any wastewater treatment.

2.3.1.1 Wastewater Types and Treatment Levels

Figure 1 below describes well the sources of wastewater with attention on domestic wastewater since the research studies the wastewater that is produced from homes;

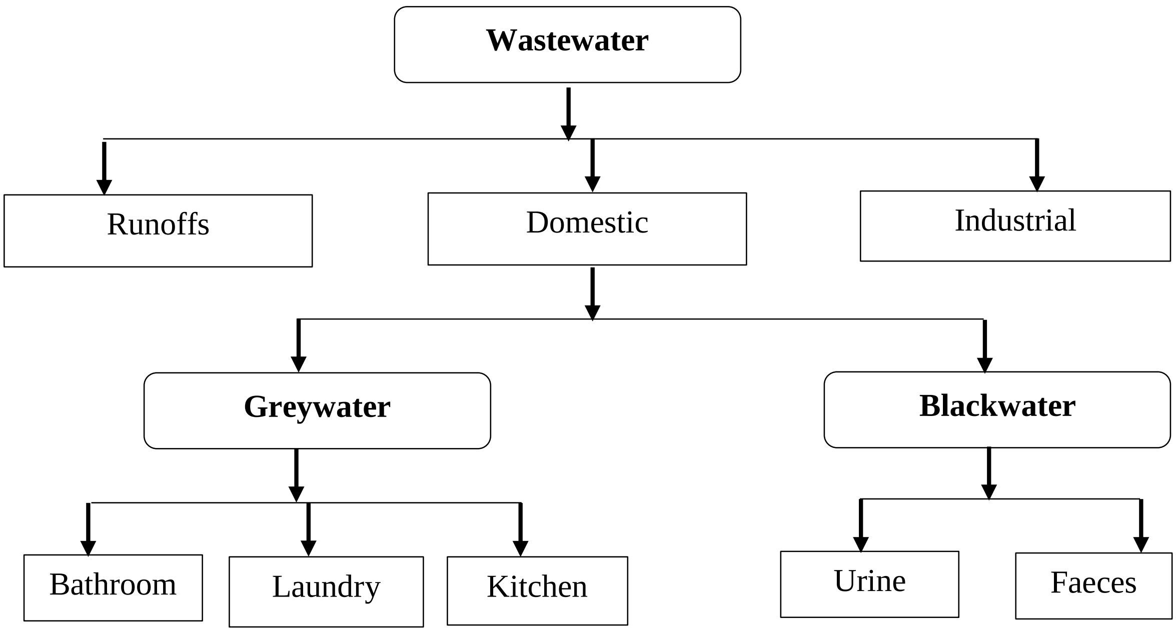


Figure 1: Wastewater types (Amoatey et al., 2011)

It is well-known that such water generated from homes is called domestic wastewater, which is the summation of graywater and black water. Figure 2 breaks down the different sources of the domestic wastewater.

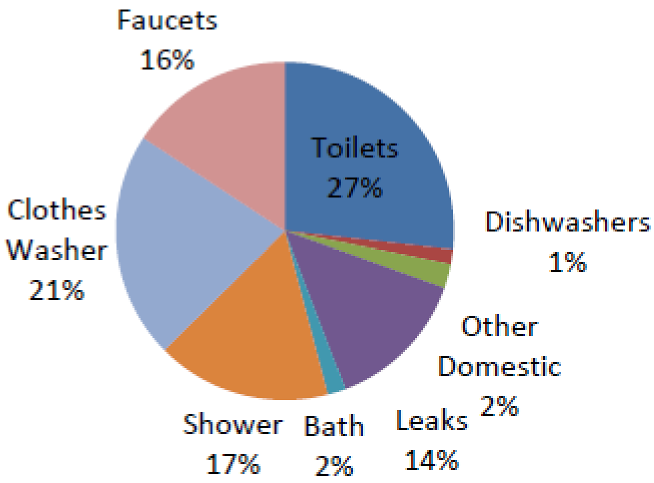


Figure 2: Sources of Domestic Wastewater (Adapted from Mayer et al., 1999).

The degree of wastewater treatment is classified by the treatment levels, which use different technologies, known as unit processes or unit operations, to remove specific pollutants of interest. Typical wastewater treatment consists of preliminary**,** primary, secondary and tertiary treatment depending on the wastewater sources, strength and the final use after treatment (the effluent). Each level of treatment beyond the first offers an increasingly higher quality of the finished effluent. Consequently, higher effluent quality requires systems of increased complexity, higher capital costs, and a good operation and maintenance by qualified operators and wastewater managers.

I. **Level 1: Preliminary Treatment Processes;** This is the first process in wastewater treatment where the raw sewage flow measurement, elimination of coarse suspended materials or solids and grits removal is carried out. The quantity of wastewater to be treated is measured at this stage and large objects and other inorganic materials like sticks, gravel are removed using bar screens or any other designed devices for this purpose in order to avoid machinery damage or clogging of the process. This later improves the operation performance of the next treatment units (NYWEA and Environmental Science Center 2013).

II. **Level 2: Primary Treatment Process;** It is a settling process from which both the organic and inorganic solids that had settled or floating materials like scum are removed. The settling tanks at this level are designed such that they are capable of removing both settled and floating solids where lighter materials like grease can float. This process generates primary sludge that is much in quantity comparing to other treatment units. Primary treatment can remove up to 50% of

BOD5 which means 65% of grease and oil in addition to 70% of suspended solids is removed but, wastewater still contains dissolved and suspended solids. The dissolved solids are very small in size and can't be seen unlike suspended solids that are visible. for example, dissolved sugar in water (Amoatey et al., 2011).

III. **Level 3: Secondary Treatment Process;** This is a biological treatment process that removes both suspended and dissolved solids remaining in wastewater after the primary treatment using either aerobic or anaerobic treatment process. The treatment process at this stage can be done using many different types of treatment processes including; activated sludge systems, Sequential Batch Reactors (SBR's), Trickling filters, Rotating Biological Contactors (RBC), Lagoon systems like oxidation ditches, Waste stabilization ponds, and constructed wetlands. However, the most common system used is Activated sludge system with SBRs becoming more popular now days. The aerobic process is where the bacteria (aerobic microorganisms) are supplied with oxygen and then feed on organic solids as their food to form biological mass that can be removed later. Another central part of secondary treatment is the following set of sedimentation or settling tanks also known as secondary clarifiers which removes the grown up biological mass. For activated sludge treatment process, there is a continuous return of sludge (organisms) from secondary clarifiers that is mixed with wastewater for effective continuous removal of dissolved solids and it's for this reason is named activated sludge system. Both activated sludge system and SBR's, oxygen is delivered by diffusers and blowers or mechanical mixing process in the aeration tank. Whereas for SBR's, the only difference with conventional activated sludge is the use of aeration tank as secondary sedimentation tank. This operates by turning air off and allow the solids to be settled down. During this separation period of wastewater from solids, wastewater flows into the next SBR tank for continuous treatment. The benefits of SBR over Activated sludge system is its capacity to remove huge amount of nitrogen and phosphorous and it can be operated at small scale area (NYWEA and Environmental Science Center 2013).

IV. **Level 4: Tertiary Treatment Process;** This is the removal of heavy metals nitrogen, bacteria, phosphorus, biodegradable organics and viruses. The removal of such nutrients, organisms, metals, and other infectious elements is known as disinfection. This means inactivation of organisms causing diseases and it can be done either with chlorination or applying ultraviolet radiation. It is essential and advised for some treatment plants to remove critical nutrients like nitrogen and phosphorous in order prevent negative impacts to the receiving water bodies and human health. For example; ammonia toxicity to fish.

2.3.1.2 Intentions for Wastewater Treatment

Wastewater treatment is very much desirable for different intents and purposes but more importantly essential for:

Removal of pathogens: Organisms causing diseases in humans, animals and plants are called pathogens and due to their very small size to the extent that they cannot be seen with naked eyes, they are mostly known as micro-organisms. For instance; viruses (hepatitis A & E virus), bacteria like vibro cholerae, fungi which include candida albicans and protozoa (giardia lamblia). These micro-organisms are largely defecated in faeces of infected people and animals (Amoatey et al., 2011).

Reduction of nutrients and organic substances concentration in the environment: High concentration of nutrients such as nitrogen and phosphorous in the receiving waterbodies and streams leads to eutrophication hence causing a dense growth of plant life unfavorably algae. The decomposition of such plants depletes/reduces the supply of oxygen leading to the death of animal life. In addition to nitrogen and phosphorous, biodegradable organic substances like Sulphur and carbons contained in organic matter are also necessarily to be broken down before released into the environment. This can be done by oxidation of wastewater into gases and then discharged into environment or remains in treated wastewater (effluent) as solution. Therefore, wastewater treatment is necessarily for the safe disposal of treated wastewater to the environment through reduction of nutrient concentration and biodegradable organic substances there by protecting the environment as well public health and aquatic life are considered.

Wastewater reuse: Increased population over the years has led to urbanization worldwide and this has greatly augmented pressure on water resources. The increase in both population and pressure on water resources means the need to improve or increase the economic growth which later in return requires high demand of water supplies. In addition, the rate of groundwater withdraw is not easy to estimate though the findings show overdrawn (National

Academy, 2005). Due to the high water demand in different human and agriculture activities, it is extremely advised to reuse treated wastewater for sustainability and balancing water demand.

2.3.1.3 Factors Affecting Technology Selection and Design of WWTS's

Wastewater treatment systems are referred as the systems for collection, conveyance, treatment and disposal of wastewater and these are also known as sewerage systems. Such systems involve physical structures including sewerage networks and sewage treatment plants. If sewerage systems are not well designed as well as the technologies to be used are not well selected, it may lead to a complete failure of the system. The following factors need to be considered in order to have an effective and appropriate system;

Engineering consideration factors:

- Design period, population to be served (Number of users and their income level), and expected average per capita wastewater generation.
- The Topography: This means the slope and terrain of the area to be served.
- Groundwater characteristics including its depth from surface level and seasonal variations.
- Soil type and bearing capacity involving rate of soil infiltration.

Environmental factors:

- Understanding the type of wastewater to be treated as well as groundwater and surface water quality where wastewater is to be disposed.
- Complying with the effluent discharge standards set by international and national regulatory authorities in order to avoid any negative impacts and likely risks to the safety of the public health and environment

Process consideration:

- Wastewater flow volumes and organic characteristics.
- Performance of the treatment units.
- Knowledge capacity in terms of available staff or labor for operation and maintenance.
- Degree of wastewater treatment required

Economic factors:

- Capital expenditure costs for construction, land purchase, equipment, etc….
- Operation and maintenance costs counting in chemicals to be used, energy costs, staff for daily operations, costs for inventory, etc...

2.3.1.4 Management responsibilities

Depending on locality situations, sanitation management must be proportionate to the accountability of various sanitation elements particularly for decentralized wastewater management including among others treatment and disposal. Figure 3 illustrates the five sanitation elements that should be critically considered in management responsibilities (De-Bruijne et al., 2007), which has four elements and is identical with the management of sewerage systems, however the onsite sanitation seems to be often limited only to the collection of faecal sludge. It later presents the constraints between waterborne and onsite systems that are obvious at household level critically in accountability management in transportation or conveyance and disposal of the wastewater and faecal (IWA, 2008).

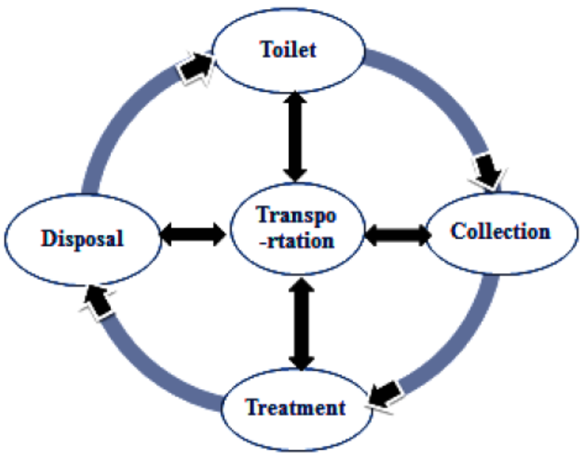


Figure 3: Sanitation elements essential for management (De-Bruijne et al, 2007)

This background information shows that there are no common developed approaches of how to manage onsite sanitation systems in many developing countries though on the other hand considerably, findings are not on the responsibilities and participation of local and commercial authorities in the management processes (NWASCO, 2008).

2.3.1.5 Community based initiatives

The development and management of sewerage system projects have been long done by community based organizations (CBOs) and other interested non-governmental organizations (NGOs), which is a successful sustainable way. For example, Orangi Pilot Project in Pakistan and Indore Slum Improvement Project have demonstrated the success of community involvement beyond the government scopes (GRZ, 2010). Similarly, in some parts of Africa like in Zambia, the NGOs in sanitation sector operate as intermediator between the communities and funding agencies or local government (Sibooli, 2013).

Though the NGOs plays a big role in sanitation service delivery (Tayler, 2010), other findings resist that community-based initiatives are less sustainable (WaterAid, 2011). On the other hand, onsite sanitation projects are community driven systems that need no or little support from outside the entire community to keep quality of service delivery and further advancements as argued by Cogswell and Ngulube in 2008. Therefore, this approves that there should be little intervention from government to avoid informal settlements and to enforce the legal instruments in the development and management of such onsite systems. Otherwise, the gap can be bridged by a collaboration between communities and NGOs through public private partnership (Djonoputo el at., 2010).

2.3.1.6 Institutional responsibilities for sanitation

In most developing countries, the main responsibilities for sanitation related agencies and authorities are listed in a formation of sanitation legal instruments (policy formulation, Sanitation Laws and Regulations) that helps and eases in planning, development, financing and management of sanitation infrastructures and other associated services. Certainly, these tasks definitely require stakeholder’s participation at all stages in all levels (Sibooli, 2013).

Even though sanitation problems are mainly caused by the deficient capacity in terms of both knowledge and finances of the service providers (Tanerfeldt and Ljung,2007), lack of systematic in-depth institutional framework has also been found as a challenge in developing countries (Cotton et al., 2002) though both findings encountered that the institutional dimness were a result of lacking a leading organization.

According to GRZ (2010), the institutional problems were greatly due to the weakness in enforcement and implementation of the ruling policies, laws and regulations. Table 3 below provides an overview on how different institutes can be involved in the sanitation services delivery according to (Zambia, 2006).

Policy formulation and elaboration	Regulation and advisory	Resource mobilisation and financial provisional	Planning, implementation and mobilisation
• Min of Local Govt & Housing (DHID) • Min of Health	• National Water and Sanitation Council • Environmental Council of Zambia • Min of Health • Local Authorities	• Min of Local & Govt Housing • Cooperating partners • Non Governmental organisation	• Commercial utilities • Local authorities • Residential Development Committees

Table 1: Institutional framework for main actors in sanitation sector (Nyambe, 2006)

2.3.2 Decentralized Wastewater Treatment Systems, DWWTSs (Semi-Centralized Sewerage Systems, SCSSs)

DWWTSs are the onsite wastewater treatment systems for small volumes of wastewater produced either from individual homes, cluster of dwellings or businesses that are treated and disposed or relatively reused. It can also be defined as the treatment of wastewater that includes preliminary, primary, secondary and tertiary treatment processes (Uleimat, 2006).

Perhaps if well managed, the decentralized treatment system specifically semi-centralized may possibly be independent of a centralized sewerage system or any other collection and treatment systems like faecal sludge treatment plants. In addition, the DWWTSs are clearly described by their low human necessity and energy consumption in comparison with the centralized systems, which need marginal maintenance, control and operation costs (GTZ, 2001; Sibooli, 2013).

2.3.2.1 Treatment elements

The principle operation for the SCSSs is the use of low cost technologies to treat wastewater at its generated site. The treated effluent might be reused and the sludge can be treated (Anh et al., 2003). The essential treatment elements for DWWTSs or SCSSs covers pre-treatment systems, wastewater collection and conveyance, wastewater treatment processes, and the effluent disposal into the environment (Anh et al., 2003; De-Bruijne et al., 2007; IWA, 2008).

2.3.2.2 Plant Capacity

SCSSs have a capacity of treating wastewater from homes and industries that have small COD to BOD ratio with flows between 1 and 1,000 m^3/day (Gutterer et al., 2010). Howver, earlier studies stated that DWWTSs were capable to serve from 200 to 1,500 people with wastewater generation of 200 l/c/d (Van-Haandel et al., 2006). Though the informal settlements were not included in the studies and are still not clear, which means that the capacity on any decentralized plant is based on the locality.

2.3.2.3 DWWTSs Locations / Areas of Applications

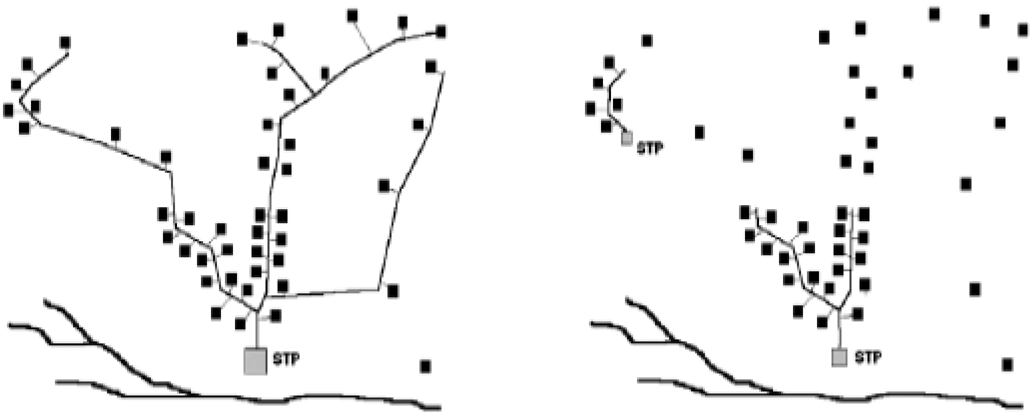
Most conducted research projects have agreed that DWWTSs/SCSSs are useful and practical in different conditions in urban and city areas of the developing countries. According to (GTZ, 2001), DWWTSs can be effective in developing countries especially in urban areas of smaller communities. Similarly, a research from Vietnam showed that SCSSs can be applied in cities with people of all kinds of income (High, medium and low household) particularly in places without or with sewer network systems (Anh et al. 2003). Furthermore, DWWTSs can fit in communities with or without a resourceful faecal sludge treatment plant disposal. However, the fact of semi-centralized wastewater treatment systems being flexible in use does not only make them an alternative technology to centralized sewerage systems but also naturally complement which means they can be integrated and match with centralized systems where necessary (Humble M. Sibooli, 2013).

Finally, due to DWWTSs dependency factor to natural climatic conditions, SCSSSs can be installed and operated anywhere according to (Gutterer et al. (2010) and in addition, they are appropriate where systemization is not an issue since they subject to the local physical and environmental circumstances.

2.3.3 Centralized Vs. Decentralized Wastewater Treatment Systems

Under certain conditions, decentralized systems may offer benefits over centralized systems, but an array of different factors needs to be considered. This section outlines and compares these two options, and also provides considerations regarding wastewater treatment infrastructure and planning options.

Decentralized wastewater treatment systems differ from conventional centralized systems in the way that they “treat and reuse or dispose wastewater at or near its source of generation” and this difference can be as well shown in Figure 4 below which includes a centralized system at left and a decentralized approach at right. It provides a graphical depiction of centralized and decentralized approaches serving a given area.



Centralized Wastewater Treatment Decentralized Approach

Figure 4: Centralized v. Decentralized System Visual Aid (EPA, 2005)

STP: Sewage Treatment Plant.

The distinction between decentralized and centralized systems can be described using the following categories:

• **Volume:** Decentralized systems treat relatively small volumes of wastewater for specific cluster of community area cluster

• **Sewer type:** Centralized systems typically use conventional gravity sewers, while cluster (decentralized) systems typically use alternatives such as small-diameter pressurized pipes (for uniformity), small-diameter gravity, and vacuum sewers, often employing on-lot settling tanks and/or grinder pumps before wastewater flows from a lot into the sewer system.

• **Treatment Efficiency:** Centralized systems usually use activated-sludge processes in the treatment of wastewater, while decentralized systems typically use many alternatives such as activated-sludge itself, SBR's, sand filters, trickling filters, etc. However, the well-managed onsite decentralized treatment plant specifically for cluster systems that are suitably designed can provide treatment efficiency corresponding to a centralized plant often at a lower cost (Humble M. Sibooli, 2013).

- **Discharge method:** Centralized systems typically discharge the treated wastewater to a surface water body, while decentralized systems typically discharge treated wastewater by infiltration into soil and this increases groundwater recharge (EPA, 2005).

- **Ownership:** Centralized systems are typically publicly owned, while decentralized systems are usually owned by a developer, homeowners' association, or another private entity.

- **Relative scale:** Centralized systems are intended to serve entire communities or substantial areas of large communities, while decentralized systems serve only a portion of a community that falls in the similar situation in terms of services provided to that specific area such as water supply services and mostly in the same range of household income.

- **Tax base conservation:** Unlike centralized systems that requires large scale coverage in line with huge investment costs, cluster decentralized wastewater treatment systems can be installed on a needed basis hence avoiding the high upfront capital costs of centralized sewerage systems.

Recently, there is a wide variety of decentralized systems, and more are being developed for residential, industrial, and commercial use. They can be scaled to meet the needs of individual homes, or for clustered treatment to meet the needs of several residential housing units or commercial facilities. Due to the competence of decentralized wastewater treatment systems, centralized technologies are now used in decentralized systems to improve the degree of wastewater treated before being disposed or reused.

2.3.4 Benefits of DWWTS's

Around 60 million people in U.S rely on decentralized wastewater treatment systems. These systems were assumed to play a better role in treatment and management of wastewater in the future regularly affordable more than conventional centralized sewerage systems due to their capabilities of operating under specific capacity of any community and site conditions (EPA, 2005).

Generally, DWWTSs are invented to be low cost and simple sanitation choice with minimal management unlike centralized sewerage systems. Figure 5 shows the summary benefits of using DWWTSs (UNESCAP, 2015).

Figure 5: Visual presentation of the benefits of decentralized wastewater treatment system (UNESCAP, 2015).

2.3 Empirical Review

2.3.1 Assessment of decentralized wastewater treatment systems;

The assessment of such decentralized wastewater treatment systems has been done in California where they were assessing decentralized wastewater treatment options in Santa Barbara County. A variety of issues related to wastewater treatment and recycling have been explored. It outlines the specific objectives associated with such projects (Kiernan et al., 2012):

- From a life cycle perspective, establish the benefits and disadvantages of centralized treatment systems compared to selected onsite technologies. Determine under which circumstances it is advantageous to use centralized over decentralized, and vice versa.

- Understand how current policies regarding decentralized wastewater treatment in Santa Barbara County relate to each technology as well as develop recommendations on how to improve the permitting process.

- Quantify and categorize the important characteristics of potential technologies for small residential community clusters and onsite treatment, based on a Multi Criteria Decision Analysis and life cycle operational energy use.

- Make recommendations to the water and sanitation authorities on the most appropriate technology to use for water conservation and recycling.

- Develop a guidance document for The Sustainability Project, designers, and policy makers to assist them in choosing an appropriate system for their projects.

The project identified potential decentralized wastewater technologies to include in the research. They also considered criteria on which these systems could be evaluated.

After the extensive data collection and analysis, they created a decision making tool in the form of a matrix, which included 11 selected technologies and 21 valuation criteria, covering economic, environmental, social and permitting considerations.

As a part of their methodology, they hosted a community workshop at the Built Green Resources Center in Santa Barbara to facilitate conversation around the topic of onsite wastewater treatment, and in particular to understand the barriers inhibiting the adoption of decentralized systems. From the workshop, valuable information and insight into decentralized systems were gathered in order to assess the life cycle impact of alternative wastewater treatment technologies.

It mainly focused on the life cycle impacts associated with the collection and treatment of wastewater across all technologies. The environmental impacts were found to be substantial, especially considering the widespread use of wastewater treatment across the globe. Furthermore, the research highlighted recommendations on how to decrease the life cycle impacts of wastewater treatment, and reviewed areas where further research is needed (Kiernan et al., 2012).

2.3.2 Design of decentralized wastewater treatment systems;

In the designing of the decentralized wastewater treatment systems, treatment-system performance cannot be precisely predicted and, therefore, calculating dimensions should not involve ambitious procedures. In the case of small- and medium-scale decentralized wastewater treatment systems, a slightly oversized plant volume adds to the operational safety.

In the case of specific demands, calculations and design must be carried out individually so that the structural details of the standardized plants can be integrated. The design introduced a simplified, quasi-standardized method of calculating dimensions using technical spreadsheets.

The design described that decentralized wastewater treatment systems are designed to be particularly robust. Nonetheless, problems may be caused by improper use or operation, insufficient maintenance or structural flaws. A malfunctioning system is a risk to public health and the environment. Reoccurring problems creates further complications, if they are not quickly attended to (Gutterer et al., 2009).

2.3.3 Review of sanitation policy and strategies;

Wastewater is addressed in several policies at the national, state and/or local level. The policies for regulating wastewater treatment and associated regulating agencies to provide an understanding of the regulatory framework as described in Kiernan et al., (2012) have been revised. The policy provided uniform requirements and conditions for the state, and potentially streamline some of the permitting process with objectives of:

• Adopting a statewide policy for Onsite Wastewater Treatment Systems (OWTS) consistent with the Porter-Cologne Water Quality Control Act and related state water quality control plans and policies adopted by the State Water Board.

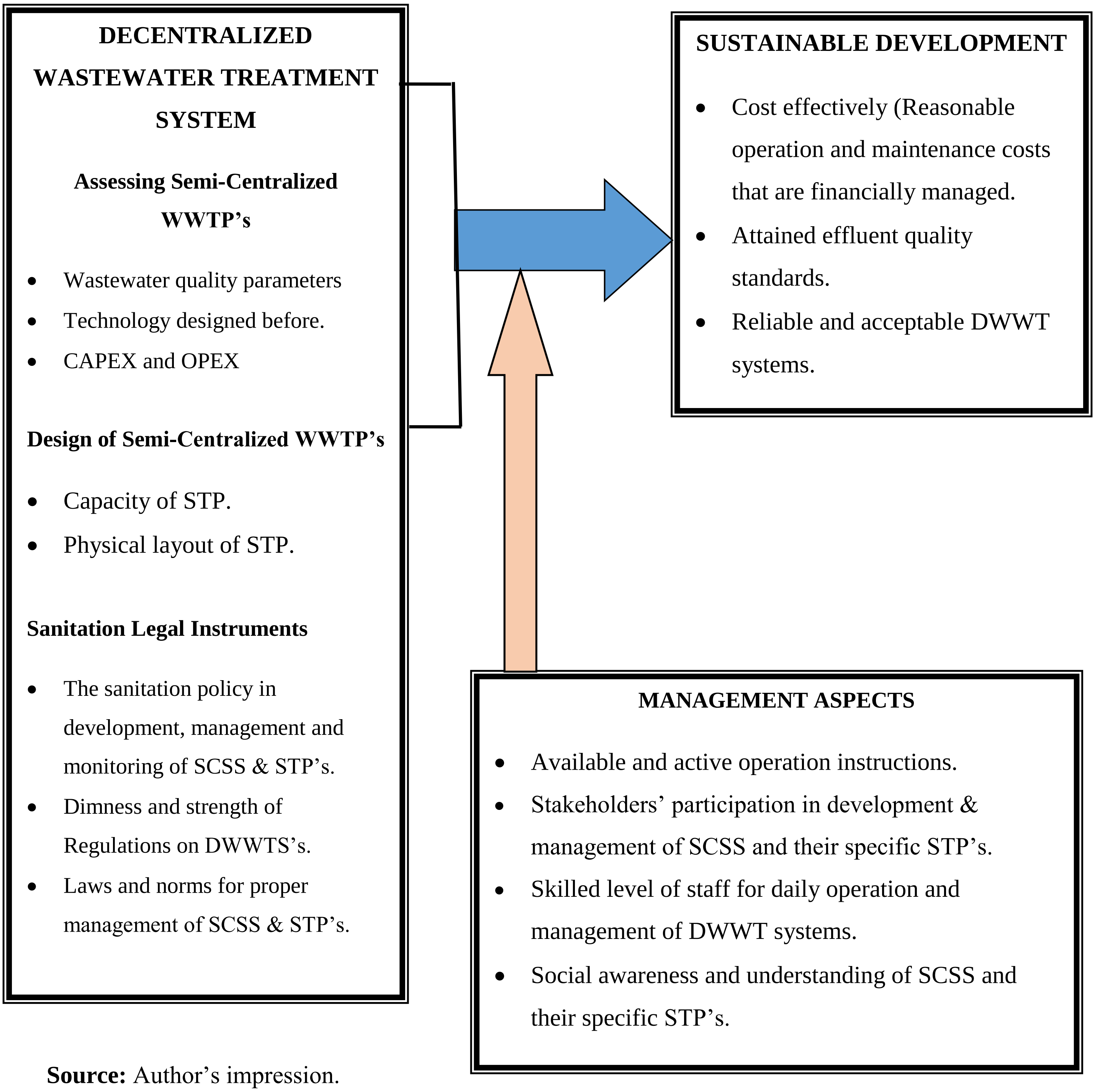
• Help ensuring that the beneficial uses of the state's waters are protected from OWTS effluent discharges by meeting water quality objectives.

• Establishing an effective implementation process that considers economic costs, practical considerations for regional and local implementation, and technological capabilities existing at the time of implementation.

The policies described above thus far address human health and environmental concerns, and also aim to improve water infrastructures. The study finally elaborates on these issues by explaining how they impact wastewater treatment (Huniu, et al., 2012).

2.4 Conceptual Framework:

Independent variables **Dependent variables**



Source: Author's impression.

2.5 Critique of the Literature

The research projects so far have not been able to address the technical and management framework to the off takers of the decentralized wastewater treatment systems and their respective wastewater treatment units (WWTU) after their installation and commissioning. This is considered to be one of the factors that leads to unsustainable DWWT systems especially in developing countries where there is also a deficient knowledge in wastewater treatment as well as limited resources to invest in social infrastructures.

2.6 Research Gaps

Some research projects demonstrated the failure in the choice of the right choice of technology that are cost-effective and environment-friendly (Karel and Heykel 2015). But on the other hand, researchers have not addressed cultural sensitivity, appropriate hygiene education and the feeling of ownership in the communities as a way that can contribute to sustainability of sanitation infrastructures. In addition, findings have not shown a fulfillment between decentralized systems and the sanitation legal instruments / policies.

This study addresses some of the knowledge gaps for the sustainability of decentralized wastewater treatment systems, in terms of technologies, design, operation, performance, and reliability with more emphasis on creating an end user ownership of the system in their operation, maintenance, and management.

2.7 Summary of Literature Review

In summary, based on the literature reviewed, the sustainability of decentralized wastewater treatment systems in densely populated cities of developing countries is based on community collaboration with non-governmental organizations that may be reached through Public Private Partnership (PPP). This requires only a little intervention of government in planning, formation, enforcement of sanitation related legal instruments and financing the sanitation services.

Safe sanitation services can contribute not only to the economic development of any developing country but also can supplement potable water significantly by reducing contaminant load on freshwater resources and the needed treatment costs for water supply, which can reduce the negative environmental impacts from the discharge of pollutant loads on receiving water bodies/streams hence protecting the entire ecosystem.

In addition, the decentralization of the well implemented and managed urban wastewater treatment systems can bring much flexibility that is affordable in a community to suit water quality objectives and since the decentralized wastewater treatment requires local reticulation systems, the long distance wastewater transportation to distant centralized treatment plants can be avoided as decentralized systems can also provide wastewater services where servicing through centralized systems are not possible.

Finally, regardless of inter-related reasons for the sustainability of decentralized wastewater treatment systems to be achieved, the sustainability of sanitation systems can be specifically divided into three categories; Limited capacity (either by material resources or knowledge) of different service providers in management of the systems including among others government institutes and communities, lack of financial revenues for Capital expenditures (CAPEX) and Operation expenditures OPEX costs, and lastly fragmented service delivery ways that has been practiced with poor understanding of government framework in sanitation sector along with rival agendas.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Introduction

This chapter presents how the research is designed and what methodology was used including the research methods of data collection, sampling, assessment and analyses. The study used both quantitative and qualitative research approaches to attain the objectives set together with primary and secondary data.

Qualitative research approach means a research that uses descriptive data obtained using approaches like designed structured or no-structured questionnaires, in-depth interviews, focus group discussions, etc., and this may be in a written form and/or spoken words (Letts et al., 2007). However, Quantitative research approach refers to analytical research method to attain universal compliance from the analysis of data collected and this approach is purposely for primary data collection (Sibooli, 2013).

The methods used in this research study for data collection methods, comprised of relevant literature review analyses, non-structured interviews, structured questionnaires, field observations and wastewater sampling on the selected DWWTSs in Kigali estates.

3.2 Study Area

The city of study is **Kigali city**. It is the capital and largest city of Rwanda that is located in the central of the country at the latitude of 1º 58’S and a longitude of 30º 07’ E (GoR, 2013). The city is made of 3 districts namely; Nyarugenge, Kicukiro and Gasabo as seen from Figure 6. It is one of the rapid urbanized city counting over 1,223,000 inhabitants with a high population growth rate of 4% living in an area of 730 km^2 (NISR, 2012).

The city is dominated by unplanned resettlements and subject to slums that were built before the establishment of Kigali city master plan in 2006. The estimated daily waste production from Kigali is about 400 tons dominated by food waste that constitutes 68 % of all waste (Kahigana, 2011). Solid and liquid wastes from Kigali city are collected and dumped together to one communal dumping site at Nduba landfill in Gasabo District (Kahigana, 2011; Isugi and Dongjie, 2016). The city produces 3,240 m3/day of domestic wastewater, 60% of which are discharged into the environment without treatment (Umuhoza et al., 2010) and this can cause the water borne diseases and interfere negatively the sanitation (Striebig et al., 2007).

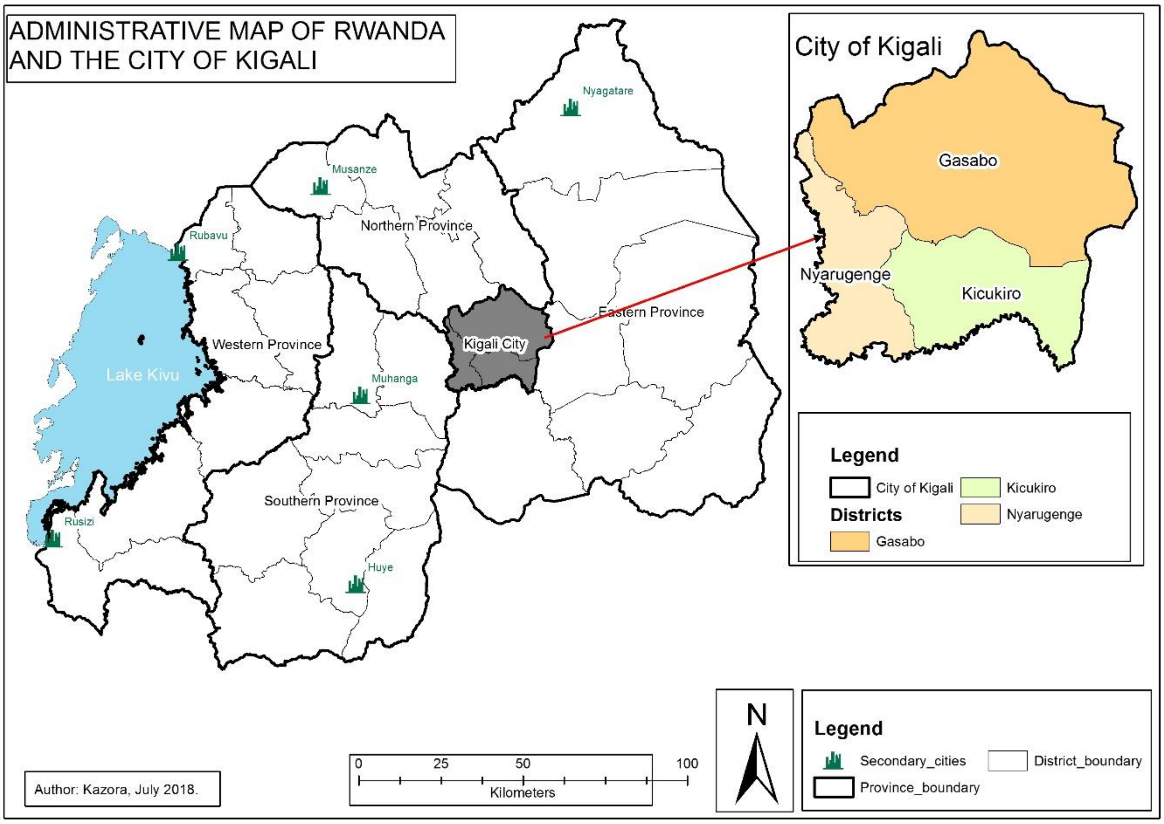


Figure 6: Administrative map of Rwanda, Kigali city (NISR, 2012).

The City of Kigali is among the fast-growing cities in Africa with 286,664 number of households (NISR, 2012) and meanwhile, there is no centralized sewerage system nor faecal sludge treatment plant for treatment of the liquid waste hence no appropriate liquid waste treatment (GoR, 2013). Of all the households in Kigali city, 91.2% use pit latrines and 60% of Kigali city population live in informal settlements where they have inadequate sanitation facilities due to insufficient waste removal and discharge (Tsinda et al., 2013).

The main challenges of wastewater management in Kigali city are due to limited governmental focus in sanitation resulted from lack of finance and skilled staff in wastewater treatment systems and management (Baptiste, A.J et, al. 2017).

In addition to limited number of private operators or companies that are experienced in wastewater treatment, there are also gaps and lack of related sanitation legal instruments that clearly addresses the planning, development and management of decentralized wastewater treatment systems at both individual and collective levels hence inappropriate sanitation practices.

3.3 Rationale

A wastewater treatment system can have many possible design options depending on a large number of factors identified significantly to be considered when selecting treatment processes for municipal wastewater treatment (Tchobanoglous et al., 2003). There are specific constraints of semi-centralized wastewater treatment plants in comparison with centralized municipal wastewater treatment plants. These include among others: Decentralized sewer networks have less buffering capacity and dwelling time, and therefore the process design must be sufficiently robust to cope with a wide variation of influent flows and qualities. In addition, unlike centralized WWTPs, decentralized WWTPs can often be left unattended for days due to different factors like intermittent water supplies and, as such, the construction and design of decentralized systems must take into account this operational and maintenance regime (Tchobanoglous et al., 2003).

This study used both qualitative and quantitative data. It drew on a range of primary information sources, including four site-based surveys covering 17 DWWT plants sites as listed in appendix D. These DWWT systems have been installed by estate developers where in most cases the installation was performed by contractors specializing in civil works, rather than by a group of engineers specializing in different disciplines such as civil, mechanical, sanitary, environmental and water engineering.

The quantitative data will be complemented by qualitative data from the same specific DWWT systems sites and relevant stakeholders within CoK; focus group discussions with users, administrative levels staff at various sites, and community management representatives who are residents of the selected estates in Kigali city; and interviews with a wide range of stakeholders including regulatory, water and sanitation, environmental management and quality standards authorities.

This study will investigate DWWT systems particularly the semi-centralized sewerage systems installed in public clusters known as estates and precisely their treatment units with a focus on existing technologies, management practices and finally the current applied and sanitation ruling instruments.

3.4 Research Design

In this study, the entire city of Kigali (CoK) represent the focused design area with 4 sampling sites, namely, Kacyiru, Gacuriro, Kabuga, and Gikondo purposively selected to represent different semi-centralized sewerage systems and sewage treatment plants of recognized estates of Kigali city. In each of the sampling sites as clearly labeled in figure 7, there are number of SCSS and STP's from which both the numerical figures, wastewater samples, and some descriptive information were obtained, giving it both a quantitative and qualitative research dimension. This allow data to be collected in time at a given site hence the use of both qualitative and quantitative approaches during sampling and data collection. Wastewater samples were collected for quality testing in the laboratory of Water and Sanitation Corporation (WASAC) Ltd., which is in charge of providing national water and sanitation services.

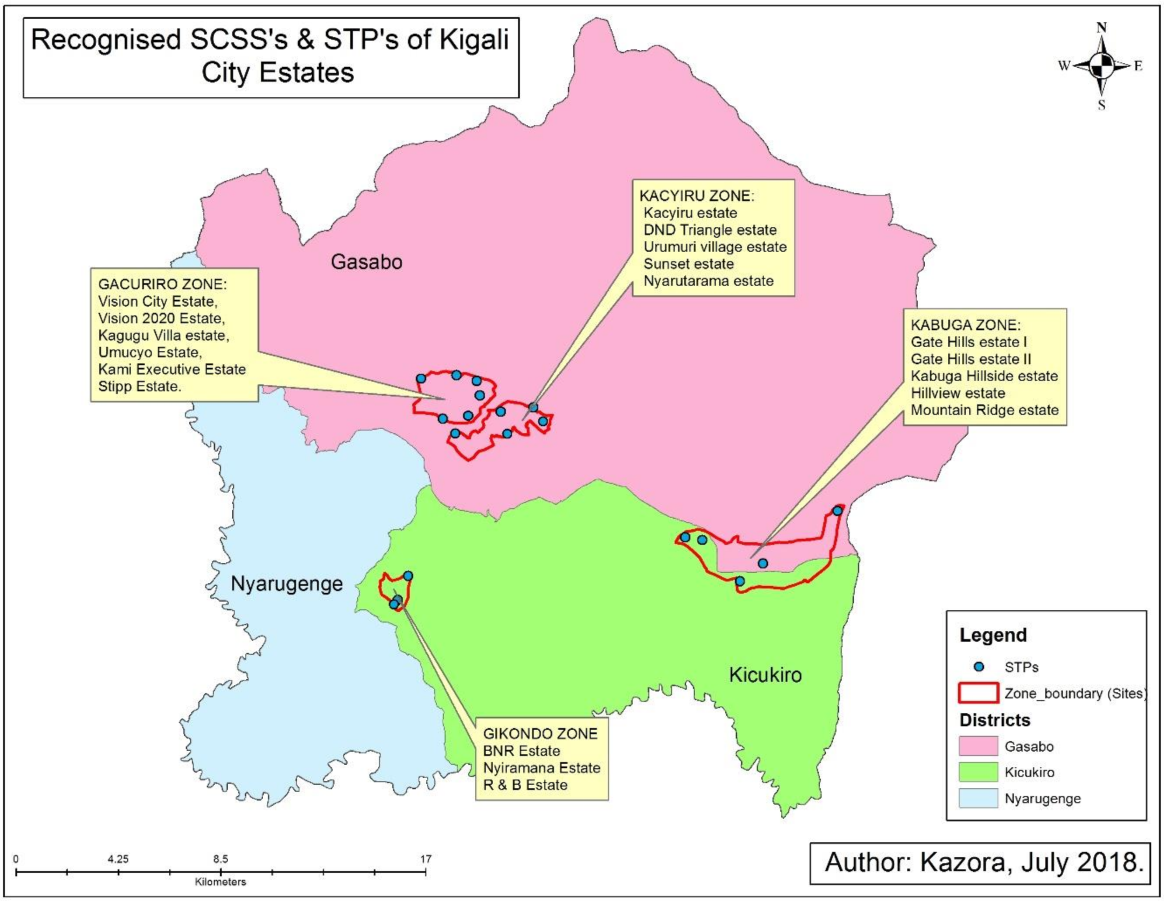


Figure 7: Sampling sites in Kigali City showing the location of19 collective STP's of Kigali city estates.

Quantitative approach was used in the collection of wastewater samples for laboratory analysis from each STP at different time frame at every inlet and outlet stage i,e; influent and effluent of the plant, whilst the qualitative approach was used to collect information from focused group discussions with end users of the facilities, different administrative levels, community management representatives of estates, labour technicians of the plants; and from designed questionnaire interviews with a wide range of stakeholders including system developers and operators, RURA, WASAC, REMA, MININFRA, MoH and CoK.

3.5 Population &Target Population

The target population of this study is both clustered DWWT plants known as semi-centralized sewage treatment plants (STP's) and residential households in Kigali city estates and the number of households vary by estate depending on number of population and their availability since it is focus group discussions. The figures for residential households were obtained from Estate developers and different local administrative levels of City of Kigali.

3.5.1 Sample size & Determination

The 4 sampling sites of Kigali city estates described above in research design of this chapter is composed of 19 recognized collective sewage treatment plants as listed in appendix D and this is the sample size of this study.

From each site, one (1) estate with semi-centralized sewerage system and its specific sewage treatment plant was selected to represent the site for their sustainable assessment as seen from figure 8.

3.5.2 Sampling Frame

Multi sampling stages were employed in assessing the sustainability of existing semi-centralized sewerage systems and their specific sewage treatment plants in order to determine if such decentralized treatment systems need to be improved for safe sanitation systems.

Stage one:

Evaluation of the infrastructures capacity for each cluster semi-centralized sewage treatment plant system in proportion to the current operation and maintenance situations in order to determine the design competence and technology used for the system reliability and opportunity for new connections (Extension), and the role and capacity of the end users in running the treatment plants.

Stage two:

Measuring process applicability of the systems for the determination of the applicable influent characteristics and system performance in terms of effluent quality & variability.

Laboratory experiments for measuring the quality (at inlet influent and final effluents) were used, and energy consumption were also determined at this stage. Monitoring systems and management of plant operations were definitely assessed. All these measures provided the status of environmental and social-economic sustainability in sense of financial capacity and willingness. Wastewater samples were taken and wastewater quality parameters were measured which include; physical, biological and chemical parameters.

Stage three:

This last stage was for analyzing the existing sanitation legal instruments with much attention to the national sanitation policy and strategies, laws and regulations in order to determine the gaps that may limit the development, implementation and management of such semi-centralized sewerage system solutions in emerging urban areas.

3.5.3 Sampling Technique

Sampling of quantitative data was conducted within 4 sampling sites of Kigali city estates identified in the research design in order to decide which semi-centralized sewerage systems and treatment units should be assessed. The survey found that all SCSSs and TUs built in 19 recognized estates of Kigali city were designed to use one common aerobic system for wastewater treatment even though they have different technologies and the initial designs were not met during implementation. Eleven (11) of 19 sewage treatment plants (STP) were designed to use Activated Sludge (AS) technic in biological treatment of wastewater but only two (2) of 11 have disinfection parts whereas others don’t have yet they were designed to have them. Other four (4) of 19 plants uses Sequencing Batch Reactor (SBR) in wastewater treatment with two (2) of them have no disinfection parts yet they were designed in early stages of execution, one (1) of these 4 has completely stopped working to the extent that the users have already constructed individual septic tanks as means of treating their waste and forgot about the STP yet it was initially designed and the remaining one SBR plant have a disinfection part with a recycling system. The remaining four (4) systems that make up 19 semi-centralized sewerage systems, three (3) of them uses collective septic tanks whereas the last one was designed as lagoon but it has completely died and not working at all where the sewerage systems that drains it were broken and drains in environment along the way (Marshland).

Therefore, after reconnaissance of study area and according to the design plans when developing the estates, the study captured three (3) critical operating conditions of existing semi-centralized wastewater treatment plants of Kigali city estates which includes; the systems that operates under AS technology, the systems that operates under SBR technology and finally the systems that operates (either under AS or SBR) without disinfection of treated effluent.

Consequently, in order to fully assess the sustainability of such decentralized wastewater treatment plants that were designed in Kigali city estates, the study considered three (3) semi-centralized sewerage systems and treatment units that operates under Activated Sludge system and one (1) that functions under SBR in treatment of their wastewater generated from estates which means a total of 4 systems were selected to ensure that the three operating conditions are well captured. Figure 8 present 4 selected estates with those specific systems that were chosen from each sample site i.e.: one estate with one STP from each sample site.

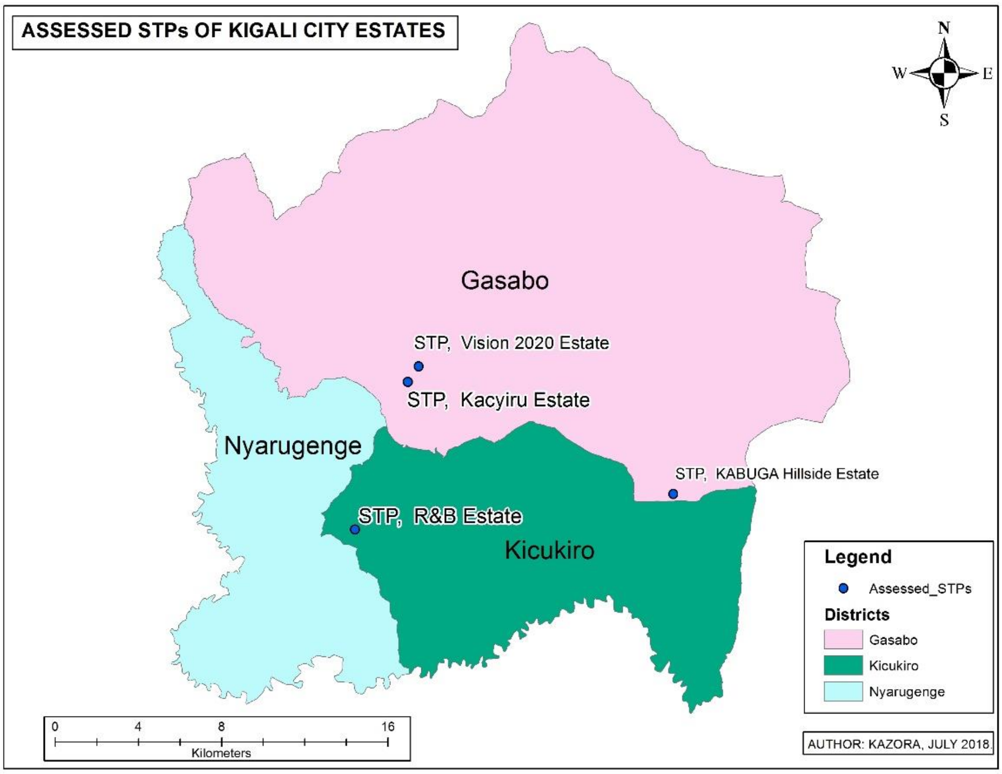


Figure 8: Assessed STP's of Kigali city estates (STP: Sewage Treatment Plants).

According to the present design of specific chosen sewage treatment plants, the only difference is importantly their disinfection parts with some minor differences in physical layouts. Kacyiru Estate use liquid chlorination for its disinfection whereas Vision 2020

Estate uses ultra-violet lights and R& B Estate has no disinfection but they all operate under Activated Sludge technology. The 4th analyzed system is Kabuga hillside Estate that uses Sequencing Batch Reactor technology with no disinfection for wastewater treatment.

The quantitative data was collected and coded from 4 selected semi-centralized sewerage systems and treatment units, then an excel master sheet was prepared before the beginning of data collection. The screening of the data pieces and marking the codes on the different variable samples collected was done to make the data ready to be assessed using the Excel database. On the other hand, this means that qualitative data from the DWWT systems was analyzed excel to get the clear records of the plant management.

The operation and management practices of the existing DWWT systems as well as the present effluent quality produced were analyzed. Descriptive statistics were used to analyze the data and data was presented in form of graphs and tables.

3.6 Data Collection Instruments

Both primary and secondary data were collected in this study. The instruments and devices for data collection depended on the required data from each specific DWWT systems.

3.6.1 Primary Data Collection Instruments

Qualitative instruments

- Interviews: Using open focus group discussions through personal observation and face to face with users, different local administrative levels, community management representatives of estates, and technical labours. The reason for this choice is that, there is lack of scientific literacy in wastewater treatment and management therefore, a face-to-face discussion was preferred using non-structured questionnaire.
- Questionnaire: Structured questionnaire is designed for interviews with a wide range of professional stakeholders from government officials, local authorities, and treatment plant developers.

Quantitative Instruments

- Wastewater samples were collected at key treatment components of each decentralized wastewater treatment plant to measure the quality of the influent and the effluent in order to evaluate the degree of wastewater generated and the competence of the treatment units in order to reduce the negative impacts to the environmental and public health.

Specific instruments, equipments and other devices were used while collecting and analyzing wastewater samples to obtain primary data and some include the following;

Figure 9: Wastewater Sampling bottles (left) and Sampler device.

Figure 10: Conduct meter for TDS, Turbid meter and DO meter.

Figure 11: Flasks (left), Jerrican, and Pipette.

Figure 12: Millipore Pump (left), Erlenmeyer and cells.

Figure 13: Test tubes (left), and Block digester/oven.

Figure 14: Spectrophotometer and GPS, Garmin 62S.

Figure 15: Laboratory sampling bottles, Colilert-18 (left) and Quanti - tray with its sealing machine.

Figure 16: Incubator (left) and Spectroline machine.

3.6.2 Secondary Data Collection Instruments

The secondary data was obtained on urban decentralized wastewater treatment systems/plants from different reports and record files of different resources including institutions, both published and unpublished papers, journals, internet and articles related to the area of study were reviewed as detailed below;

- Statistical reports about population census.
- National sanitation master plan for the City of Kigali.
- National and international wastewater quality standards for different purposes.
- Government Plans, Policies, laws, regulations and Reports on sanitation (From MININFRA, RNRA, REMA, RURA, and WASAC)
- GIS and Remote sensing data
- Internet (Scientific publications on decentralized wastewater treatment plants and/or systems; Journals, researches, etc…)

3.7 Data Processing and Analysis

According to (Gutterer et al., 2009), the treatment of the wastewater is considered insufficient if it does not correspond to the desired discharge standards in one or several of the following categories:

- Bio-chemical Oxygen Demand (BOD)
- Chemical Oxygen Demand COD
- Suspended solids
- Heavy metals
- Faecal contamination

The quantitative data of the collected wastewater samples from each of 4 selected semi-centralized sewage treatment plant were taken to carter for assessment of environmental sustainability using a designed WASAC sampling form as provided in appendix E. The samples were collected at inlet and outlet treatment unit stages (Influent and Effluent) of each plant in considerable time frame and then taken to the laboratory for physical, chemical and microbiological testing. The parameters measured and analyzed for each wastewater sample collected include the following; Faecal Coliform, E. coli, color, Electrical conductivity, Total Phosphorous (TP), Total Nitrogen (TN), Dissolved Oxygen (DO), Total Chemical and Bio-chemical Oxygen Demand (COD and BOD), Total Suspended Solids (TSS), Total Dissolved Solids (TDS), PH (Concertation of hydrogen ions), Temperature variation, and Turbidity.

Since the study considers also the socio-economic and technical sustainability of the sewerage systems and their specific treatment plants, the qualitative data were collected from the focus group discussions with a wide range of stakeholders comprising user communities and different local administrative level including RURA, WASAC, REMA, MININFRA, Local municipality (CoK), Private operators and/or developers, MINISANTE, and other associated parties in the field using and through questionnaires, interviews, and meetings.

In addition to focus group discussions, secondary data were also considered where the as-built documents/drawings of the 4 selected STP’s, different related sanitation policies, laws, regulations and research papers with respect paid to the gaps created by unfamiliar sanitation legal instruments in addressing proper development and management of urban wastewater treatment systems were reviewed. The present Rwanda national sanitation policy and strategies (NSPS), laws and regulations were intervened in order to fully assess the gaps created by unapprised legal sanitation instruments for effective and sustainable management of SCSSs.

All the collected data both quantitative and qualitative were given codes and entered in excel master sheet that was prepared before the beginning of data collection. The screening of the data pieces and marking the codes on the different variables were done to avoid confusions in data analysis.

While collecting the data, observation was also key means for analyzing the specific semi-centralized treatment plants and evaluating the perception of government officials and users on the use and management of SCSS.

According to (E Bahar et al. 2017), it is essential to consider social-economic, cultural, and environmental factors for strategic management of domestic wastewater in the way that system and technology used in treating wastewater is environmentally friendly, socially acceptable and finally reasonably priced (low-cost).

3.7.1 Categories for assessing the sustainability of semi-centralized sewerage systems and sewage treatment units

The principles for sustainable development of domestic wastewater management are indicated by numerous factors including financing, community, institutional and legal instruments, technology, and the environment which are grouped into four categories as detailed below;

- **Legal and Institutional aspects:**

  The institutional setups/framework and availability of decentralized sanitation legal instruments is an important indicator for the sustainability of wastewater treatment system though, not all instruments can be considered realistic and practical (TTZ Bremerhaven 2012). The diverseness of domestic wastewater treatment systems needs a working systems that involves reasonable regulations therefore, the institutional itself functions as regulators, decision making, and service providers through policies, laws, and guidelines (E Bahar et al. 2017). In connection with the technical features that are needed to meet the legal instruments like complexity, costs, etc…, the capacity of the authorities should be realistic (TTZ Bremerhaven 2012). Furthermore, the enforcement, review and updating of instruments particularly regulations for public health improvement and protection of the water quality for the receiving water bodies in the environment should be reflected (TTZ Bremerhaven 2012).

- **Management aspects:**
  Technology is one of the critical useful indicator in management aspect for sustainability of wastewater treatment systems which affects the reliability of any system, irregularities in the effluent quality and plant processing. The more complex and expensive the technology is, the more unsustainable the system will become since its management involves human resource capacity (E Bahar et al. 2017). Development, operation and maintenance of domestic wastewater treatment plants need high financial commitments as the benefits are indirect and without community will to operate and maintain the WWT system after its provision, treatment units or plants in general are designed for failure especially for new technologies where the users tend to show careful forethoughts by avoiding excess costs, etc… (TTZ Bremerhaven 2012).
- **Social – Economic aspects:**
  This commonly focuses on evaluating whether the new solutions brought have a positive social impact on societies. The indicators for the economic sustainability of domestic wastewater treatment systems suggests the financing value that is accepted by the community for their interests without exceeding the benefits and these include affordability, investment, operating and maintenance costs (E Bahar et al. 2017). For the sustainability and successful acceptance of the system by the public, the technology must take into consideration the local values and more importantly ensure basic understanding of the technology for all inhabitants of the entire local community (TTZ Bremerhaven 2012). Community involvement and participation in the planning, development and implementation should be considered for the better management of domestic wastewater treatment systems. For the case study, the awareness of community and their contribution should be considered in hiring and purchase of the houses for sustainable management of wastewater treatment facilities. If not so, Ignorance, perceptions and behaviors / habits will negatively affect the domestic waste water treatment systems hence unsustainability of such systems (E Bahar et al. 2017).
- **Environmental aspects:**
  The global indicator of sustainability of any domestic wastewater treatment system is quality of wastewater (effluent) discharged by the system into the environment. The

quality of wastewater generated by the system will either give less risks to public health and environmental pressure or not depending on how systems are managed (E Bahar et al. 2017). All the technologies and strategies that are developed in the context of managing wastewater systems should be implemented in a such way that they minimize negative impacts to the both public health and environment such as waterborne diseases, vector diseases, atmospheric emissions, eutrophication and land degradation (TTZ Bremerhaven 2012).

In analyzing while assessing the sustainability of semi-centralized sewerage systems of Kigali city estates, Excel was used to determine the management sustainability level based on various attributes. The qualities of each measurement (dimension) includes social-economic qualities, technical, institutional framework, legal instruments, and environmental quality.

3.7.2 Assessing the Sustainability of semi-centralized sewerage systems and Sewage Treatment Plants of Kigali City Estates

The methods for evaluating the sustainability of different wastewater treatment systems has been altered depending on the locality in relation to the research scope (Karel Mena-Ulecia et al. 2015), they include Life Cycle Assessment (LCA), Rapid appraisal (Rap-fish) commonly known as R-Software, Environmental impact study, Target plot diagram, Exergy analysis and Decision analysis as tools for assessing the system sustainability (E Bahar et al. 2017; Karel Mena-Ulecia et al. 2015; Donnelly et al. 2007). For all these tools, a set of criteria sometimes indicators are divided to different dimensions including technical, environmental, socio-economical, institutional and legal systems.

According to different researches, the sustainability assessment is only achieved when using a multidisciplinary technique by means of sustainability indicators (Karel Mena-Ulecia et al. 2015) and as long as the end solution is generated from an integral point of view (Molinos-Senante et al. 2014).

Therefore, according to the case study, the rating (scoring) used by target plot diagram tool in assessing the more sustainable technology for decentralized treatment of domestic wastewater indicators (Karel Mena-Ulecia et al. 2015) was adopted and modified in a way that they can be used in excel format while assessing both the sewerage system and sewage treatment plants with their existing technologies. The rating is done by setting weight values of the criteria for which later are based on in ranking the sustainability level of the systems through the obtained scoring points of each dimension, attributes, and criteria that already set as indicators (Karel Mena-Ulecia et al. 2015). For our case study, the criterion indicators of each dimension are clearly defined in table 2 and 3 below.

The approach of analyzing the scores using excel eased the interpretation and understanding of a such complex problem of assessing the sustainability of semi-centralized sewerage systems and sewage treatment plants of Kigali city Estates including their technology since the target plot diagram approach does not provide a complete assessment. The approach does not measure the entire sustainability as whole (i.e.; the whole system from the wastewater producers up to effluent discharge) rather it simply helps in technology selection to be used in a certain collective community (Karel Mena-Ulecia et al. 2015).

The procedure for assessing the sustainability level of the decentralized wastewater treatment system of the case study is as follows:

The criteria are rated in the range score of 0 – 10 which was initiated during the assessment process and implemented for each attribute. The range is divided into three categories of sustainability as Unsustainable, Less/Fairly Sustainable and Sustainable and these are later classified as Low, Medium and High scoring respectively. This range has a closer relationship to both negative and positive impacts that each dimension generates to the system, whether technical, environmental, socio-economic, institutional and legal framework in this case.

The first class is Low (L) which represents any parameter in this case regarded as criteria from any dimension that performs poorly and this makes it scoring at low level hence classified as unsustainable parameter in the range of 0 – 3. The second class is Medium (M) that ranges from 4 – 6 which links low and high classes. It signifies moderate performing criteria (parameter) and is regarded as Less Sustainable if the score is close to the unsustainable category (If the score is between 4 and 5) or can be considered as Fairly Sustainable if the score is between 5 and 6 which means close to high class. Lastly is Highly (H) scoring class which ranges from 7 – 10 and is automatically categorized as sustainable.

Each criterion is assumed to have full maximum score of 10, the criteria for each dimension and its specific attribute were rated according to the responses obtained from respondents including professional wastewater treatment stakeholders' in Kigali City, Estate residents, technical labours of the systems, and finally Estate developers / Operators through both structured and non-structured questionnaires as clearly described in appendix A, Band C. Not only the responses from concerned stakeholders were considered but also the results form laboratory testing of wastewater samples collected from STP's.

In the situation where one dimension had a criteria closer for a lower value which means scoring in the value interval of 0 – 3.9, this indicator would have high negative impact generation to the system and this is rated as Low hence scoring weight criteria of 3 points. In case where the scoring is in value interval between 4 and 6.9, at this point the impact generation is moderate in comparison with the lowest and highest scoring criteria and this is graded as Medium and will score weight criteria of 6 points. Lastly, in conditions where the criteria score the value in interval of 7 – 10 represents the parameter with high positive impact generation to the system performance for its sustainability and this makes it rated as High performance parameter with weight criteria of 10 points.

Afterwards, all criteria and their weight scored for each dimension were entered into excel database prepared for assessing the sustainability level of semi-centralized sewerage systems and their sewage treatment plants. For the case study, each dimension has its total score depending on the number of criteria analyzed which later classify the specific dimension in a certain sustainability class. The dimensions with the lowest score are the ones that generates major negative influences to the system performance and hence the most unsustainable dimensions. The sustainability indicators for all assessed dimensions and the picture of how they have been analyzed in excel tables are shown in figure 4 and 5.

3.7.3 Indicators of the sustainability of semi-centralized sewerage systems and treatment units

The indicators of any dimension were selected and evaluated to reflect the sustainability of each selected semi-centralized sewerage system. the attributes considered on each dimension. Different dimensions were considered in accordance with their attributes which has its criteria conditions for which was given weight criteria in the range of 0 to 10. Table 2 and 3 summarizes dimensions/attributes and their criteria that were adapted while assessing the sustainability of SCSS and their sewage treatment plants according to E Bahar et al. 2017; Karel and Heykel 2015 and TTZ Bremerhaven 2012.

Table 2: Indicators for Sustainability Assessment of Technical, Environmental and Socio-economic of SCSS's & STP's in Kigali city Estates.

Dimensions / Attributes	**Scaling**	**Low**	**Medium**	**High**	**Criteria**
Technical		**0 - 3**	**4 - 6**	**7-10**	
Physical Conditions and Layout Conformity					
					Construction according to design plan
					In the design plan horizon (Period)
					Construction of infrastructure works according to design
					Modified (Rehabilitated and Upgraded)
					Operation of plant
					Noise generation
					Odor generation
Plant Capacity					
					Designed inflow (Influent)
					Number of Inhabitants
Efficiency					
					Wastewater complexity (Designed level of BOD5 for influent)
					Treatment efficiency for the removal of BOD5 and COD (The effluent quality)
					Complexity of operation and maintenance
Technical Operations					
					Energy (Power) demand
					Availability of treatment reagents
					Skilled staff
Environmental	**Scaling**	**Low**	**Medium**	**High**	**Criteria are based on RS 110:2017 WW Discharge Limit Standards**
		0 - 3	**4 - 6**	**7-10**	
PH					5.0 - 9.0
Colour (mg/l PtCo).					200
Total Suspended Solids (mg/l).					50
Total Dissolved Solids (mg/l).					1500
Electrical Conductivity (µS/cm).					-
Temperature Variation (^{0}c).					3
Turbidity (NTU).					30 (WHO, 2006)

Dissolved Oxygen (mg/l).					-
Chemical Oxygen Demand (mg/l).					250
Biological Oxygen Demand (mg/l).					50
Total Nitrogen (TN), (mg/l).					30
Total phosphorous (TP), (mg/l).					5
Faecal coliform (MPN/100 ml).					<400
E. Coli (MPN/100 ml).					-
Socio-Economic	**Scaling**	**Low**	**Medium**	**High**	**Criteria**
		0 - 3	**4 - 6**	**7-10**	
Costs					
					Capital Expenditures (CAPEX)
					Operational Expenditures (OPEX)
					Depreciation of fixed costs
					Extension costs for service coverage
Community					
					Social awareness and understanding of SCSS and their specific treatment units
					Social acceptance and expectancy
					Community involvement in planning, development and management of SCSS
Service Satisfactory					
					Reliability of the services
					Affordability of the services

Table 3: Indicators for Sustainability Assessment of Institutional and Legal framework in development and management of SCSS's & STP's of Kigali city Estates.

Dimension / Attributes	**Class of Institute**				**Conditions**
	Institutes	**Name of Institute**			
	Scaling	**Low**	**Medium**	**High**	**Criteria**
		0 - 3	**4 - 6**	**7-10**	
Institutional and Legal Instruments					
Sanitation Policy					

					Available
					Available but not addressing proper development and management of SCSS
					Available but not addressing complete development and management of SCSS
					Available and fully addresses complete development and management of SCSS
					Enforcement
Sanitation Laws					
					Available
					Accountability for breaking laws that runs the working conditions of SCSS
					Enforcement
Regulations on Decentralized Wastewater Treatments Systems					
					Available
					Political will to give SCSS an appropriate attention
					Enforcement
Institutional Framework					
					Defined roles and responsible institutions in sanitation policy
					Accountability for mismanagements or failures of semi-centralized sewage treatment plants.
					Institutional collaboration
					Consistency among responsible institutions
					Power delegation to the responsible institutions
					Institutional will

CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter presents the performance evaluation of the studied communal decentralized wastewater treatment systems precisely semi-centralized sewerage systems and their specific sewage treatment plants of Kigali City Estates. It presents the results of the data collected from the case study based on the methodologies represented in chapter three of this study all intended to assess the sustainability of the collective public wastewater treatment systems in cities of developing countries specifically Kigali city. In meeting the objective set for the study, the research questions described in chapter were also addressed.

The results of the assessment consist of quite large number of measured criteria distributed to specific dimensions including legal, institutional, technical, socio-economic and environmental aspects. These dimensions are complex to interpret but often provides noteworthy conclusions thus in order to ease both the analysis and understanding of this multi criteria conditions, the excel database was developed in preparation for final analysis as well described previously in methodology.

In summary, the systems were assessed for their sustainability based on four different dimensions; Technical performance, Environmental standards for discharge of domestic wastewater, Socio-economical aspect, and finally Legal and Institutional framework in management of such decentralized wastewater treatment systems.

The sub-sections of this chapter evaluates the existing technical operations and management practices of wastewater treatment systems for collective communities of Kigali estates. They also provide an overview picture on the effluent quality disposed into the environment in compliance with national and international limitation standards for discharging domestic wastewater. This is useful as it answers research objectives 1 & 2 as well as the research questions 1, 2 & 3 are concerned. The sub-sections draw the sustainability level of the ruling sanitation legal instruments and institutional framework in addressing the development and management of decentralized wastewater treatment systems and this responds to the remaining research question and objective. Finally, the sub-sections discuss on the general opinions from respondents and interviews with stakeholders about semi-centralized wastewater treatment system of Kigali city estates and thus highlighting some of the gaps identified specifically in national sanitation policy and regulations. The findings presented in this study were produced from the data collected and analyzed through interviews with different stakeholders and laboratory testing of wastewater samples collected at sewage treatment plants of Kigali city estates.

4.2 Technical Evaluation

As seen in Table 4, the technical aspects were grouped in extensive and intensive criteria, and also grouped according to their attributes, such as plant capacity, technical operations, efficiency, physical conditions and layout conformity. These criteria were made for better assessment among these attributes.

Table 4: Technical Assessment of SCSS's and STP's of Kigali City Estates.

Dimensions / Attributes	**Scaling**	**Low**	**Medium**	**High**	**Criteria**
Technical		**0 - 3**	**4 - 6**	**7-10**	
Physical Conditions and Layout Conformity					
			6		Construction according to design plan
			4		In the design plan horizon (Period)
			4		Construction of infrastructure works according to design
		3			Modified (Rehabilitated and Upgraded)
			5		Operation of plant
			6		Noise generation
			5		Odor generation
Plant Capacity					
		3			Designed inflow (Influent)
			4		Number of Inhabitants
Efficiency					
		3			Wastewater complexity (Designed level of BOD5 for influent)
		3			Treatment efficiency for the removal of BOD5 and COD (The effluent quality)
		3			Complexity of operation and maintenance
Technical Operations					
		3			Energy (Power) demand
		3			Availability of treatment reagents
		3			Skilled staff
Sub-total	**150**	24	33		
Average	**10**	**3.77**			

4.3 Socio-economical Evaluation

As represented in Table 5, the CAPEX and OPEX are indicators that often defines the suitable alternative system especially much more in countries where financial investments in wastewater treatment are limited (Karel and Heykel 2015).

As it can be seen from table 4, the irregular operations of semi-centralized wastewater treatment systems of Kigali city are subjected to high costs which makes the public tend to ignore their responsibilities / ownership in management of treatment facilities.

Table 5: Socio-economic Assessment of SCSS's and STP's of Kigali City Estates.

Socio-Economic	**Scaling**	**Low**	**Medium**	**High**	**Criteria**
		0 - 3	**4 - 6**	**7-10**	
Costs					
		3			Capital Expenditures (CAPEX)
		3			Operational Expenditures (OPEX)
		3			Depreciation of fixed costs
		3			Extension costs for service coverage
Community					
			5		Social awareness and understanding of SCSS and their specific treatment units
			4		Social acceptance and expectancy
		3			Community involvement in planning, development and management of SCSS
Service Satisfactory					
			5		Reliability of the services
			4		Affordability of the services
Sub-total	**90**	15	17		
Average	**10**	**3.53**			

4.4 Environmental Evaluation

The quality of effluent from any wastewater treatment facility reflects the performance of the treatment system in both technical and environmental aspects. For this reason, it was imperative to take samples at 4 selected semi-centralized wastewater treatment plants of Kigali city estates to assess their performance. For that end, different samples have been taken at inflow and outflow of treatment plant at different period and analyzed at WASAC's Central Laboratory using the standard methods as well described in appendix G and H.

The summary for results obtained from the environmental indicators in all 4 semi-centralized domestic wastewater treatment systems examined are presented in Table 6. The parameter that does not meet the standards for discharge limits according to Rwanda Standards Board, RS 110:2017 means the most negative impacts generated by sewage treatment plants. According to Table 6, the effluent color, electrical conductivity, turbidity, DO, TSS, faecal coliform and E. coli have the lowest scale than any other parameter measured.

Table 6: Environmental Assessment of SCSS's and STP's of Kigali City Estates.

Environmental	**Scaling**	**Low**	**Medium**	**High**	**Criteria are based on RS 110:2017 WW Discharge Limit Standards**
		0 - 3	**4 - 6**	**7-10**	
PH				10	5.0 - 9.0
Colour (mg/l PtCo).		3			200
Total Suspended Solids (mg/l).		3			50
Total Dissolved Solids (mg/l).				10	1500
Electrical Conductivity (µS/cm).		3			-
Temperature Variation (0c).				10	3
Turbidity (NTU).		3			30 (WHO, 2006)
Dissolved Oxygen (mg/l).		3			-
Chemical Oxygen Demand (mg/l).				8	250
Biological Oxygen Demand (mg/l).				7	50
Total Nitrogen (TN)				7	30
Total phosphorous (TP)				8	5
Faecal coliform (MPN/100 ml).		3			<400
E. Coli (MPN/100 ml).		3			-
Sub-total	**140**	21		60	
Average	**10**	**5.75**			

4.5 Legal and Institutional Evaluation

This study aimed to evaluate the influence of three major instruments that are useful in sanitation sector when addressing the development and management of decentralized wastewater treatment systems for public. Namely; Sanitation policy, law and regulations on decentralized wastewater treatment systems and also the institutional framework in management of semi-centralized sewerage systems.

Unfortunately, according to the results from respondents through questionnaires as well as the survey done, the sanitation sector in Rwanda is controlled by only two legal instruments which are subjected to public decentralized wastewater treatment systems particularly for management of wastewater generated from the residential households and these include, National Sanitation Policy and Regulations on decentralized wastewater treatment systems.

There is no sanitation law in Rwanda though it is now under formulation and not yet at the stage of approval, the only law adapted for use is environmental organic law for which does not cater for development and all management aspects of decentralized wastewater treatment systems thus this was considered for its role in present monitoring of domestic wastewater discharged in environment.

Table 7 and 8 below presents the examined criteria with their weight while assessing the efficiency of current ruling national sanitation policy, laws and regulations on decentralized wastewater treatment systems with an emphasis on development and management of collective decentralized wastewater treatment systems purposely for public.

The attributes in legal and institutional features include sanitation policy, sanitation law, regulations on decentralized wastewater treatment systems and the institutional framework and these attributes have their respective criteria as shown in table 7 and 8 below.

The institutes were divided into two classes according to their roles as “Policy makers and Regulators” and “Implementers” in order to provide the relationship between how the targets developed are being implemented.

Table 7: Legal and Institutional Framework Assessment of SCSS's and STP's of Kigali City Estates by Implementers.

Dimension / Attributes		Implementers (CoK and WASAC)									Conditions
	Institute	CoK I			CoK II			WASAC			
	Scaling	Low	Medium	High	Low	Medium	High	Low	Medium	High	Criteria
		0 - 3	4 - 6	7-10	0 - 3	4 - 6	7-10	0 - 3	4 - 6	7-10	
Institutional and Legal Instruments											
Sanitation Policy (50)											
				10	3					10	Available
		3			3				6		Available but not addressing proper development and management of SCSS
		3			3			3			Available but not addressing complete development and management of SCSS
		3			3			3			Available and fully addresses complete development and management of SCSS
		3			3			3			Enforcement
Sub-total	**400**	12		10	15			9	6	10	
Average / Class of Institute	**10**	**4.13**									
Sanitation Law (30)											
			6			6		0			Available
		0			0			0			Accountability for breaking laws that runs the working conditions of SCSS

		0			0			0			Enforcement
Sub-total	**240**	0	6		0	6		0			
Average / Class of Institute	**10**	**1.33**									
Regulations on Decentralized Wastewater Treatments Systems (30)											
				10	3					10	Available
			6		3				6		Political will to give SCSS an appropriate attention
		3			3			3			Enforcement
Sub-total	**240**	3	6	10	9			3	6	10	
Average / Class of Institute	**10**	**5.22**									
Institutional Framework (60)											
			6		3				6		Defined roles and responsible institutions in sanitation policy
		3			3			3			Accountability for mismanagements or failures of semi-centralized sewage treatment plants.
				10			10	3			Institutional collaboration
		3				6		3			Consistency among responsible institutions
		3			3			3			Power delegation to the responsible institutions
			6			6			6		Institutional will
Sub-total	**480**	9	12	10	9	12	10	12	12		

Average / Class of Institute	**10**	**4.78**	
Average / Class of Institute	**10**	**3.87**	

Table 8: Legal and Institutional Framework Assessment of SCSS's and STP's of Kigali City Estates by Policy makers and Regulators.

Dimension / Attributes	**Policy makers and Regulators (MININFRA, REMA, RURA, MoH)**																**Conditions**
	Institute	**MININFRA**			**REMA I**			**REMA II**			**RURA**			**MoH**			
	Scale	**Low**	**Med**	**Hig**	**Low**	**Med**	**Hig**	**Low**	**Med**	**Hig**	**Low**	**Med**	**Hig**	**Low**	**Med**	**Hig**	**Criteria**
		0 - 3	**4 - 6**	**7-10**	**0 - 3**	**4 - 6**	**7-10**	**0 - 3**	**4 - 6**	**7-10**	**0 - 3**	**4 - 6**	**7-10**	**0 - 3**	**4 - 6**	**7-10**	
Institutional and Legal Instruments																	
Sanitation Policy (50)																	
				10			10			10			10			10	Available
		3			3			3			3			3			Available but not addressing proper development and management of SCSS
		3			3			3			3			3			Available but not addressing complete development and
																	management of SCSS

		3			3			3			3			3			Available and fully addresses complete development and management of SCSS
			6			6			6		3			3			Enforcement
Sub-total	**400**	9	6	10	9	6	10	9	6	10	12		10	12		10	
Average / Class of Institute	**10**	**4.76**															
Sanitation Law (30)																	
		3			3			3			3				6		Available
		0			0			0			0			0			Accountability for breaking laws that runs the working conditions of SCSS
		0			0			0			0			0			Enforcement
Sub-total	**240**	3			3			3			3			0	6		
Average / Class of Institute	**10**	**1.2**															
Regulations on DWWT Systems (30)																	
				10	3					10			10	3			Available
			6		3				6				10	3			Political will to give SCSS an appropriate attention
			6		3				6				10	3			Enforcement
Sub-total	**240**		12	10	9				12	10			30	9			

Average / Class of Institute	**10**							**6.13**									
Institutional Framework (60)																	
			6		3			3			3			3			Defined roles and responsible institutions in sanitation policy
		3			3			3			3			3			Accountability for mismanagements or failures of semi-centralized sewage treatment plants.
			6			6		3				6		3			Institutional collaboration
			6		3			3			3			3			Consistency among responsible institutions
			6		3				6			6		3			Power delegation to the responsible institutions
			6			6			6		3			3			Institutional will
Sub-total	**480**	3	30		12	12		12	12		12	12		18			
Average / Class of Institute	**10**							**4.1**									

4.6 Sustainability Assessment of Semi-centralized wastewater treatment system of Kigali City

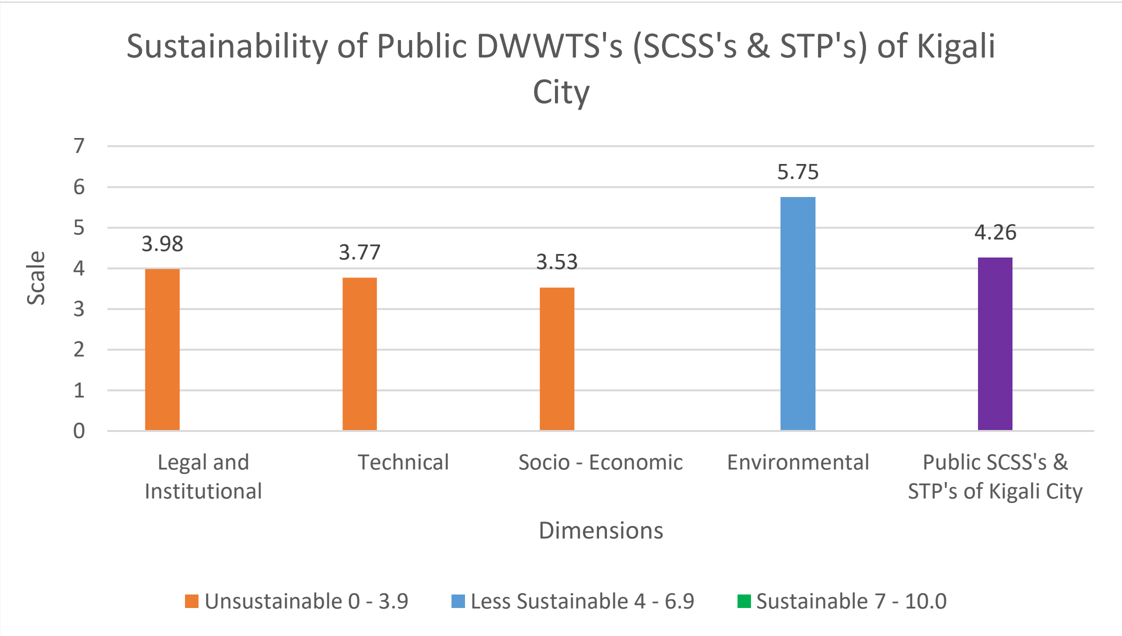
The overall assessment combines scoring weight criteria for technical, socio-economic, environmental, Legal and institutional attributes evaluated for their sustainability from each semi-centralized sewerage system and sewage treatment plant. As shown in table 9 and presented in figure 17, the sustainability level of semi-centralized wastewater treatment systems of Kigali city is generally **Less Sustainable** with technical, socio-economic, legal and institutional dimensions considered the most in generating negative impacts to the system. This is generally due to poor management practices and enforced legal instruments which not in place to some extent.

Table 9: Sustainability level for Public SCSS's & STP's of Kigali City.

Categories	Scaling	Legal and Institutional	Technical	Socio - economic	Environmental	Public SCSS's & STP's of Kigali City
Unsustainable	0 - 3.9	3.98	3.77	3.53		
Less Sustainable	4 - 6.9				5.75	4.26
Sustainable	7 - 10.0					

The dimensions linked with community involvement and institutional framework are the ones seems to be negatively affected the efficient performance of SCSS’s and STP’s.

Figure 17: Sustainability of Public SCSS's & STP's of Kigali City.



The assessment of the semi-centralized sewerage systems in the estates was conducted in 4 different estates representing the four sampling sites in Kigali city as well described in research methodology, the detailed assessment findings and challenges/problems encountered are presented here.

The table 10 below summarizes Technical, Environmental and Socio-economic assessment of Kigali city estates. The assessment was developed from average of the 4 estates assessed which are also well detailed in appendix I and J.

Table 10: Technical, environmental and Socio-economic assessment of Kigali city estates.

Categories	Scaling	Technical	Environmental	Socio - Economical	Technical, Env. And Socio - Economical for SCSS's & STP's of Kigali City Estates
Unsustainable	0 - 3.9	3.77		3.53	
Less Sustainable	4 - 6.9		5.75		4.35
Sustainable	7 - 10.0				

It was noticed that most of the sewerage network systems actually carries both sanitary sewage and large part of storm water from the estate houses, yet they were initially designed to carry the sanitary sewage only. This is automatically against their initial designs, and it is caused by the dwellers who illegally channel storm water into the sewerage network system. Moreover, most of the grease removal units on households' connections have been clogged while others have been sealed which shows lack of regular sewer operations and inspection.

During the assessment, it was realized that the plant does not have designed sampling points at inlet and out let of each treatment unit (settlers and bioreactor), and wastewater quality monitoring for each unit separately is not possible. Consequently, samples could only be collected at WWTP inlet and outlet points. The effluent which is discharged from the plant into the environment is not regularly tested. In addition, there is no regular records keeping system for activities carried out at the plant.

The main technical problems have been mainly due to insufficient aeration and low residence time in the final settling tank and this have been proven by laboratory results hence negative environmental impacts. There is high concentration of faecal coliforms detected in the effluent of each plant compared to the discharge limit indicates the microbial contamination of the receiving environment. The TSS level is also high compared to the standards. This may be due to the irregular desludging of settlers. An average reduction of about 45% was observed between the raw wastewater and the final effluent. Figure 18 below provides proportion of each dimension in technical, environmental and socio-economic sustainability of Kigali city estates.

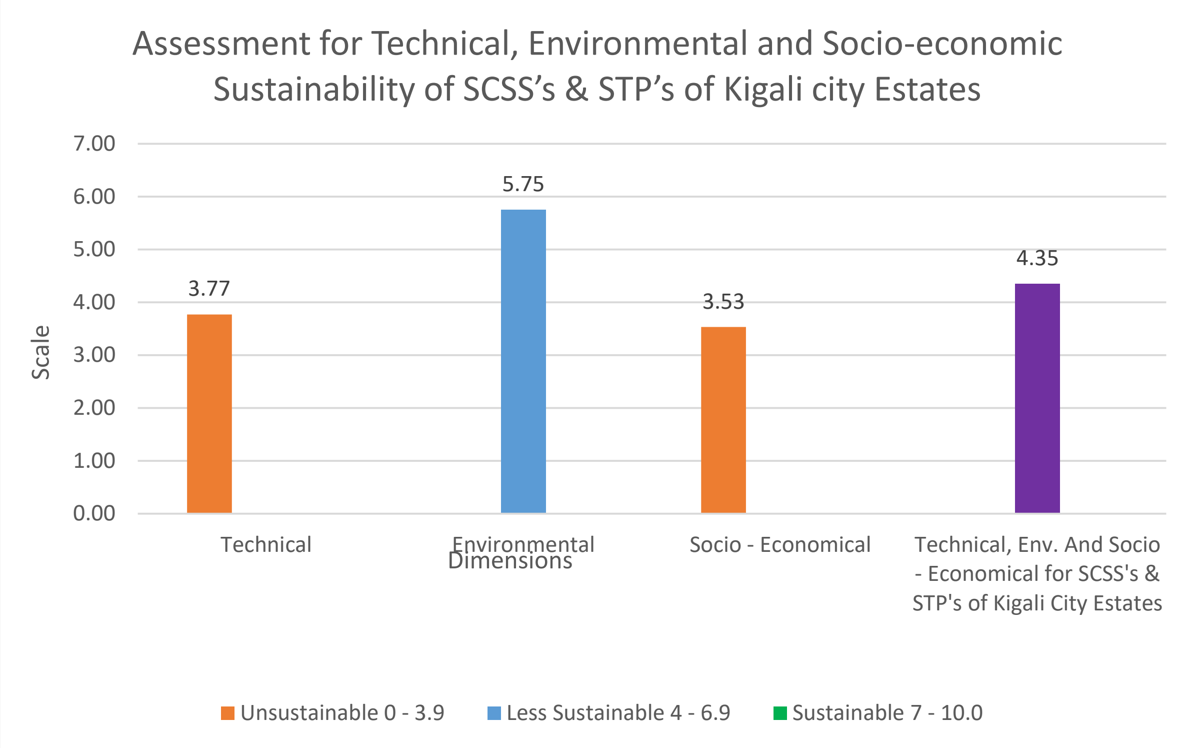


Figure 18: Technical, environmental and Socio-economic assessment of Kigali city estates.

Some of wastewater treatment plants have been recently rehabilitated but since then they still face problems of poor performance mostly due to irregularly operations and this makes them not meeting the environmental standards while experiencing storm water intrusion for which they were not designed for. Furthermore, whether rehabilitated sewage treatment plants or not, the common cross technical problem is the unskilled staff involved in daily management / running of treatment plants. In addition, the disinfection parts of treatment systems have been replaced by soak away pits and to some extent, the effluent is discharged freely with no disinfection yet these reclamation parts were initially designed.

From the assessment done, it has been revealed that the highest percentage of poorly performing dimensions or parameters are the ones associated with community involvement more especially right from implementation and management plan such as technical and socio-economic sustainability. The most criteria affecting negatively are social awareness, understanding, and expectancy of SCSS's and STP's.

The findings under this section also give an understanding on the influence of the legal and institutional frameworks on collective on site sanitation particularly on practical development and management decentralized wastewater treatment system. Table 11 summarizes the picture of sustainability level for legal instruments used in monitoring DWWTS's in line with institutional framework to enforce the supervision.

Table 11: Legal and Institutional assessment of Kigali city estates.

Categories	Scaling	Sanitation Policy	Sanitation Law	Regulations on DWWTS's	Institutional framework	Legal and Institutional
Unsustainable	0 - 3.9		1.25			3.98
Less Sustainable	4 - 6.9	4.53		5.79	4.35	
Sustainable	7 - 10.0					

The attributes for legal and institutional assessment include the sanitation policy, law, regulations on management of DWWTS's and finally institutional framework. The sanitation law was realized to be the only attribute to lower the performance other attributes. This is simply because there is no sanitation law in Rwanda. Not only the sanitation law, when you look on institutional framework, it close to unsustainable which shows characters of contradictions among the responsible institutions as it was well captured from the questionnaires distributed among the institutions. The figure 19 below provide an overview on sustainability level across all attributes and their impression in the perceptive of responsible institutes.

As regards to sector stakeholders, the findings approved that the National Sanitation Policy, Environmental Organic Law, and Regulations on Decentralized Wastewater Treatment Systems the main legal instruments committing the stakeholders to delivery of sanitation services. In Figure 19, the respondents mentioned the Sanitation law as most affecting dimension with weight of <u>1.25</u> in decentralized wastewater treatment systems hence unsustainable, <u>4.35</u> aggregate was rated for institutional framework and <u>4.53</u> for sanitation policy which puts them in less sustainable class. Finally, the majority quoted regulations on decentralized wastewater treatment systems as moderate performance in comparison with other available attributes which makes it fairly sustainable with weight aggregate of <u>5.79</u>. However, expressed lack of enforcement on regulation hence affecting decentralized sanitation.

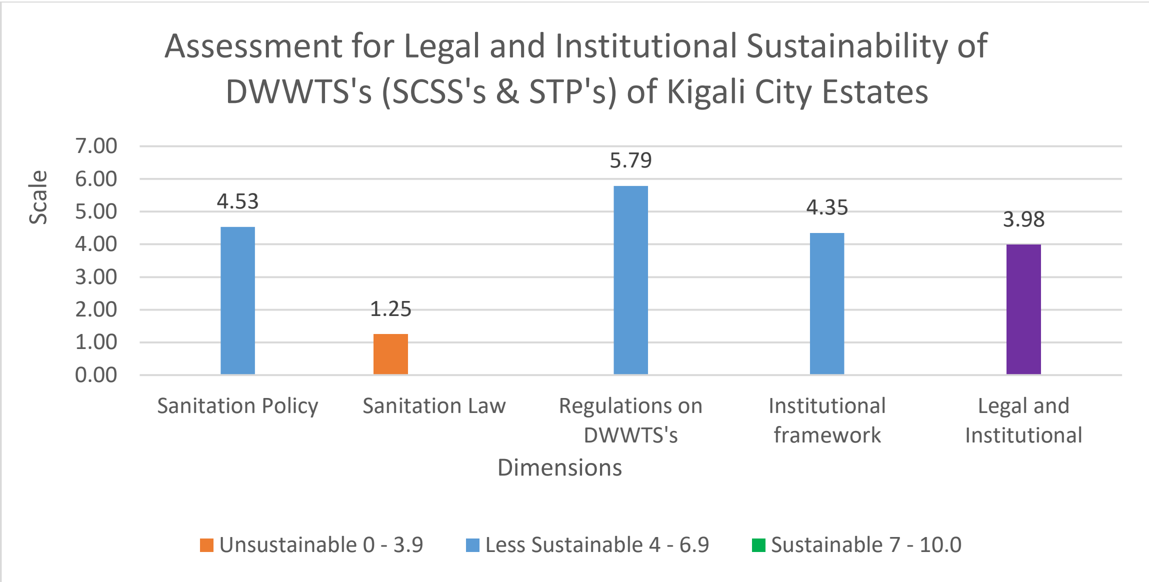


Figure 19: Legal and institutional assessment of Kigali city estates.

4.7 Discussion on Wastewater Treatment Options for the case study

Generally, Rwanda as a country has achieved millennium development goals particularly goal 7 in its article 3 which includes proportion of population using an improved sanitation facility to be met at 83.4% in 2014 beyond MDG target of 72.5% (NISR, 2016 / EICV4).

The majority of Rwandese rely on on-site sanitation and this appears to be affordable although around two thirds are proven to be improved sanitation facilities in accordance with the definitions of such amenities from international standards specifically millennium development goals (MININFRA, 2017). Installed flush toilets are rare in Rwanda as country which means that water is mainly used for washing and cooking and then finally discharged mainly on surface, whereas excreta is discharged or managed openly in waterless latrines (MININFRA, 2017).

The proportion of households with access to improved sanitation in City of Kigali (CoK) shows an increase from 83.3% in 2010-11 to 93.2% in 2013-14 with a significant improvement in all poorest quantiles based on EICV3 of 2012 and EICV4 of 2016 (NISR, 2012; NISR, 2016).

The population of Kigali city are largely dependent on septic tanks and pit latrines as their sanitation facilities with 95% uses on-site sanitation systems, 80% of these are pit latrines (Baptiste, A.J et, al. 2017). However, only 2% of the households in Kigali city empty the sludge from their pit latrines (Tsinda et al. 2013). The little percentage of emptied sludge is also not treated for proper disposal rather it is just dumped in an open environment that is called NDUBA dumping site (Landfill) and this later causes health and environmental problems as well as improper functioning of the ecosystem and sometimes displacement of the neighborhood population.

There is no sewerage system that is installed anywhere in densely populated urban areas of Rwanda including Kigali city among others for collective sanitation services except few developed sewerage systems constructed or installed by estate developers (Cluster of houses) of course for small communities of high income household levels in Kigali city which is about 1,000 in total number. In addition, there are also some other semi-centralized sewerage systems developed by business owners in some public areas like hospitals, hotels, government institutions on the regulation from the government (MININFRA, 2016; Baptiste, A.J et, al. 2017).

The status of access to improved sanitation normally in Rwanda is highlighted in Rwanda EICV4 (Integrated Household Living Conditions Survey) Thematic report utilities and amenities approved in march 2016 are presented in table 12 (NISR, 2016).

Table 12: Access to Improved Sanitation in Rwanda.

EICV4	% Improved sanitation	% improved but not shared	Flush toilet	Pit latrine with solid slab	Pit latrine without solid slab	No toilet facility
			% improved sanitation		% unimproved sanitation	
Rwanda	83.4	63.5	1.8	81.6	13.5	3.2

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This last chapter follows the results and discussions of the study findings. It is divided into two main sections; the first section is the general conclusion based on research objectives of this study, followed by the second section which provides the recommendations on the proposed management framework of SCSS's and their treatment units for sustainable development. Based on this study, the conclusions captured the concerns related to the technical performance, socio-economic and environmental aspects as well as legal and institutional framework is concerned.

5.2 Conclusions:

The study was required to determine the sustainability of DWWTS's precisely for collective SCSS's and STP's of public estates of Kigali city in satisfying wastewater treatment in the cities of developing countries. This was evaluated through technical, environmental, socio-economic, legal and institutional assessment for their performance.

Generally, the technology system which is complex in operation and maintenance or poorly installed and fails to accomplish the expectancy of its users, poses significant challenges for sustainability. The decentralized wastewater treatment in the case study showed significant failures of critical biological elements signifying deprived effluent quality and performance for which SCSS's and STP's would attain if well managed and monitored hence semi-centralized treatment systems are not effective in complying the effluent quality requirements for discharging. Regardless of the varying treatment capacities that might be caused by different technologies used and management practices among others, the study provided sufficient evidences to determine the potential of SCSS's in providing collective wastewater treatment services in densely populated areas of cities under development including Kigali city.

The intermittent water supply to the community that may lead to the low flow rate of wastewater during rationing could also make the SCSS's less sustainable for the community. however, attaining sustainable wastewater treatment systems is only possible if the treatment plant is well designed and properly managed.

In the case of quality for physical infrastructures, complete construction of civil works like construction of biological treatment tanks and reclamation parts are essential but not satisfactory conditions for sustainability. Despite other issues related to operation and maintance of the treatment system, good quality of construction works is central to substantial service life span and this can only be undermined by poor quality and incomplete civil construction works as it was observed that may be caused by unprofessional practices.

Without clear adequate and sustainable legal instruments for the planning, development and management of decentralized wastewater treatment systems specifically SCSS's and STP's for collective urban communities, the legal and institutional framework will continue being less supportive towards semi-centralized sewerage systems in the small communities of densely populated areas in the cities of development countries. Therefore, to avoid such constraints, there are needs in redefining, restructuring and enforcement of principles that governs SCSS's.

Therefore, based on the responses from all stakeholders and the results from the assessed attributes and parameters, the semi-centralized wastewater treatment systems are more favorable in densely populated areas of small communities in cities of developing countries.

5.3 Recommendations

The study has provided some technological recommendations necessary for the efficient development and management of semi-centralized wastewater treatment systems in the cities of developing countries including Kigali city. Further recommendations are for the future research needed to supplement in the development of SCSS's in small communities of densely populated areas. The lessons learnt from other findings were useful in advising for more sustainable management strategies of collective DWWTS's. The recommendations include the following:

- ❖ Adequate and proper monitoring of system developers and operators is subsequently essential right from the commencement of the request for construction permits, plant installation and during operation. If the promotion of improved safe sanitation is not carried out at a very high standard and systematically carefully, the sustainable results should not be expected. Therefore, the implementation of **"software"** aspects in operation and management of semi-centralized wastewater treatment systems is also important to ensure improved quality performance of the system.

- ❖ Collective semi-centralized wastewater management systems of urban community in the cities of developing countries requires contribution from the users either in terms of cash or in-kind like labour and local materials especially in countries with limited finances and this is rarely enclosed for the case study as it would create sense of community ownership. The community need to be informed on the wastewater management system earlier in the purchase of houses and in addition, they need to be taught about the working conditions of wastewater treatment processes and technology installed before handover of the treatment facilities. This would avoid social tendency of negative anticipation like thinking that there are extra charges for operation and management of the system but rather will make them feel it as ownership responsible cost for management of treatment facilities hence cementing community ownership of semi-centralized sewerage systems and consequently contribute to sustainability of such DWWTS's.

- ❖ Even though a sanitation system may be physically operating (functioning) and used, if a domestic wastewater management system either individual or collective system pollutes the environment and hence frightening the public health, then the system consequences cannot be expected to be sustainable. The safety of effluent quality for the receiving water bodies and the conceptual attention given to sanitation are two inter-related environmental features that need to be considered in designing of semi-centralized wastewater treatment systems. For the case study, wastewater management is thought in terms of both how to treat and dispose it for which it is too narrow to think of wastewater management systems. The by-products should be handled as resources to be carefully re-used instead of just being disposed thus this insight leads to environmental sustainability.

- ❖ In the context of struggle for sustainability, legal instruments have important functions for accountability and management that are about knowledge and action. These instruments have to ensure that the wastewater treatment services provided are affordable, suitable, in compliance with standards and clearly addresses comprehensive wastewater management taking local situation into consideration. In addition, the responsible/mandated institutions have to be clearly accountable for the system failures in terms of performance. Based on the results from the survey specifically from questionnaires, there is a need for sustainable and applicable legal instruments for the case study as well as in developing countries. The ruling national sanitation policy and regulations on decentralized wastewater treatment systems should be reviewed with reflection on the institutional responsibilities, government incentives and subsidies on the development of SCSS's and complete management and monitoring of such decentralized wastewater treatment systems.

- Lastly but not least, the study recommended decentralized wastewater treatment system over centralized sewerage systems in the cities of developing countries according to the case study based on both quantitative and qualitative results of the study. In addition to the literature viewpoint of chapter 2 in this study, the results show that DWWTS's are reliable in quality performance if well managed, affordable in terms of cost especially when it comes to their development, takes little time during construction and are more suitable considering the relief/ topography of the case study (High altitude City) to cut off the cost for pumping where might be applicable. Finally, for collective decentralized wastewater treatment system in the cities of developing countries, the preferably and more sustainable technology in the treatment of wastewater is Sequencing Batch Reactor (SBR) over Activated Sludge (A.S). This is mainly due to small land size from which these systems are a located on and this does not allow fully activation of biological treatment in A.S hence short residence time.

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APPENDICES

Appendix A: Research Budget

Item	Unit	Quantity	Unit Price (USD)	Amount (USD)	Budget Notes
Flight Ticket	No.	1	804	804	The local currency for this item is exclusively in Algerian Local currency, Dinars (Dz) and was paid purposely to go and conduct research study for the case study Rwanda, one round return flight ticket from Tlemcen-Algeria to Rwanda and back.
Transportation for collection of wastewater samples	Ls	1	113	113	This money was paid for transport of carrying on-field lab equipments and of laboratory technician and myself while collecting wastewater samples which were later analyzed in WASAC laboratory. These costs were used in Rwanda.
Wastewater Quality Analysis (Laboratory Test)	Ls	1	2,084	2,084	The money was paid to the WASAC Ltd bank account for wastewater quality parameters analyzed in central Laboratory. Wastewater samples were collected from 4 sampling sites represented by **4 Treatment Plants** as clearly identified in appendix H and WASAC Invoice. The number of samples analyzed are far more than the number of samples paid simply because WASAC allowed to analyze for me the remaining samples on free of charge for the completion of my research objectives.
TOTAL				**3,001**	The Total grant amount provided for Research Thesis was all used as well described but it was clearly not enough to accomplish the research as it was initially designed.

Appendix B: Questionnaire for Kigali City Estate - SCSS & WWTU Developers / Operators: Structured Questions

Kigali, June 2018

I am Amos SHYAKA KAZORA, a MSc student at Pan African University Institute of Water and Energy Sciences (PAUWES) including Climate Change pursuing a Master's Degree in Water Sciences carrying out a research on sustainability of decentralized wastewater treatment systems specifically semi-centralized sewerage systems (SCSS) and wastewater treatment units (WWTU) in the cities of developing countries case of Kigali city.

The survey aims to assess the management practices of the generated wastewater from the small community households of Kigali city estates regarding to its effects on the environment and public health. Your responses to questionnaire is completely voluntary and valuable. You can ignore the questions that you don't like to answer. You will not be individually identified and your answers will be only used for statistical and academic purposes.

PART I: General Information

1. Name & Position of Respondent: ……………………………………………………
2. Telephone: …………………………… E-mail: ……………………………….…
3. Name & Address of the company: ……………………………………………........

   ……………………………………………………………………………

4. Sex: Male [ ] or Female[ ] Age (Years): 10 - 20 [ ], 21 - 30 [ ], 31 - 40 [ ], 4 - and above [ ]
5. Educational level: a) Diploma b) Bachelors c) Master d) Dr. / PhD
6. Field of Study: ……………………………………………………………………
7. Name of Estate: …………………………………………………………………….
   Nº of Households: ….…
8. Number of population served: ………………………
9. Location: Cell: ………………. Sector: ………………… District: ……………………
10. Type of contract to operate the plant facility:
    a) Renewable: …………. (Years), b) Open ………… c) Others, Specify ………………
11. Time period (In years) operating the plant:
    a) Less than a year [ ] b) 1 - 5 years [ ] c) 4 - 10 years [ ]. d) 10 years - and above [ ]
12. Work experience in sanitation related fields specifically wastewater treatment systems

a) Less than a year [ ] b) 1 - 5 years [ ] c) 6 - 10 years [ ]. d) 10 years - and above [ ]

13. Contacts at wastewater treatment plant facility

Names: ………………………………………… Telephone ………………………….

E-mail: …………………………………………………………………………

PART II: Technical issues

14. Is the wastewater system fully operating, partially operating or completely not in operation? Describe. If partially or not, what is the cause, physical damage, incomplete infrastructures, power loss or any other reason? ………………………………

…..……………………………………..…………………………………………………

15. Which technology did you choose for wastewater treatment? Why?
    a) Activated Sludge treatment
    b) Sequencing Batch Reactor (SBR)
    c) Trickling Filters
    d) Rotating Biological Contactors (RBC)

16. Which disinfection choice do you use? Why?
    a) Chlorination
    b) Ultra Violet (UV) lights
    c) None

17. What is the process for this system (flow-chart)? ……………………………………

……...……………………………………………..……………………………………

18. What is the function of each part? …………………………………………………..

………………………………………………………………………………………

………………………………………………………………………………………

19. What is the performance of this system;

The designed capacity (m3/d) ………………. The designed capacity (PE) ……………..

The current total loading (m3/d): ………… The current total loading (PE)……………..

The area occupied by the plant (m^2): ………… Available area for extension (m^2) ………

Indicators	Quality of Influent Wastewater	Quality of Effluent Treated Water
COD (mg/l)		
BOD_5 (mg/l)		
SS (mg/l)		

PH

Pathogen

20. Is there any possibility for new connections to the sewerage system? Yes [ ] or No [ ].
21. What kind of standards does the treated effluent water comply with?
    a) Rwanda Standards Board (RSB)
    b) EU,
    c) WHO
    d) Others, please mention ……………………...
22. Is there control or any other improved systems to regulate plant operations and performance (Like SCADA, STOAT, etc…)? Yes [ ] or No [ ]. If yes, please specify; …………………………………………………………………………………………
23. What is the reclaimed water used for? (Multiple choice)
    a) Toilet water
    b) Landscaping
    c) Fire-fighting water
    d) Car-washing water
    e) Industry cooling water
    f) Agriculture irrigation
    g) Others, please specify ………………………………….
24. Is the semi-centralized sewerage system and wastewater treatment unit being monitored? Yes [ ] or No [ ].
25. How to operate and how often do you maintain the system?

    a) Automatic and just need periodically maintenance

    b) Need technical operators and periodically maintenance

    c) Can be operated by normal workers and need periodically maintenance

    d) Other ways, please specify …………………………………………………….

    Describe the maintenance period ………………………………………………….

26. Are there any technical problems occurred during the construction and operational period?
    Yes. It is about: ……………………………………………………………………….
    No [ ]
27. How many times per year does a system failure occur?
    ……………………failures/year
28. Which parts of the wastewater management system failed/was out of order? What was the problem? When and how often does it happen? How did you solve it and who did it?

Part of the system	Problem	When? (Date)	Often? (t/m/y)	Solution	Solved

29. When the sanitation system fails, what is the average down time in hours? ....hours/failure
30. Do you have a schematic (Plan) representation of your catchment area (Sewer Plan)? Yes [ ] or No [ ].
    If available or possible, please provide in a separate file a digital map (in shape file or any other format) of your sewer plan.
31. Are there any clinic/hospital/ health center in the catchment of WWTP? Yes [ ] or No [ ].
32. What type of sewer drains your catchment?
    a) Separate sewers
    b) Combined sewers
33. Do you expect significant exfiltration in the sewerage system such as wastewater loses from sewer network or house connection? Yes [ ] or No [ ]. If yes, can you estimate how much in terms of % of the total inflow……………………………………..…...
34. Is there any special infrastructure like retention basins, etc… to regulate wastewater flow in the system before the influent of WWTP for real time control? Yes [ ] or No [ ]. If no, how do you regulate undesired inflow or overflow? …………………………….
    ………………………………………………………………………………………………
35. Are there flow meters installed to measure the raw wastewater influent?
    Yes [ ]
    No [ ].
    If yes, where are they located? ……………………………………………………….
    ……………………………………………………………………………………….....
36. What are the estimates of the dry weather per day for;
    Total wastewater volume ……………. (m3/day)
    Minimum flow …………. (L/day)
    Maximum flow …………… (L/day)
    Maximum flow (Wet weather) …………… (L/day)
37. Where does exactly the points for wastewater samples are collected;

    The influent

    After screening [ ]

After primary clarifier [ ]

The effluent
After secondary clarifier
After disinfection

Others, please specify
…………………………………………………………………………….

38. Which sampling mode do you use;
    Time proportional [ ]
    Volume prop [ ]
    Flow prop [ ]
    Grab (Manual) sampling [ ] Please provide how many samples per day or month:
    ………..
39. Is there a need for short term assistance such as lab support, treatment chemicals, fuel, etc.)? Yes [ ] or No [ ].
40. Do you ever experience a by-pass of wastewater that might adversely impact the wastewater treatment plant system (describe)?
    Yes [ ] , If yes how much time did it take in hours:
    No [ ].

PART III: Economic issues

41. What about the cost?
    The investment: ……………….
    The operation expense: …………………
    The price per household: …………………
42. Do you think there are any opportunities to extend the market?
    Yes [ ] (go to question 44)
    No [ ] (Please explain and go to question 46)
43. Which kind of difficulties will be encountered? ……………………………………..
    ....
    ....
44. How to solve them? ………………………………………………………………..
    ....
45. Is there stock for the system's assets been inventory? Yes [ ] or No [ ].
46. Do you have any recommendation for this system? Yes [ ] or No [ ]. Please explain your answer ……………………………………………………………………………
    ……………………………………………………………………………………
    ……………………………………………………………………………………
    ……………………………………………………………………………………

PART IV: Additional notes

According to the case study of Rwanda as a developing country specifically Kigali city, which system between decentralized and centralized wastewater treatment system (Sewerage system) would you recommend and for what reasons? Please explain your answer in brief on the blank page below;

Thank you for your patience and relevancy in filling this questionnaire and importantly being a part of this research paper.

Appendix C: Questionnaire for Professional Wastewater Treatment Stakeholders' in Kigali City: Structured Questions

Kigali, June 2018

Dear Respondent,

I am Amos SHYAKA KAZORA, a MSc student at Pan African University Institute of Water and Energy Sciences (PAUWES) including Climate Change pursuing a Master's Degree in Water Sciences carrying out a research on sustainability of decentralized wastewater treatment systems specifically semi-centralized sewerage systems (SCSS) and wastewater treatment units (WWTU) in the cities of developing countries case of Kigali city.

This questionnaire is designed to consult professional wastewater treatment plant staff and local authorities with reflective knowledge or information on the estates and semi-centralized wastewater treatment plants (SCWWTP) under investigation.

The survey aims to assess the management practices of the generated wastewater from the small community households of Kigali city estates regarding to its effects on the environment and public health. Your responses to questionnaire is completely voluntary and valuable. You can ignore the questions that you don't like to answer. You will not be individually identified and your answers will be only used for statistical and academic purposes.

PART I: General Information

1. Name & Position of Respondent: …..…………………………….………………
2. Telephone: …………………………… E-mail: ………………………………
3. Name & Address of the company……………………………………......................

   ………………………………………………………………………..
4. Sex: Male [ ] or Female[ ] , Age (Years): 10 - 20 [ ], 21 - 30 [ ], 31 - 40 [ ], 41- and above [ ]
5. Educational level: a) Diploma b) Bachelors c) Master d) Dr. / PhD
6. Field of Study: …………………………………………………………………
7. Time period (In years) living in Kigali city:
   a) Less than a year [ ] b) 1 - 5 years [ ] c) 6 - 10 years [ ]. d) 10 years - and above [ ]
8. Work experience in sanitation (wastewater treatment systems) related fields
   a) Less than a year [ ] b) 1 - 3 years [ ] c) 4 - 6 years [ ]. d) 6 years - and above [ ]

PART II: Technical issues

9. The existing sanitation sewerage facilities for public connection are not adequate for the population residing in Kigali city
   Yes [ ], May be [ ] or No [ ].
10. The improved access to safe sanitation systems in Kigali city Estates is one of the top priorities for increasing high and medium income households living in the Estates?
    Yes [ ], May be [ ] or No [ ].
11. The provision and supervision of construction works for SCSS and WWTU in Kigali Estates is a responsibility of the Estate owners
    Yes [ ], May be [ ] or No [ ].
12. Which number of persons per household that should best be used in estimation of residential population to be connected to the SWWTP in Kigali city estates? …………
    Please provide a clear reason for your choice………………………………………
    ……………………………………………………………………………………
13. For disposal units of any WWTP, is there an observation needed? Why?.......................
    ……………………………………………………………………………………
14. Are the wastewater issues (problems) important to your organization? Yes [ ] or No [ ]. If yes, to what extent? If no, why? ……………………………………….....
    ……………………………………………………………………………………
15. Should wastewater be treated before disposal? Yes [ ] or No [ ], why? ……………..
    ……………………………………………………………………………………
16. Can the treatment of wastewater before disposal lead to the economic development of any country? Yes [ ] or No [ ]. If yes, How? …………………………………..
    ……………………………………………………………………………………
    …….…………………………………………………………………………………
17. Is there government compliance monitoring programs for wastewater treatment generated from Kigali estates? Yes [ ] or No [ ]. If yes, please describe at least two?
    ....…………………………..…………………………………………………
    ……………………………………………………………………………………
18. Is there any agreement between your organization/institute and private operators in operationalization of SCWWTPs in Kigali estates to comply with quality (Either construction or wastewater quality) standards? Yes [ ] or No [ ]. If yes, continue to next question. If no, skip next question.
19. Was there ever a disagreement between your organization/institute and private operators of SCWWTPs in Kigali estates about the most suitable compliance technology or method for wastewater treatment? Yes [ ] or No [ ]. If yes, which measures were taken? ……………..……..…………..……………………………….....
    ....
20. Low-cost sewerage system specifically SCSS will probably achieve and promote improved safe sanitation, public hygiene and preserved environment because of ease to operate and their performance efficiency. Yes [ ], May be [ ] or No [ ].

21. In densely populated areas of Kigali city, treatment of small volumes of sewage from small community such as Estates using low-cost sewerage systems can provide safe treatment and disposal of human waste. Yes [ ], May be [ ] or No [ ].
22. Location of decentralized treatment systems or plants within the community can be a risk to health of the population and environment. Yes [ ], May be [ ] or No [ ].
23. Unstructured physical planning and development could make much more difficult development of decentralized systems or low-cost sewerage services.
24. Yes [ ], May be [ ] or No [ ].
25. Decentralized systems will undoubtedly increase risks to public health and pollution of aquatic environment (i.e. land and watercourses) if not properly managed.
26. Yes [ ], May be [ ] or No [ ].
27. Do you know of any national policies, laws or legal provisions available for the provision and management of decentralized wastewater treatment systems? Yes [ ] or No [ ]. Explain your answer…………………………………………………………… ……………………………………………………………...…………………………… ……………………………………………………………………………………………
28. If yes, are these policies and legal sanitation instruments clear on how to develop, manage and monitor decentralized wastewater treatment systems (DWWTS) and plants (DWWTS)?
    Yes [ ] or No [ ]. Explain your answer ………………………………………… ……………………………………………………………………………………………… ………..…………………………………………………………………………………
29. What control systems/programs or regulations are applicable to planning, development, and management of such DWWTS and plants? ……………………………………. ………………………………………………………………………………………………
30. Do regulatory authorities and service providers enforce/implement the regulations that exist which requires quality compliance?
31. Can the development of decentralized systems be subjected to any other legal sanitation related instrument which gives powers to plan, develop and management or monitoring, of SCWWTP and related decentralized sanitation works? Yes [ ] or No [ ]. If yes, give an example of how it can be addressed in legal instruments such as in policy……………….…………….…...………………...……………………………… ……………………………………………………………………………………………
32. Is there any consultative process involving stakeholders in developing semi-centralized wastewater treatment systems and plants especially for Kigali city Estates?
    Yes [ ] or No [ ].
33. What are some of the incentives or conditions necessary to support and activate the promotion, development and management of semi-centralized wastewater treatment systems and plants in Kigali city? Explain your answer ....

PART III: Economic issues

34. Do the government financial investments to the sanitation sector often prioritize and include support to develop semi-centralized wastewater treatment systems and plants? Yes [ ], May be [ ] or No [ ]. Explain your answer with facts …………………………
…………………………………………………………………………………………
…………………………………………………………………………………………

PART IV: Social issues

35. What do you think about the working efficiency of SCSS & WWTU in Kigali Estates?
…………………………………………………………………………………………
…………………………………………………………………………………………
36. Did you get any complaints from the customers (End users/Households tenants of the estates)?
a) Yes (go to question 3)
b) No (go to question 4)
37. What are the complaints about? (Multiple choices)
a) Odors of the reclaimed water
b) Colors of the reclaimed water
c) Safety of the reclaimed water
d) Price of the reclaimed water
e) Others……………………….
38. What kind of benefits of the waste water management system do you experience?
…………………………………………………………………………………………
…………………………………………………………………………………………
39. What kind of drawbacks of the waste water management system do you experience?
…………………………………………………………………………………………
…………………………………………………………………………………………
40. Do you have any recommendation(s) for the development and improving the performance efficiency of semi-centralized sewerage system and their respective wastewater treatment units? Yes [ ]or No [ ]. If yes, please provide your opinion
…………………………………………………………………………………………
…………………………………………………………………………………………

PART V: Additional notes

According to the case study of Rwanda as a developing country specifically Kigali city, which system between decentralized and centralized wastewater treatment system (Sewerage system) would you recommend? For what reasons?

Thank you for your patience and relevancy in filling this questionnaire and importantly being a part of this research paper.

Appendix D: Questionnaire for Kigali City Estate Residents and Technical Labours: Non-Structured Questions

Kigali, June 2018

Dear Respondent(s),

I am **Amos SHYAKA KAZORA**, a MSc student at Pan African University Institute of Water and Energy Sciences (PAUWES) including Climate Change pursuing a Master's Degree in Water Sciences carrying out a research on sustainability of decentralized wastewater treatment systems specifically semi-centralized sewerage systems and wastewater treatment units in the cities of developing countries case of Kigali city.

The survey aims to assess the management practices of the generated wastewater from the small community households of Kigali city estates regarding to its effects on the environment and public health. Your responses to questionnaire is completely voluntary and valuable. You can ignore the questions that you don't like to answer. You will not be individually identified and your answers will be only used for statistical and academic purposes.

At the beginning of any question, there are letters highlighted and bolded in color to represent whose question is addressed to with the following meanings;

(R) = Question for Residents.

(TL) = Question for Technical Labours.

(B) = Question for both Residents and Technical Labours.

1. Do you know where is the end destination of your grey water and black water? **(R)**
2. Do you use the combined system for both sewage and storm water? **(R)**
3. Did the system ever clogged? If yes, how did you managed it? **(R)**
4. Are you aware of the existing system for wastewater generated from your homes? **(R)**
5. If yes at question 4 above, are you satisfied with the system? **(R)**

6. Have you ever experienced odors of wastewater at your homes or a long sewer network system? **(R)**
7. Do you pay for sewerage services? If yes, how much (Per month or else)? If no, are you willing to pay? **(R)**
8. What do you think about the working condition of this system?
   a) good enough,
   b) acceptable,
   c) no opinions
   d) not satisfied: Because…………………………………………….………..**(B)**
9. Are you willing to pay for extra cost for sewerage services provided that the services are improved? **(R)**
10. Have you ever discussed with operator or any person about the working conditions of the sewerage system and how to maintain the system? If yes, what are the main points did you discuss on? **(R)**
11. Do you have an estate manager? If yes, what are his/her responsibilities? **(R)**
12. What is the chance that you could come into direct contact with untreated or partially treated water (in percentages)? ……………% ? **(B)**
13. Have you suffered from any kind of illness due to this wastewater management system? **(B)**
14. What kind of diseases (direct or indirect) that may have been caused by poor sewerage system or access to wastewater? **(B)**
15. Do you know the type of technology and sewerage system you are using? **(TL)**
16. What is the capacity (Design capacity in m^3/d and PE) of the sewerage system? **(TL)**
17. Did the system ever fail to operate/function? If yes, what were the problems? **(TL)**
18. Who is responsible for maintaining the plant in case of any damage or clogging? **(TL)**
19. Do you measure the performance efficiency of the plant? If yes, how often? **(TL)**
20. Which standards do you refer to for effluent quality discharge? **(TL)**
21. Do you meet the effluent quality standards for discharge? **(TL)**
22. Have you ever been offered a training about operation and maintenance of these sewerage systems? If yes, how regularly? **(TL)**
23. Do you have tertiary treatment in your system? If yes, how do you think about the system you are using? (good enough, acceptable, no opinions, not satisfied) Because……. **(TL)**
24. Did you get any complaints from the customers? **(TL)**

25. What are the complaints about? (Multiple choices) **(TL)**

    a) Odors of the reclaimed water

    b) Colors of the reclaimed water

    c) Safety of the reclaimed water

    d) Price for treatment services

    e) Others ……………………………………………………………………

    ………………………………………………………………………………

26. What kind of benefits do you realize from the wastewater management system? **(B)**
27. What kind of drawbacks from the wastewater management system? **(B)**
28. Do you have any recommendations for future improvements in terms of operation, management, and support? **(B)**

Thank you for your patience and being a part of this research paper.

Appendix E: List of Recognized Semi-Centralized Sewerage Systems of Kigali City Estates

#	NAME	LOCATION	ESTATE DEVELOPER / PLANT DESIGNER / TECHNOLOGY USED
1	KACYIRU ESTATE	Gasabo District - Kigali City	RSSB / ENVIRONCARE / A.S
2	Vision 2020 Estate	Gasabo District - Kigali City	RSSB / ENVIRONCARE / A.S
3	Vision city Estates	Gasabo District - Kigali City	RSSB / ECO – PROTECTION / SBR
4	UMUCYO Estate	Gasabo District - Kigali City	RSSB / ECO – PROTECTION / A.S
5	Lagoon Nyarutarama	Gasabo District - Kigali City	Unknown / NPD-COTRACO / Lagoon
6	Urumuri Village Estate	Gasabo District - Kigali City	Unknown / Unknown / A.S
7	SUNSET Estate	Gasabo District - Kigali City	TPGL / ECO – PROTECTION / A.S
8	KAGUGU VILLA Estate	Gasabo District - Kigali City	REAL - CONTRACTORS / REAL - CONTRACTORS / A.S
9	KABUGA HILLSIDE Estate	Kicukiro District - Kigali City	REAL - CONTRACTORS / REAL - CONTRACTORS / SBR
10	MASAKA HILL VIEW Estate	Kicukiro District - Kigali City	KCB BANK / Unknown / SBR
11	GATE HILLS Estate I	Kicukiro District - Kigali City	SEKIMONDO / ENVIROCARE / A.S
12	GATE HILLS Estate II	Kicukiro District - Kigali City	SEKIMONDO / ENVIROCARE /SBR
13	R&B Estate	Kicukiro District - Kigali City	MARTIN / ECO – PROTECTION / A.S
14	NYIRAMANA Estate	Kicukiro District - Kigali City	NYIRAMANA / ENVIROCARE / A.S
15	MOUNTAIN RIDGE Estate	Gasabo District - Kigali City	Dr. MARTIN / ECO – PROTECTION / A.S
16	KAMI EXECUTIVE Estate	Gasabo District - Kigali City	Unknown / Unknown /A.S
17	DND TRIANGLE REAL Estate	Gasabo District - Kigali City	DND TRIANGLE REAL ESTATE DEVELOPERS / S.T
18	STIPP Estate	Gasabo District - Kigali City	GAPOSHO / S.T
19	BNR Estate	Kicukiro District - Kigali City	BNR / S.T

NOTE: A.S = Activated Sludge

SBR = Sequencing Batch Reactor

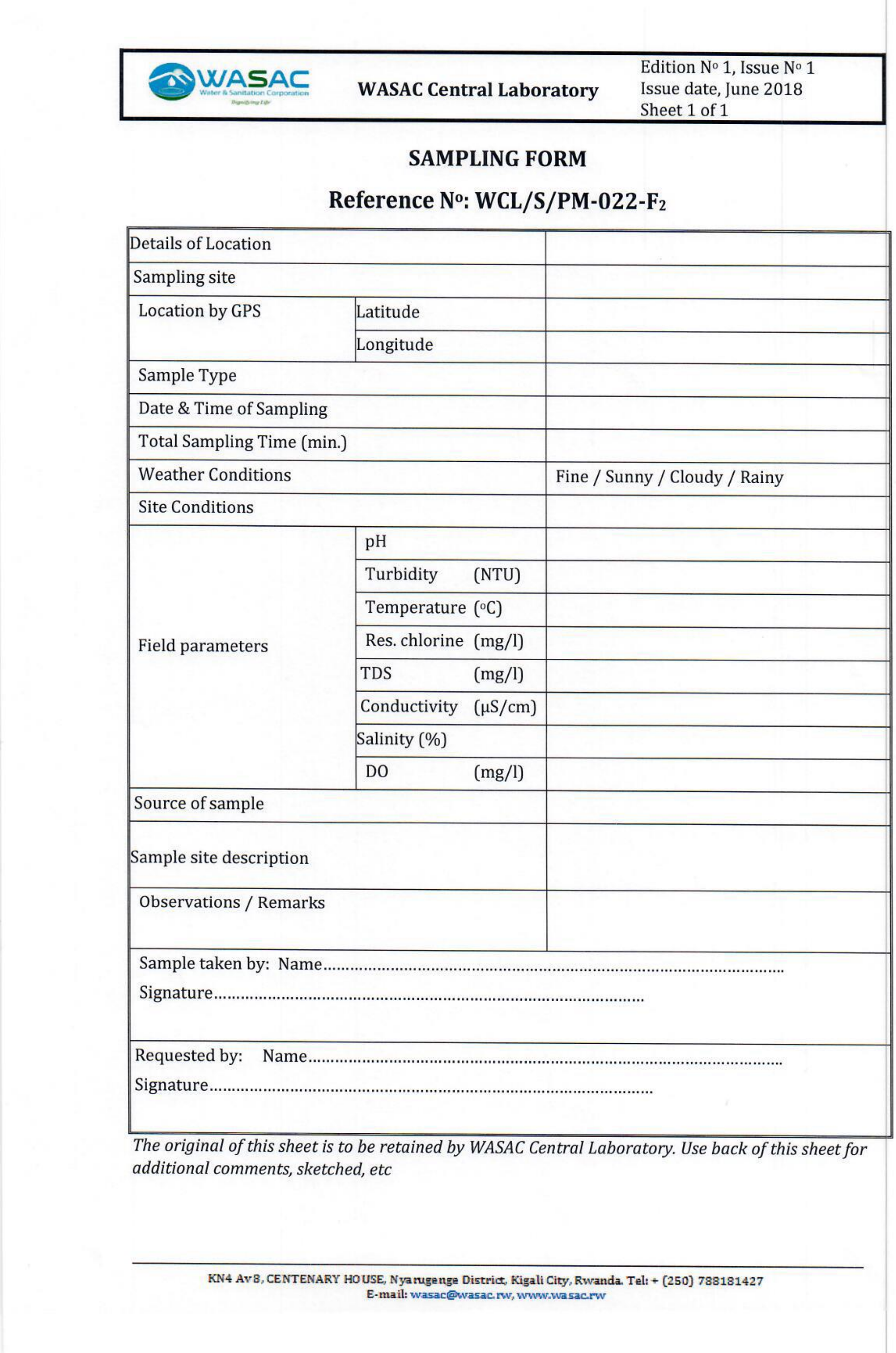
S.T = Septic tank (Either individual or collective)

Appendix F: Sustainability Assessment for Technical, Environmental, Legal and Institutional framework of SCSS's & STP's of Kigali City Estates

Dimensions / Attributes	Scaling	Low	Medium	High	Criteria
Technical		**0 - 3**	**4 - 6**	**7-10**	
Physical Conditions and Layout Conformity					
			6		Construction according to design plan
			4		In the design plan horizon (Period)
			4		Construction of infrastructure works according to design
		3			Modified (Rehabilitated and Upgraded)
			5		Operation of plant
			6		Noise generation
			5		Odor generation
Plant Capacity					
		3			Designed inflow (Influent)
			4		Number of Inhabitants
Efficiency					
		3			Wastewater complexity (Designed level of BOD5 for influent)
		3			Treatment efficiency for the removal of BOD5 and COD (The effluent quality)
		3			Complexity of operation and maintenance
Technical Operations					
		3			Energy (Power) demand
		3			Availability of treatment reagents
		3			Skilled staff
Sub-total	**150**	24	33		
Average	**10**	**3.77**			
Environmental	**Scaling**	**Low**	**Medium**	**High**	**Criteria are based on RS 110:2009 WW Discharge Limit Standards**
		0 - 3	**4 - 6**	**7-10**	
PH				10	5.0 - 9.0
Colour (mg/l PtCo).		3			200
Total Suspended Solids (mg/l).		3			50
Total Dissolved Solids (mg/l).				10	1500

Electrical Conductivity (µS/cm).		3			-
Temperature Variation (0c).				10	3
Turbidity (NTU).		3			30 (WHO, 2006)
Dissolved Oxygen (mg/l).		3			-
Chemical Oxygen Demand (mg/l).				8	250
Biological Oxygen Demand (mg/l).				7	50
Total Nitrogen (TN)				7	30
Total phosphorous (TP)				8	5
Faecal coliform (MPN/100 ml).		3			<400
E. Coli (MPN/100 ml).		3			-
Sub-total	**140**	21		60	
Average	**10**	**5.75**			
Socio-Economic	**Scaling**	**Low**	**Medium**	**High**	**Criteria**
		0 - 3	**4 - 6**	**7-10**	
Costs					
		3			Capital Expenditures (CAPEX)
		3			Operational Expenditures (OPEX)
		3			Depreciation of fixed costs
		3			Extension costs for service coverage
Community					
			5		Social awareness and understanding of SCSS and their specific treatment units
			4		Social acceptance and expectancy
		3			Community involvement in planning, development and management of SCSS
Service Satisfactory					
			5		Reliability of the services
			4		Affordability of the services
Sub-total	**90**	15	17		
Average	**10**	**3.53**			
Total Score for Kacyiru Estate		**380**		**169**	
Average Score for Kacyiru Estate		**10**		**4.44**	

Appendix G: Wastewater Sampling Form



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SAMPLING FORM

Reference N°: WCL/S/PM-022-F2

Details of Location		
Sampling site		
Location by GPS	Latitude	
	Longitude	
Sample Type		
Date & Time of Sampling		
Total Sampling Time (min.)		
Weather Conditions		Fine / Sunny / Cloudy / Rainy
Site Conditions		
Field parameters	pH	
	Turbidity (NTU)	
	Temperature (°C)	
	Res. chlorine (mg/l)	
	TDS (mg/l)	
	Conductivity (μS/cm)	
	Salinity (%)	
	DO (mg/l)	
Source of sample		
Sample site description		
Observations / Remarks		
Sample taken by: Name... Signature..		
Requested by: Name... Signature..		

The original of this sheet is to be retained by WASAC Central Laboratory. Use back of this sheet for additional comments, sketched, etc

KN4 Av8, CENTENARY HOUSE, Nyarugenge District, Kigali City, Rwanda. Tel: + (250) 788181427
E-mail: wasac@wasac.rw, www.wasac.rw

Appendix H: Results of Laboratory Test for Influent and Effluent Wastewater Samples from 4 STP's of Kigali city Estates

WASAC Water & Sanitation Corporation

WASAC Central Laboratory

Edition N° 1, Issue N° 1
Issue date, May 2018

ORIGINAL
Sheet 1 of 5

Directorate of Urban Water and Sanitation Services (DWSS)
Quality Assurance Services (QAS)

WASAC CENTRAL LABORATORY (WCL)

TEST REPORT FORM

Report N°: 07/18-007

1. DETAILS OF THE SAMPLE

Name of the Requester	**Amos SHYAKA KAZORA**
Address of the Requester	**Kigali, Rwanda**
WCL Sample Code	**See Results Tables**
Names of the Samples	**See Results Tables**
Sampling site/ Location	**Kigali City**
Sampling person	**WASAC Central Laboratory Staff**
Date of delivery of sample	**See Results Tables**

2. ANALYSIS OF THE SAMPLE

Condition of the Sample	**Good**
Date analysis Started	**See Results Tables**
Date analysis Completed	**See Results Tables**
Name of Laboratory	**WASAC Central Laboratory**
Environmental Conditions	**Suitable**
Parameters	**Physico-chemistry and Bacteriology**

3. STANDARD(S) USED

The quality of this effluent was evaluated based on Rwanda National Standards for Tolerance limits of Discharged Domestic wastewater **RS 462-2009**

4. LABORATORY RESULTS

The laboratory results are presented in the following tables according to the sampling periods. Influent and effluent samples have been taken from same semi-centralized sewerage systems in different periods for assessing the efficiency of treatment and effluent compliance with the Standards Requirements.

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NT

4.1. Laboratory results for influent and effluent samples from Vision 2020 Estate, R&B Estate, Kacyiru Estate and Kabuga Estate taken on June 06, 2018

The Laboratory analyses started the same date and were completed on June 11, 2018 as the Biological Oxygen Demand takes five day period for reading the results.

Parameters	Unit	Sample Code 20180606-								Max Limits	Method
		022	023	024	025	026	027	028	029		
		Vision 2020 estate-Influent	Vision 2020 estate-Effluent	R & B estate-Influent	R & B estate-Effluent	Kacyiru estate-Influent	Kacyiru estate-Effluent	Kabuga estate-Influent	Kabuga estate-Effluent		
pH		7.0	7.5	7.5	7.5	7.5	7.0	7.5	8.0	5.0-9.0	EPA 150.1
Total Suspended Solids	mg/l	138	49	236	57	1094	90	1116	66	50	HACH 8006
Total Dissolved Solids	mg/l	412	405	746	8.44	8.30	9.46	8.89	10.35	1500	HI 98360
Electrical Conductivity	µS/cm	818	806	1491	16.99	16.24	19.84	17.96	20.71		HI 98360
Temperature Variation	°c	23.2	23.1 (0.1)	23.0	22.9 (0.1)	22.9	22.9 (0)	23.1	22.7 (0.4)	3	HI 98360
Turbidity	NTU	60.8	38.3	107	59.3	741	92.6	1422.5	35.8	30	EPA 180.1
Dissolved Oxygen	mg/l	0.23	0.18	0.05	1.05	0.10	0.03	0.40	3.82	-	HACH 10360
Chemical Oxygen Demand	mg/l	342	167.5	565	147.5	1215.5	217.5	836.5	117.5	250	EPA 410.4
Biological Oxygen Demand	mg/l	151.2	39	193	30	90.6	37.8	155	4.5	50	EPA 5210B
Total Nitrogen (TN)	mg/l	24.1	17.4	11.9	29.8	<1.7	22.1	117.6	37.1	30	HACH 10072
Total phosphorous (TP)	mg/l	7.76	2.71	3.03	1.91	2.01	1.61	7.91	7.925	5	HACH 8190
Faecal coliform	MPN/100 ml	>241960	86640	>241960	155310	>241960	155310	>241960	14670	400	EPA 9223
E. Coli	MPN/100 ml	>241960	57940	>241960	141360	241960	86640	>241960	11190		EPA 9223

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4.2. Laboratory results for influent and effluent samples from Vision 2020 Estate, R&B Estate, Kacyiru Estate and Kabuga Estate taken on June 19, 2018

The samples were taken on June 19, 2018 and laboratory analyses started the same date and were completed on June 24, 2018 as the Biological Oxygen Demand takes five day period for reading the results.

Parameters	Unit	Sample code 20180619-								Max Limits	Method
		055	056	057	058	059	060	061	062		
		Kabuga estate-Influent	Kabuga estate-Effluent	Vision 2020 estate-Inlfuent	Vision 2020 estate-Effluent	Kacyiru estate-Influent	Kacyiru estate-Effluent	R & B estate-Influent	R & B estate-Effluent		
PH		7	7.5	7	7	7.5	7	7.5	7.5	5.0-9.0	EPA 150.1
Colour	mg/l PtCo	3610	880	1755	827.5	1635	977.5	2060	517.5	-	HACH 8025
Total Suspended Solids	mg/l	480	109	257	82	236	122	266	55	50	HACH 8006
Total Dissolved Solids	mg/l	632	694	503	471	421	321	497	567	1500	HI 98360
Electrical Conductivity	µS/cm	1263	1387	1003	941	842	641	992	1125	-	HI 98360
Turbidity	NTU	631	93.1	305	105	329	124	324	63.3	30	EPA 180.1
Dissolved Oxygen	mg/l	0.07	5.38	0.06	0.10	0.64	0.06	0.14	2.33	-	HACH 10360
Chemical Oxygen Demand	mg/l	738.5	166	723.5	192	461	270.5	552.5	95	250	EPA 410.4
Biological Oxygen Demand	mg/l	148.8	19.2	142.5	31.65	54.6	55.2	117.3	15.3	50	EPA 5210B
Total Nitrogen (TN)	mg/l	8.2	33.2	9.6	24.4	20.1	23.5	2.5	No rgt	30	HACH 10072
Total phosphorous (TP)	mg/l	-	-	-	-	-	-	-	-	5	HACH 8190
Faecal coliform	MPN/100 ml	>241960	>241960	>241960	>241960	>241960	>241960	>241960	>241960	400	EPA 9223
E. Coli	MPN/100 ml	241960	>241960	>241960	>241960	>241960	>241960	>241960	>241960		EPA 9223

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4.3. Laboratory results for influent and effluent samples from Vision 2020 Estate, R&B Estate, Kacyiru Estate and Kabuga Estate taken on June 19, 2018

The samples were taken on June 25, 2018 and laboratory analyses started the same date and were completed on June 30, 2018 as the Biological Oxygen Demand takes five day period for reading the results.

Parameters	Unit	Sample code 20180625-								Max Limits	Method
		074	075	076	077	078	079	080	081		
		Kabuga estate-Effluent	Kabuga estate-Influent	Vision 2020 estate-Effluent	Vision 2020 estate-Influent	Kacyiru estate-Effluent	Kacyiru estate-Influent	R & B estate-Effluent	R & B estate-Influent		
PH		7.5	7	7	7	7	7.5	7	8	5.0-9.0	EPA 150.1
Colour	mg/l PtCo	1016	3858	644	1429	1232	1026	402	1989	-	HACH 8025
Total Suspended Solids	mg/l	136	823	95	247	172	161	41	335	50	HACH 8006
Total Dissolved Solids	mg/l	748	595	510	359	361	238	661	565	1500	HI 98360
Electrical Conductivity	µS/cm	1499	1189	1023	719	718	478	1318	1134	-	HI 98360
Temperature Variation	⁰c	25.5 (1.6)	27.1	28.1 (0.1)	28.2	27.8 (0.2)	27.6	26 (0.4)	25.6	3	HI 98360
Turbidity	NTU	94.6	1130	54.8	208	125	125	27.1	395	30	EPA 180.1
Dissolved Oxygen	mg/l	1.79	1.85	0.30	1.71	0.97	2.96	0.83	2.17	-	HACH 10360
Chemical Oxygen Demand	mg/l	196	4518.5	221	750.5	311.5	267.5	100	917.5	250	EPA 410.4
Biological Oxygen Demand	mg/l	28.8	235.5	84.6	124.5	96	81.9	24.3	250.5	50	EPA 5210B
Faecal coliform	MPN/100 ml	>241960	>241960	>241960	>241960	>241960	>241960	>241960	>241960	400	EPA 9223
E. Coli	MPN/100 ml	241960	>241960	>241960	>241960	>241960	>241960	>241960	>241960		EPA 9223

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5. INTERPRETATION OF RESULTS

The results highlighted exceeded the National Standards Requirements for Dischargeable Domestic Effluent. These parameters are mostly **Total Suspended Solids (TSS)** and **Turbidity**. The **Faecal Coliforms** were not complying with the Standards Requirements for both Semi-Centralized Sewerage systems for all sampling periods.

6. RECOMMENDATIONS

It is recommended to improve the disinfection process where it is applied and to use disinfection where it is not applied in order to improve the bacteriological quality of the effluent and environment protection. The bacteriological and phsico-treatments should also be efficiently monitored in order to reduce the exceeding parameters such as suspended matter, turbidity, biochemical oxygen demand, chemical oxygen demand and nutrients.

Reported by:

Jean Baptiste NTAGUNGIRA
Sewer Treatment Works Officer

Sylvie UWIKUNDA
Sanitation Central Laboratory Operator

Approved by:

Yvette-Carine KASINE
Head of Water Central Laboratory

WATER AND SANITATION CORPORATION
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Appendix I: Summary for Laboratory results of Wastewater influent and effluent samples from 4 STP's of Kigali city Estates

Parameters	**Unit**	**Domestic Wastewater Samples from 4 Kigali Estates June - 2018**								**Limits (Max.)**	**Method**
		Vision 2020 estate-Influent	**Vision 2020 estate-Effluent**	**R & B estate-Influent**	**R & B estate-Effluent**	**Kacyiru estate-Influent**	**Kacyiru estate-Effluent**	**Kabuga Hillside estate-Influent**	**Kabuga Hillside estate-Effluent**	**RS 110:2017**	
P^H		7	**7.2**	7.7	**7.3**	7.5	**7**	7.2	**7.67**	**5.0 - 9.0**	**EPA 150.1**
Colour	mg/l PtCo	1592	**735.8**	2024.5	**459.8**	1330.5	**1104.75**	3734.0	**1896.00**	**200**	**HACH8025**
Total Suspended Solids	mg/l	214	**75**	279	**51**	497	**128**	806	**104**	**50**	**HACH 8006**
Total Dissolved Solids	mg/l	425	**462**	603	**412**	222	**230**	412	**484**	**1500**	**HI 98360**
Electrical Conductivity	µS/cm	847	**923**	1206	**820**	445	**460**	823	**969**	**-**	**HI 98360**
Temperature Variation	^0c	26	25.6 **(-0.6)**	25	24.45 **(0.55)**	25	25.4 **(-0.4)**	25	24 **(1)**	**3**	**HI 98360**
Turbidity	NTU	191	**66**	275	**50**	398	**114**	1061	**223**	**30 (WHO, 2006)**	**EPA 180.1**
Dissolved Oxygen	mg/l	0.7	**0.2**	1.1	**1.4**	1.2	**0.4**	0.8	**3.7**	**-**	**HACH 10360**
Chemical Oxygen Demand (COD)	mg/l	605	**194**	678	**114**	648	**267**	2031	**160**	**250**	**EPA 410.4**
Biological Oxygen Demand (BOD_5)	mg/l	139	**52**	187	**23**	76	**63**	180	**18**	**50**	**EPA 5210B**
Total Nitrogen (TN)	mg/l	17	**21**	12	**30**	11	**23**	63	**35**	**30**	**HACH 10072**
Total phosphorous (TP)	mg/l	8	**3**	3	**2**	2	**2**	8	**8**	**5**	**HACH 8190**
Faecal coliform	MPN/100 ml	>241960	**164300**	>241960	**198635**	>241960	**198635**	>241960	**128315**	**<400**	**EPA 9223**
E. Coli	MPN/100 ml	>241960	**149950**	>241960	**191660**	>241960	**164300**	>241960	**253150**	**-**	**EPA 9223**

Appendix J: Technical, Environmental and Socio-economic assessment of selected and analyzed SCSS's and STP's of Kigali City Estates

1. Sustainability assessment for Vision 2020 Estate

Dimensions / Attributes	Scaling	Low	Medium	High	Criteria
Technical		**0 - 3**	**4 - 6**	**7-10**	
Physical Conditions and Layout Conformity					
			6		Construction according to design plan
		3			In the design plan horizon (Period)
			6		Construction of infrastructure works according to design
		3			Modified (Rehabilitated and Upgraded)
		3			Operation of plant
			6		Noise generation
		3			Odor generation
Plant Capacity					
		3			Designed inflow (Influent)
			6		Number of Inhabitants
Efficiency					
		3			Wastewater complexity (Designed level of BOD5 for influent)
		3			Treatment efficiency for the removal of BOD5 and COD (The effluent quality)
		3			Complexity of operation and maintenance
Technical Operations					
		3			Energy (Power) demand
		3			Availability of treatment reagents
		3			Skilled staff
Sub-total	**150**	33	24		
Average	**10**	**3.80**			
Environmental	**Scaling**	**Low**	**Medium**	**High**	**Criteria are based on RS 110:2009 WW Discharge Limit Standards**
		0 - 3	**4 - 6**	**7-10**	
PH				10	5.0 - 9.0
Colour (mg/l PtCo).		3			200

Total Suspended Solids (mg/l).		3			50
Total Dissolved Solids (mg/l).				10	1500
Electrical Conductivity (µS/cm).		3			-
Temperature Variation (0c).				10	3
Turbidity (NTU).		3			30 (WHO, 2006)
Dissolved Oxygen (mg/l).		3			-
Chemical Oxygen Demand (mg/l).				10	250
Biological Oxygen Demand (mg/l).		3			50
Total Nitrogen (TN)				10	30
Total phosphorous (TP)				10	5
Faecal coliform (MPN/100 ml).		3			<400
E. Coli (MPN/100 ml).		3			-
Sub-total	**140**	24		60	
Average	**10**	**6.00**			
Socio-Economic	**Scaling**	**Low**	**Medium**	**High**	**Criteria**
		0 - 3	**4 - 6**	**7-10**	
Costs					
		3			Capital Expenditures (CAPEX)
		3			Operational Expenditures (OPEX)
		3			Depreciation of fixed costs
		3			Extension costs for service coverage
Community					
			6		Social awareness and understanding of SCSS and their specific treatment units
			6		Social acceptance and expectancy
		3			Community involvement in planning, development and management of SCSS
Service Satisfactory					
		3			Reliability of the services
			6		Affordability of the services
Sub-total	**90**	18	18		
Average	**10**	**4.00**			
Total Score for Vision 2020 Estate		**380**		**177**	
Average Score for Vision 2020 Estate		**10**		**4.66**	

2. Sustainability assessment for R & B Estate

Dimensions / Attributes	Scaling	Low	Medium	High	Criteria
Technical		**0 - 3**	**4 - 6**	**7-10**	
Physical Conditions and Layout Conformity					
			6		Construction according to design plan
		3			In the design plan horizon (Period)
		3			Construction of infrastructure works according to design
		0			Modified (Rehabilitated and Upgraded)
			6		Operation of plant
			6		Noise generation
		3			Odor generation
Plant Capacity					
		3			Designed inflow (Influent)
		3			Number of Inhabitants
Efficiency					
		3			Wastewater complexity (Designed level of BOD5 for influent)
				10	Treatment efficiency for the removal of BOD5 and COD (The effluent quality)
		3			Complexity of operation and maintenance
Technical Operations					
		3			Energy (Power) demand
		3			Availability of treatment reagents
		3			Skilled staff
Sub-total	**150**	30	18	10	
Average	**10**	**3.87**			
Environmental	**Scaling**	**Low**	**Medium**	**High**	**Criteria are based on RS 110:2017 WW Discharge Limit Standards**
		0 - 3	**4 - 6**	**7-10**	
PH				10	5.0 - 9.0
Colour (mg/l PtCo).		3			200
Total Suspended Solids (mg/l).		3			50
Total Dissolved Solids (mg/l).				10	1500
Electrical Conductivity (µS/cm).		3			-
Temperature Variation (0c).				10	3

Turbidity (NTU).		3			30 (WHO, 2006)
Dissolved Oxygen (mg/l).		3			-
Chemical Oxygen Demand (mg/l).				10	250
Biological Oxygen Demand (mg/l).				10	50
Total Nitrogen (TN)		3			30
Total phosphorous (TP)				10	5
Faecal coliform (MPN/100 ml).		3			<400
E. Coli (MPN/100 ml).		3			-
Sub-total	**140**	24		60	
Average	**10**	**6.00**			
Socio-Economic	**Scaling**	**Low**	**Medium**	**High**	**Criteria**
		0 - 3	**4 - 6**	**7-10**	
Costs					
		3			Capital Expenditures (CAPEX)
		3			Operational Expenditures (OPEX)
		3			Depreciation of fixed costs
		3			Extension costs for service coverage
Community					
		3			Social awareness and understanding of SCSS and their specific treatment units
		3			Social acceptance and expectancy
		3			Community involvement in planning, development and management of SCSS
Service Satisfactory					
			6		Reliability of the services
		3			Affordability of the services
Sub-total	**90**	24	6		
Average	**10**	**3.33**			
Total Score for R & B Estate		**380**		**172**	
Average Score for R & B Estate		**10**		**4.53**	

3. Sustainability assessment for Kacyiru Estate

Dimensions / Attributes	Scaling	Low	Medium	High	Criteria
Technical		**0 - 3**	**4 - 6**	**7-10**	
Physical Conditions and Layout Conformity					
			6		Construction according to design plan
		3			In the design plan horizon (Period)
		3			Construction of infrastructure works according to design
		3			Modified (Rehabilitated and Upgraded)
		3			Operation of plant
			6		Noise generation
				10	Odor generation
Plant Capacity					
		3			Designed inflow (Influent)
		3			Number of Inhabitants
Efficiency					
		3			Wastewater complexity (Designed level of BOD5 for influent)
		3			Treatment efficiency for the removal of BOD5 and COD (The effluent quality)
		3			Complexity of operation and maintenance
Technical Operations					
		3			Energy (Power) demand
		3			Availability of treatment reagents
		3			Skilled staff
Sub-total	**150**	36	12	10	
Average	**10**	**3.87**			
Environmental	**Scaling**	**Low**	**Medium**	**High**	**Criteria are based on RS 110:2009 WW Discharge Limit Standards**
		0 - 3	**4 - 6**	**7-10**	
PH				10	5.0 - 9.0
Colour (mg/l PtCo).		3			200
Total Suspended Solids (mg/l).		3			50
Total Dissolved Solids (mg/l).				10	1500
Electrical Conductivity (µS/cm).		3			-

Temperature Variation (0c).				10	3
Turbidity (NTU).		3			30 (WHO, 2006)
Dissolved Oxygen (mg/l).		3			-
Chemical Oxygen Demand (mg/l).		3			250
Biological Oxygen Demand (mg/l).		3			50
Total Nitrogen (TN)				10	30
Total phosphorous (TP)				10	5
Faecal coliform (MPN/100 ml).		3			<400
E. Coli (MPN/100 ml).		3			-
Sub-total	**140**	27		50	
Average	**10**	**5.50**			
Socio-Economic	**Scaling**	**Low**	**Medium**	**High**	**Criteria**
		0 - 3	**4 - 6**	**7-10**	
Costs					
		3			Capital Expenditures (CAPEX)
		3			Operational Expenditures (OPEX)
		3			Depreciation of fixed costs
			6		Extension costs for service coverage
Community					
		3			Social awareness and understanding of SCSS and their specific treatment units
		3			Social acceptance and expectancy
		3			Community involvement in planning, development and management of SCSS
Service Satisfactory					
		3			Reliability of the services
		3			Affordability of the services
Sub-total	**90**	24	6		
Average	**10**	**3.33**			
Total Score for Kacyiru Estate		**380**		**165**	
Average Score for Kacyiru Estate		**10**		**4.34**	

4. Sustainability assessment for Kabuga Hillside Estate

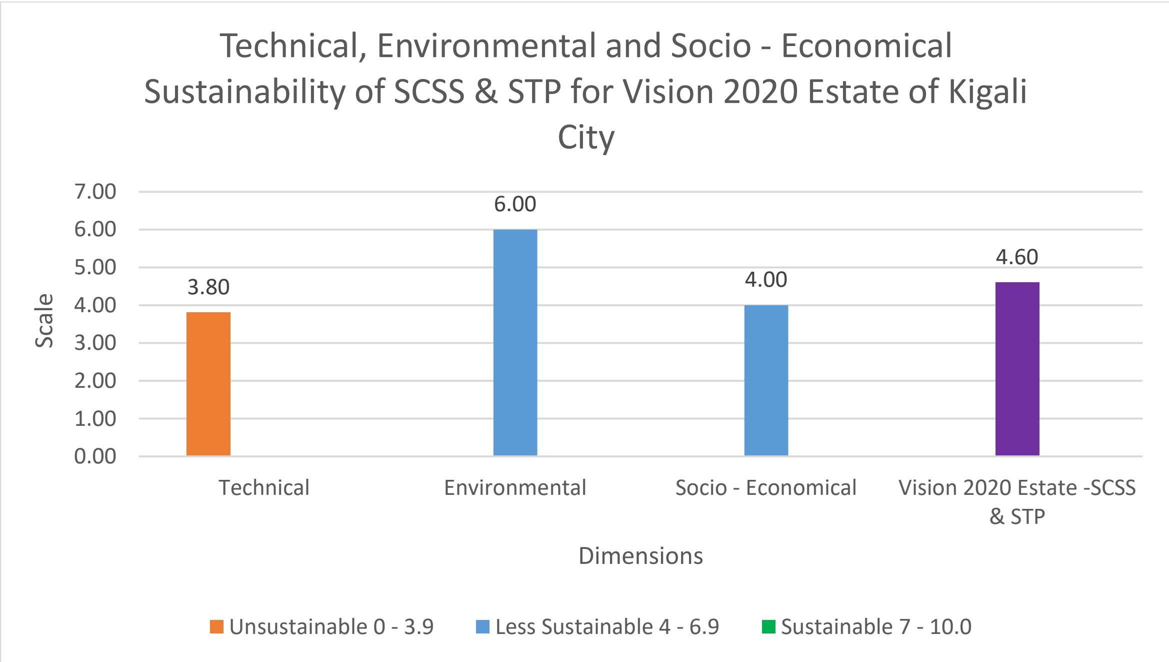
Dimensions / Attributes	**Scaling**	**Low**	**Medium**	**High**	**Criteria**
Technical		**0 - 3**	**4 - 6**	**7-10**	
Physical Conditions and Layout Conformity					
			6		Construction according to design plan
			6		In the design plan horizon (Period)
		3			Construction of infrastructure works according to design
		0			Modified (Rehabilitated and Upgraded)
			6		Operation of plant
			6		Noise generation
		3			Odor generation
Plant Capacity					
		3			Designed inflow (Influent)
		3			Number of Inhabitants
Efficiency					
		3			Wastewater complexity (Designed level of BOD5 for influent)
				10	Treatment efficiency for the removal of BOD5 and COD (The effluent quality)
		3			Complexity of operation and maintenance
Technical Operations					
		3			Energy (Power) demand
		3			Availability of treatment reagents
		3			Skilled staff
Sub-total	**150**	27	24		
Average	**10**	**3.40**			
Environmental	**Scaling**	**Low**	**Medium**	**High**	**Criteria are based on RS 110:2009 WW Discharge Limit Standards**
		0 - 3	**4 - 6**	**7-10**	
PH				10	5.0 - 9.0
Colour (mg/l PtCo).		3			200
Total Suspended Solids (mg/l).		3			50
Total Dissolved Solids (mg/l).				10	1500

Electrical Conductivity (µS/cm).		3			-
Temperature Variation (0c).				10	3
Turbidity (NTU).		3			30 (WHO, 2006)
Dissolved Oxygen (mg/l).		3			-
Chemical Oxygen Demand (mg/l).				10	250
Biological Oxygen Demand (mg/l).				10	50
Total Nitrogen (TN)		3			30
Total phosphorous (TP)		3			5
Faecal coliform (MPN/100 ml).		3			<400
E. Coli (MPN/100 ml).		3			-
Sub-total	**140**	27		50	
Average	**10**	**5.50**			
Socio-Economic	**Scaling**	**Low**	**Medium**	**High**	**Criteria**
		0 - 3	**4 - 6**	**7-10**	
Costs					
		3			Capital Expenditures (CAPEX)
		3			Operational Expenditures (OPEX)
		3			Depreciation of fixed costs
		3			Extension costs for service coverage
Community					
			6		Social awareness and understanding of SCSS and their specific treatment units
		3			Social acceptance and expectancy
		3			Community involvement in planning, development and management of SCSS
Service Satisfactory					
			6		Reliability of the services
		3			Affordability of the services
Sub-total	**90**	21	12		
Average	**10**	**3.67**			
Total Score for Kabuga Hillside Estate		**380**		**161**	
Average Score for Kabuga Hillside Estate		**10**		**4.24**	

Appendix K: Summary for Technical, Environmental and Socio-economic assessment of selected and analyzed SCSS's and STP's of Kigali City Estates

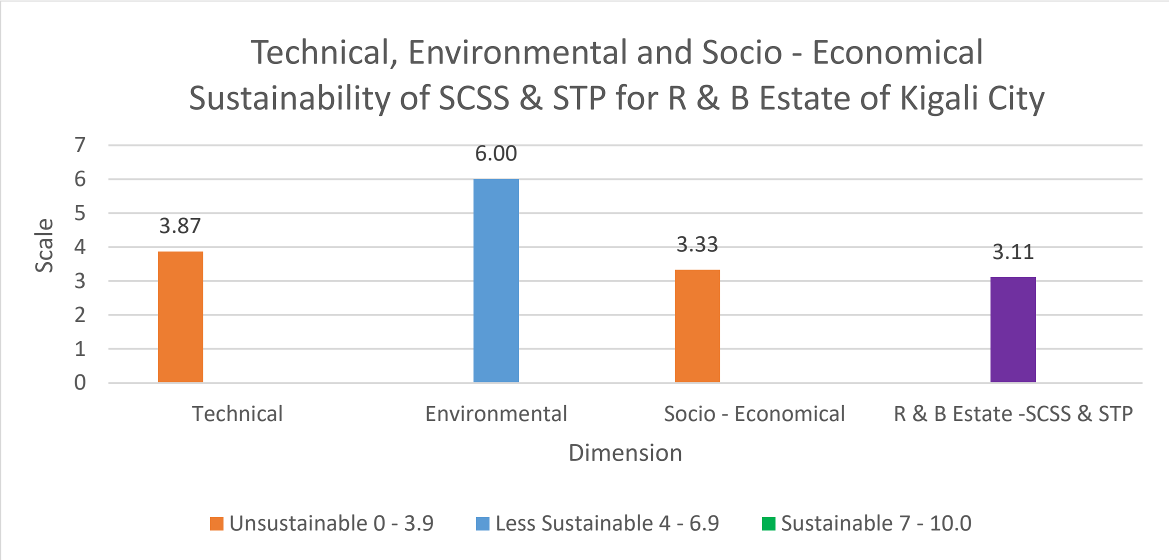
1. Sustainability Assessment for Vision 2020 Estate

Categories	Scaling	Technical	Environmental	Socio - Economical	Vision 2020 Estate -SCSS & STP
Unsustainable	0 - 3.9	3.80			
Less Sustainable	4 - 6.9		6.00	4.00	4.60
Sustainable	7 - 10.0				



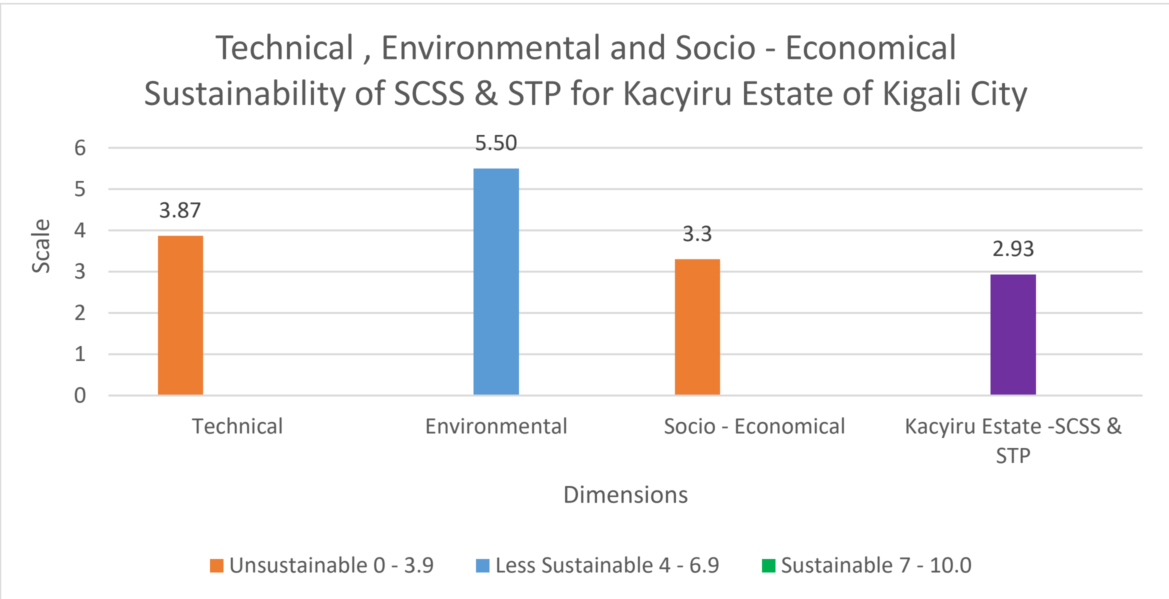
2. Sustainability Assessment for R & B Estate

Categories	Scaling	Technic al	Environmental	Socio - Economical	R & B Estate -SCSS & STP
Unsustainable	0 - 3.9	3.87		3.33	
Less Sustainable	4 - 6.9		6.00		3.11
Sustainable	7 - 10.0				



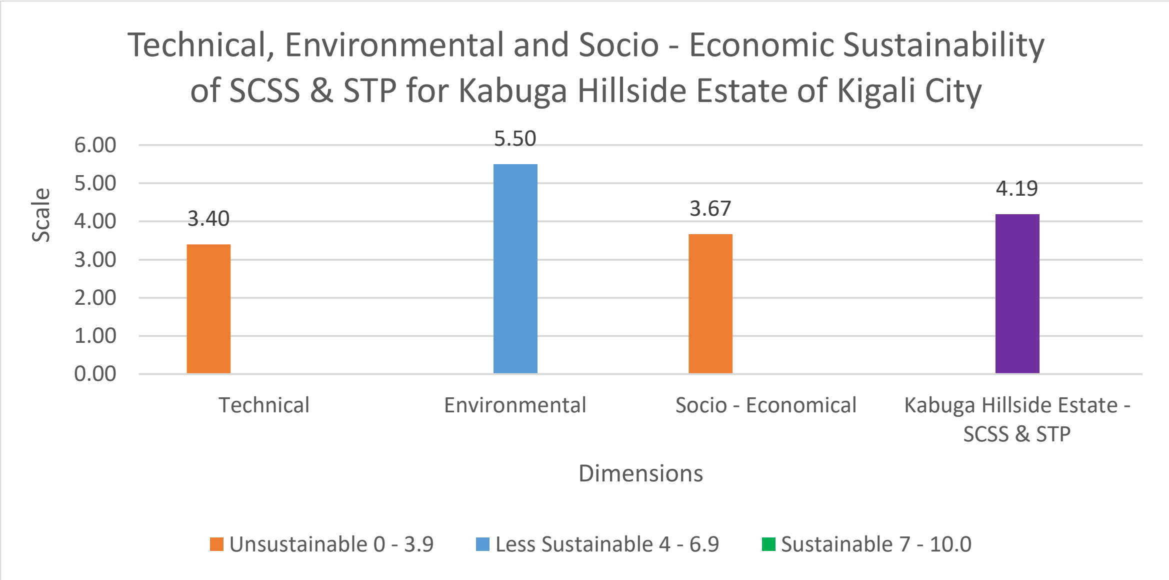
3. Sustainability Assessment for Kacyiru Estate

Categories	Scaling	Technical	Environmental	Socio - Economical	Kacyiru Estate -SCSS & STP
Unsustainable	0 - 3.9	3.87		3.3	
Less Sustainable	4 - 6.9		5.50		2.93
Sustainable	7 - 10.0				



4. Sustainability Assessment for Kabuga Hillside Estate

Categories	Scaling	Technical	Environmental	Socio - Economical	Kabuga Hillside Estate - SCSS & STP
Unsustainable	0 - 3.9	3.40		3.67	
Less Sustainable	4 - 6.9		5.50		4.19
Sustainable	7 - 10.0				



Appendix L: Sustainability assessment for Legal and Institutional framework of SCSS's and STP's of Kigali City Estates

Dimension / Attributes		Policy makers and Regulators (MININFRA, REMA, RURA, MoH)															Implementers (CoK and WASAC)									Conditions
	Institutes	MININFRA			REMA I			REMA II			RURA			MoH			CoK I			CoK II			WASAC			
	Scaling	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High	Criteria
		0 - 3	4 - 6	7-10	0 - 3	4 - 6	7-10	0 - 3	4 - 6	7-10	0 - 3	4 - 6	7-10	0 - 3	4 - 6	7-10	0 - 3	4 - 6	7-10	0 - 3	4 - 6	7-10	0 - 3	4 - 6	7-10	
Institutional and Legal Instruments																										
Sanitation Policy (50)																										
				10			10			10			10			10			10	3					10	Available
		3			3			3			3			3			3			3				6		Available but not addressing proper development and management of SCSS
		3			3			3			3			3			3			3			3			Available but not addressing complete development and management of SCSS
		3			3			3			3			3			3			3			3			Available and fully addresses complete development and management of SCSS
			6			6			6		3			3			3			3			3			Enforcement
Sub-total	400	9	6	10	9	6	10	9	6	10	12		10	12		10	12		10	15			9	6	10	
Average / Class of Institute	10	4.76															4.13									
Average / Attribute	10	4.53																								
Sanitation Law (30)																										
		3			3			3			3				6			6			6		0			Available
		0			0			0			0			0			0			0			0			Accountability for breaking laws that runs the working conditions of SCSS
		0			0			0			0			0			0			0			0			Enforcement
Sub-total	240	3			3			3			3			0	6		0	6		0	6		0			
Average / Class of Institute	10	1.2															1.33									
Average / Attribute	10	1.25																								
Regulations on Decentralized Wastewater Treatments Systems (30)																										
				10	3					10			10	3					10	3					10	Available
			6		3				6				10	3				6		3				6		Political will to give SCSS an appropriate attention
			6		3				6				10	3			3			3			3			Enforcement
Sub-total	240		12	10	9				12	10			30	9			3	6	10	9			3	6	10	
Average / Class of Institute	10	6.13															5.22									
Average / Attribute	10	5.79																								
Institutional Framework (60)																										
			6		3			3			3			3				6		3				6		Defined roles and responsible institutions in sanitation policy
		3			3			3			3			3			3			3			3			Accountability for mismanagements or failures of semi-centralized sewage treatment plants.
			6			6		3				6		3					10			10	3			Institutional collaboration
			6		3			3			3			3			3				6		3			Consistency among responsible institutions
			6		3				6			6		3			3			3			3			Power delegation to the responsible institutions
			6			6			6		3			3				6			6			6		Institutional will
Sub-total	480	3	30		12	12		12	12		12	12		18			9	12	10	9	12	10	12	12		
Average / Class of Institute	10	4.1															4.78									
Average / Attribute	10	4.35																								
Average / Class of Institute	10																3.87									
Total Dimension Attribute	40	15.92																								
Average Score for Institutional and Legal Instruments	10	3.98																								