THE REPUBLIC OF RWANDA

MINISTRY OF INFRASTRUCTURE

CONSULTANCY SERVICES FOR THE STUDY ON APPROPRIATE SEMI-CENTRALIZED WASTEWATER TREATMENT TECHNOLOGIES AND FEACAL SLUDGE MANAGEMENT IN RWANDA

FINAL REPORT

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February, 2019

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Submitted to

MINISTRY OF INFRASTRUCTURE (MININFRA)

Contract Number: **00 -000001/C/ICB/2017/2018/MININFRA**

Submission Date: February 2019

Document Prepared by: HICE Consult

DOCUMENT CONTROL FORM

Project Name: **CONSULTANCY SERVICE FOR THE STUDY ON APPROPRIATE SEMI-CENTRALIZED WASTEWATER TREATMENT TECHNOLOGIES AND FAECAL SLUDGE MANAGEMENT IN RWANDA**

Report for: **MININFRA**

Service Provider: **HICE Consult**

Contract Number: **00 -000001/C/ICB/2017/2018/MININFRA**

PREPARATION, REVIEW AND AUTHORISATION

Report Title:	**Final Report**			
Revision	***Date***	***Prepared by***	***Reviewed by***	***Approved for Issue by***
R0	11/02/19	A.U J.N.B	A.B	A.B

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LIST OF ABBREVIATIONS AND ACRONYMS

Abbreviation / acronym	Meaning
EDPRS II	Economic Development and Poverty Reduction Strategy 2
EIA	Environmental Impact Assessment
GoR	Government of Rwanda
IWRM	Integrated Water Resources Management
MDGs	Millennium Development Goals
MINAGRI	Ministry of Agriculture and Animal Resources
MININFRA	Ministry of Infrastructure
MINIRENA	Ministry of Natural Resources
NISR	National Institute of Statistics of Rwanda
FSM	Faecal Sludge Management
FS	Faecal Sludge
PE	Population Equivalent
PPP	Public private partnership
RNRA	Rwanda Natural Resources Authority
SWG	Sector Working Group
WASH	Water, Sanitation and Hygiene
WATSAN	Water and Sanitation
WSS	Water Supply and Sanitation
WSSP	Water and Sanitation Strategic Plan
WTP	Water treatment plant
WWTP	Wastewater treatment plant

EXECUTIVE SUMMARY

1. Background

Access to improved sanitation services has been observed as one of the integral development strategies to reach the country's medium and long-term vision of the country. Inadequate sanitation services are detrimental to public health as well as environment. Interestingly, access to sanitation facilities is the key solution to end those issues and another way to protect the environment. It is also an indicator to end poverty and gearing up the national development of the country. The Government of Rwanda has set target to reach un100 Percent universal access to basic sanitation services by 2024 as highlighted in the National Strategy for Transformation (NST) as well as Water and sanitation sector strategic plan 2018-2014.

However, the sanitation sub-sector recognizes gaps on appropriate wastewater treatment technologies and faecal sludge management for the collective sanitation facilities. It is in this framework that the Ministry of Infrastructure wishes to put in place a study on the appropriate semi-centralised wastewater treatment technologies and management of faecal sludge for different registered users that might be applied in the City of Kigali and other peri-urban Cities.

HICE Consult has therefore been hired to assist the Ministry of Infrastructure to conduct a study on the appropriate decentralized, semi-centralized, wastewater technologies and faecal sludge management in Rwanda. The overall objective of the study is to unveil the appropriate semi-centralized, decentralized, wastewater technologies and faecal sludge management that can be referred on in future by any private operator, developer, or contractor in developing sanitation facilities in Rwanda.

2. Methodology

The Consultant Project Team visited Estates, public places, IDP Village, public schools and hospital, Prisons, existing landfills, slums and settlement center in Kigali city and different provinces of Rwanda to inform themselves of the status of existing semi-centralized WWTP and the existing faecal sludge management. The investigations were done through field surveys, visual inspection, questionnaires, interviews targeting existing systems and key stakeholders (users, providers and local communities). Where available, secondary data from previous studies were used to document on the status and the efficiencies of the sewage treatment systems. The systems were classified according type of system (individual or semi-centralized), treatment technology, status of the structure, system sizing, and adequacy of the sewer system, nuisance to the surrounding and effluent quality.

The study exploited relevant documents related to sanitation in Rwanda. They included Rwanda Vision 2020, the Economic Development and Poverty Reduction Strategy 2013-2018 (EDPRS 2), Kigali Sanitation Master Plan, the National Sanitation Policy, National Sanitation Policy implementation strategy, National Strategy for Transformation, Water and sanitation sector strategic plan 2018-2024, Environment Law N° 04/2005 of 08/04/2005, National and international norms and Requirements applicable to wastewater treatment systems and effluents. The Water and Sanitation Sector Strategic Plan 2013-2018, Lake Victoria Water Supply and Sanitation Program phase II (LV WATSAN II), Rwandan Water Law and National Policy for water resource management were also reviewed.

With the objective of highlighting the performance and applicability of different wastewater treatment technologies taking into account national regulation, social acceptance, affordability, construction and maintenance requirements; the study reviewed the existing semi-centralized wastewater treatment technologies. These include but not limited to the waste stabilization ponds, Constructed wetlands, Biogas systems, activated sludge process, sequencing batch reactors, Jet Commercial Sewage Treatment Plant, BioKube, etc).

The study also reviewed the best faecal sludge management practices from emptying, collection, transport, treatment, reuse/recycling and disposal with the objective to highlight their adaptability in Rwandan context (regulation, social acceptance, affordable, construction and maintenance technically feasible and performance).

The stratified random sampling method was used to determine the study sites; selected from different categories, referred to as strata. These include the existing real estates, public institutions and places, prisons, slums, IDP models, settlements/ centres, semi-centralized sewage treatment plants and landfills or disposal sites.

3. Findings

3.1 Estates

The survey has shown that the real estates in Kigali use septic tanks (33%), activated sludge reactor and its modification (26%) and individual septic tanks and or soak away pits. Some systems were apparently working properly based on eye observation (Aesthetic, intact, not damaged, and working). Those systems are the following:

- Kabuga hillside estate with activated sludge reactor,
- Kacyiru Estate with Activated sludge reactor,
- Mountain Ridge Estate with Activated sludge reactor,
- Gate hills Estate II Activated sludge reactor,
- Land mark apartment with Activated sludge reactor,
- Vision City Estate with Sequencing Batch Reactor.

Other estates had sewer systems were found with operational problems ranging from inappropriate design, poor system maintenance, lack of spare parts, with objectionable effluent discharge, offensive odours and flies. Those systems are:

- Vision 2020 Estate with Activated sludge that receive both mixed storm water and domestic wastewater,
- Umucyo estates with Activated sludge reactor suffering from the lack of operation and maintenance services,
- Kagugu villas Housing Estate with Sequencing Batch Reactor, discharging the objectionable effluent, due to the lack of appropriate operation and maintenance services,
- Kami Executive apartment with Activate sludge treatment lacking the appropriate operation and maintenance services.

There were estates with sewer systems out of service due to the lack of the appropriate operation and maintenance services. These are:

- Masaka Hill view estate with Activated sludge reactor,
- Sunset Estate supposed to have the activated sludge process that was never complete and the sewer system is now destroyed. The estate is now discharging the sewage in the open land and open pit/tank,
- Juru Estate with a completely destroyed sewer system due to the lack of appropriate operation and maintenance services for the sewerage and waste Stabilization ponds. Fresh faecal materials are being discharged in open space.

Other estates like BNR, Rujugiro, Umucyo Estate, Gaposho (Stipp Estate), Urukumbuzi, COHAKI and Goboka Estates were using the septic tanks and soak away pits with regular sludge emptying services.

The results from laboratory tests for wastewater treatment effluents have shown that only one treatment plant (Vision City), complied with the National Standards Requirement for tolerance limits for discharged domestic wastewater for all measured parameters (pH, Electrical conductivity (EC), Total Suspended Solids (TSS), Biological Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), Total Phosphorus (TP), Total Nitrogen (TN), Chloride and E-coli).

Most of wastewater treatment plants did not comply with the National Standards Requirement for tolerance limits for discharged domestic wastewater. Previous studies conducted by WASAC in 2017 indicated that Kagugu Villa Estate, was the only real estate complied with wastewater treatment system in the time of sampling. Note that Kagugu Villa Estate that complied for all parameters in 2017 was in uncompliant in 2019 for many raisons including insufficiency lack of monitoring discharge effluent, lack of operation and maintenance. This explains well the need for regular monitoring to ensure the continuous of performance of wastewater treatment systems.
It is absurd that systems like Juru Estate and Sunset estate that were discharging untreated faecal material in open environment from 2017 at time of WASAC study and were still discharging them two years later (2019). This means much more effort is needed to enforce the sanitation strategies and environmental laws, through regular monitoring of wastewater treatment structural integrity and effluent discharge.

3.2 Status of other wastewater treatment systems across the country

Apart from estates in the City of Kigali, countrywide field surveys (observations and interviews) were conducted at different places.

- **Modern markets and tax parks**

A majority of markets and tax parks in four provinces of Rwanda and city of Kigali use on-site sanitation facilities. Pour flush toilet, Ventilated improved toilet and flush toilet are the most used in those places and soak away pit, septic tanks as the only options of handling the sewage. Some of the modern markets (Musanze modern market and Nyarugenge market) are using on-site package sewage treatment system namely the activated sludge treatment or sequencing-batching reactor. The emptying of fecal sludge from pit and septic tank is done manually or mechanically by private operators and transported to the nearby landfills, Nduba Dumping site or land filled for agriculture purpose.

- **Schools and Hospitals**

As the same to markets and tax parks, wastewater from Schools and hospital either black or grey water are disposed mostly in septic tank or soak pit as the only options of handling the sewage. Most of those institutions building have their own systems. The emptying of fecal sludge from pit and septic tank is done manually or mechanically by private operators and transported to the nearby landfills, to Nduba Dumping site in the city of Kigali and to dedicated dumping areas upcountry. Solid wastes in rural areas are composed where they are used as fertilisers for agriculture purpose. The University of Rwanda was found to have his own sewage suction truck, while the other institutions offered one-year contract to private operators for the sewage emptying.

- **Prisons**

All surveyed prisons have biogas system as a treatment system for the black water. Flush toilets are aligned and connected to the biogas digester tanks. Biogas slurry (sludge) is conveyed to the pit for settling. After settling, the supernatant effluent is discharged to cesspool/pit to be reused for agriculture purpose or to be discharged to open space. The operational and maintenance of biogas systems is in charge of Rwanda Collection Service.

With the exception of Mageragere prison that uses a constructed wetland for the grey water from kitchen and bathrooms, other prison do not have a treatment system for the grey water. It is discharged fresh to the open space or pit. However, the treatment efficiency of this wetland seems inadequate as the effluent is very turbid and smells bad.

- **Rural centres and settlements**

In rural centre and settlement, most people use pit latrines, whereas grey water is mostly disposed in pit or open spaces. Most of the faecal waste is disposed through ordinary or soak pits in individual premises and there is no integrated collection, transportation and treatment facility available for faecal waste treatment.

- **Slums**

In all surveyed slums, pit latrines were the most used systems to handle faecal material, whereas grey water was disposed in storm water drain, soak pit or in open space. There is no framework for emptying, collection and transportation of faecal sludge when pits latrines for final disposal or reuse.

4. Appropriate Technologies for sewage treatment and Fecal Sludge Treatment

The study findings showed that all sewage treatment systems including septic tanks can operate effectively, if properly designed, operated and maintained. There is any single type of sewage treatment system that can work well without the good operation and maintenance services. Therefore, whatever the selected system, what matters the most is the proper design, operation and maintenance instead of the type of system.

4.1 Appropriate Technologies for sewage treatment

To identify the appropriate technology for sewage treatment technologies, the multi-criteria analysis was used. The analysis considered the sewage operational indicator including reliability, affordability (cost of systems installation, operation, and maintenance), land requirement, pollutant removal efficiency, simplicity, social acceptability and sustainability.

The study has identified waste stabilization ponds, oxidation ditch, activated sludge process and sequencing batch reactor as the most suitable systems in Rwandan context. Waste stabilization ponds (WSP) and oxidation ditch scored high because of their flexibility, financial, economic, and operation simplicity, while the activated sludge process and sequencing batch reactor scored high because of their efficiency and low land requirements. Although waste stabilization pond scored high, its implementation in Rwanda, especially in urban area is a challenge due to the country's land scarcity. However, when land is available, WSP can best fit Rwandan context because of its affordability, simplicity and sustainability.

While the activated sludge process and sequencing Batch Reactor and their modifications can be used for buildings without fund constraints (real estates, hotels, etc), WSP (with option of biogas production in anaerobic system) could be used in area without land constraints and where their end products (gas, sludge and effluent) can be safely evacuated, recycled or disposed (suburbs, rural areas, prisons, markets, schools and IDP models).

The alternative to waste stabilization pond, activated sludge process and sequencing batch reactor, is the oxidation ditch that has higher treatment efficiency, and less land requirements than waste stabilization ponds. The oxidation ditch is easier to control than the activated sludge, but requires higher land than the activated sludge.

Although overall, septic tanks scored low, these systems scored high in terms of affordability, simplicity and social embracement. Most buildings use septic tanks and their full replacement should be progressive. Septic tanks can be used as temporal or transitional or short to mid-term solution (2-5 years) systems to the buildings that are not able to afford the cost and land requirements for the activated sludge process and sequencing Batch Reactor, and waste stabilization respectively. As temporal sewage treatment systems, septic tank could be designed in such a way to allow further connection to the semi-centralized or centralized systems. Septic tanks could also be considered the only affordable systems in slums and low income without financial and operational capacities.

Septic tanks can be used as temporal, transitional or short to mid-term (up to 5 years) solution systems to the buildings that are not able to afford the cost and land requirements for the activated sludge process and sequencing Batch Reactor, and waste stabilization and biogas systems respectively. Septic tanks should be used as semi-centralized or decentralized individual household systems that could further be connected to semi-centralized or centralized systems.

Although the treatment performance of the septic tank is low, the septic tank can operate effectively, if properly designed, operated and maintained, with regular and professional desludging, transport, treatment, reuse/recycle or disposal of the septic sludge. Septic tanks could be considered as the only suitable technologies in slums, due to lack of space, vehicular access and financial and operational capacities.

4.2 Appropriate Technologies for Fecal Sludge Treatment

Similar to wastewater treatment systems, the selection of appropriate technology for faecal sludge treatment was done based on multi-criteria analysis. As for the wastewater treatment system, the analysis considered the cost of system installation, operation & maintenance, land requirements, pollutant removal efficiency, simplicity, system sustainability and social embracement or acceptability. Co-composting of faecal sludge with biodegradable wastes scored higher because of its simplicity, affordability and sustainability.
It was followed by a conventional multistage faecal sludge treatment system/ landfill with screening, grit removal, thickening, drying, composting & effluent treatment and disposal. This system is good because of its efficiency and possibility to recover nutrients through compost. Char Briquette manufacturing and Incineration with energy recovery scored low because of their high-energy requirements and greenhouse emissions.

Therefore, this study highly recommends three technologies (Co-composting, multistage landfill system and biogas system) that can interchangeably being used depending on the availability of funds (multistage landfill system), availability of land and market for compost (co-composting system) or possibility to reuse the system by-products (biogas system).

4.3 Link the study with recent completed master plan of Kigali City and Kigali centralized sewerage system to be located at Giticyinyoni

We understand that first ever Kigali Centralized Sewerage System (KCSS) will be constructed at Giticyinyoni near the road crossings Kigali-Musanze and Kigali-Muhanga. Also given the topography of the Kigali city, the centralized sewage system will not be able to connect all areas of Kigali City. While Semi-centralized and individual sewage systems located inside the area of coverage of the centralized sewer line should connect to it, buildings outside the area of coverage can still use semi-centralized or individual systems. Therefore, the institution in charge of sanitation (e.g WASAC) should issue the sewage effluent discharge permits to support the compliance to the sewage effluent discharge.

The sewage treatment operator should apply for a permit for connection to the centralized sewer system and pay a bill proportional to sewage discharge and pollutant load in terms of BOD, COD, TSS, TDS, nitrogen, phosphorus, pathogens, acidity/basicity, etc. A compliant system may be exempted for effluent discharge fees, while the non-compliant system may be penalized. Special attention should be paid to the effluent with high content of trash, grit material and suspended material, whose discharge to the sewer system may interfere with the proper functioning of the system.

The sewer operator should ensure these materials are avoided or kept at the lowest quantity. This calls for regular monitoring of the characteristics of the effluent being discharged to the centralized sewer line. Buildings outside the coverage of the central sewer line should be encouraged to have their own sewage treatment systems and the government should help to establishing semi-centralized sewage systems.

4.4 Monitoring and Evaluation framework of the implementation of appropriate semi-centralized wastewater treatment technologies and faecal sludge management

4.4.1 Monitoring and Evaluation framework of the implementation of appropriate semi-centralized wastewater treatment technologies

The proposed Monitoring and evaluation framework of the implementation of appropriate semi-centralized wastewater treatment technologies. The framework identifies the most important indicators for discharge wastewater effluent, where those indicators will be measured, how they will be measured, what are the guidelines, what is the measurement cost, the frequency of measurements, measurement and reporting responsibilities.

The discharger or the operator in a real estate should have a logbook for keeping records on effluent characteristics and monthly report to the competent authority (WASAC). Every discharger must provide appropriate arrangements to make accessible the effluent to any person at any occasion. Failing to keep records on effluent characteristics or reporting in due time to the competent authority or to make accessible the effluent, should be considered as non-compliance to regulation of discharge of wastewater.

4.4.2 Monitoring and Evaluation framework of the implementation of appropriate semi-centralized wastewater treatment technologies and faecal sludge management

The report presented the Monitoring and evaluation framework of the implementation of appropriate faecal sludge management. Like wastewater treatment monitoring framework, the faecal sludge treatment system operator should have a logbook for keeping records on the air quality, effluent, end products characteristics of the system and monthly report to the competent authority (WASAC).

Arrangements should be done to make accessible the points of discharge (air emission, effluent, end products and residues) to any person at any occasion. Failing to keep records on effluent characteristics or reporting in due time to the competent authority or to make accessible the effluent, should be considered as non-compliance to regulation of discharge of faecal sludge.

1. GENERAL INTRODUCTION

1.1 Background

Sanitation generally refers to the provision of facilities and services for the safe disposal of human urine and faeces. It plays a vital role in preventive health care and quality of life. Therefore, the Government of Rwanda has made the provision of sustainable sanitation services as one of the priorities of the National Development Agenda hence established supportive policies. The Government of Rwanda has set target to reach 100 Percent improved sanitation coverage by 2020 as stipulated in the recently approved National Sanitation policy and its related Implementation Strategy.

The Ministry of Infrastructure, in its mandate, has developed a National Sanitation Policy and its related Implementation Strategy to ensure the proper implementation of all set activities in the sanitation sub-sector. The Policy was approved in December 2016 by the Cabinet and it outlines different initiatives to overcome sanitation related challenges and exploit existing opportunities in an integrated manner which will effectively contribute towards achieving the goals of the National Development Agenda and SDGs.

Access to improved sanitation facilities has been observed as one of the integral development strategy to reach the country's medium and long-term vision. Inadequate sanitation services are detrimental to the health and well-being of the population.

Inappropriate disposal of human waste is dangerous to human being as it might lead to disease like Giardia and can contaminate water supplies and soil. Interestingly, access to sanitation facilities is the key solution to end those issues and another way to protect the environment. It is also an indicator to end poverty and gearing up the national development of the country.

However, sanitation sub-sector recognizes gaps on appropriate wastewater treatment technologies and faecal sludge management for the collective sanitation facilities. It is in this framework that the Ministry of Infrastructure wishes to put in place a study on the appropriate semi-centralised wastewater treatment technologies and management of faecal sludge for different registered users or that might be applied in the City of Kigali and other peri-urban Cities.

HICE Consult has therefore been hired to assist the Ministry of Infrastructure to conduct a study on the appropriate decentralized, semi-centralized, wastewater technologies and faecal sludge management in Rwanda.

1.2 Study objectives

The overall objective of the study is to unveil the appropriate semi-centralized, decentralized, wastewater technologies and faecal sludge management in Rwanda.

Specific objectives of the assignment are:

(i) To conduct a research on the appropriate semi-centralized, decentralized, wastewater treatment technologies applicable to Rwanda;
(ii) To assess the current situation for faecal sludge management of the existing semi-centralized wastewater treatment plants
(iii) To identify best practices in faecal sludge management
(iv) To propose a Monitoring and Evaluation framework of the implementation of appropriate semi-centralized wastewater treatment technologies and faecal sludge management.

1.3 Scope of work

The Government of Rwanda is aspired to increase safe sustainable sanitation services in the entire country. Human waste management is highly recommendable and in doing so, there is a need to firstly conduct a study on the appropriate semi-centralized wastewater technologies and faecal sludge management which can be referred on in future by any private operator or contractor in developing sanitation facilities in the country.

The firm is therefore requested to conduct a study which will include but not limited:

(i) To review all existing semi-centralized waste water treatment technologies in all Estates and present status of their operationalization;
(ii) To assess the current situation and propose best practices for faecal sludge management in Rwanda;
(iii) To link the study with recent completed master plan of the city of Kigali and provide an option of interconnecting the existing or planned semi-centralised wastewater treatment plants with Kigali centralized sewerage system to be located at Giticyinyoni;
(iv) To propose the operationalization of the proposed appropriate semi-centralized wastewater treatment technologies;
(v) To propose a Monitoring and Evaluation framework to check the efficiency of proposed appropriate semi-centralized wastewater treatment technologies.
(vi) The firm will offer training (transfer of knowledge) to the client's staff where necessary.

1.4 Brief methodological approach used to conduct the assignment

1.4.1 Collection and Assessment of Information

1.4.1.1 Site investigations

The Consultant Project Team visited the Kigali city and different provinces of Rwanda to inform themselves of the status of existing semi-centralized WWTP and the existing faecal sludge management. Table 1 gives a list of real estates visited in Kigali city, while Table 2 lists other places visited across the country.

Table 1: List of study real estates in Kigali City

No	Estate	Location
1	KABUGA HILLSIDE HOUSING ESTATE	Nyagahinga, Rusororo, Gasabo
2	MASAKA HILL VIEW	Masaka sector, Kicukiro District
3	SUNSET	Kibagabaga, Kimironko Sector, Gasabo District
4	UMUCYO ESTATE	Gaculiro, Kinyinya sector, Gasabo District
5	GAPOSHO (STIPP ESTATE)	Kagugu cell Gasabo sector
6	KACYIRU ESTATE	Kacyiru, Gasabo District
7	VISION 2020 ESTATES	Kinyinya sector, GasaboDistrict
8	MOUNTAIN RIDGE ESTATE	Kabuga II cell, in Rusororo sector, Gasabo District
9	URUKUMBUZI ESTATE	Gasharu cell, in Kinyinya sector, Gasabo District
10	KAGUGU VILLAS HOUSING ESTATES	Gasabo District, Kagugu Sector
11	JURU ESTATE (NYARUTARAMA LAGOONS)	Remera sector, Gasabo District
12	BNR ESTATE	Gikondo sector, Rebero

No	Estate	Location
13	RUJUGIRO ESTATE	Gikondo sector, Kicukiro sector
14	GATE HILLS ESTATE I (SEKIMONDO)	Kanombe cell/ Nyarugunga Sector/ Kicukiro District.
15	GATE HILLS ESTATE II (SEKIMONDO)	Kanombe cell/ Nyarugunga Sector/ Kicukiro District.
16	KAMI EXECUTIVE APPARTEMENT	Kinyinya sector, Gasabo District
17	LAND MARK APPARTEMENT (KIRENGA)	Kinyinya sector, Gasabo District
18	COMFORT HOME ESTATE	Kimisange Cell, Rebero, Kicukiro District
19	COOPERATIVE COHAKI ESTATE	Gasharu cell, Kinyinya sector, in Gasabo district
20	GAHANGA COMPLEX APARTMENT	Karembure cell, in Gahanga sector, in Kicukiro district
21	KARUMEYI VILLAGE ESTATE	Kanombe cell neaby Rubirizi in Kicukiro district
22	VISION CITY ESTATE	Kinyinya sector, near vision 2020 estates
23	GOBOKA ESTATES	Kibagabaga Near Akillah University, Kigali
24	IZUBA CITY ESTATES	Gisozi, Kigali
25	KIGALI REAL ESTATE / BAPFAKURERA	Gaculiro/Kibagabaga /Kagugu
26	R&B ESTATE (MARTIN ESTATES)	Kicukiro / Gikondo – Rebero

Table 2: Sampling strata in different provinces of the country

Strata	Eastern Province		Kigali City			Southern Province		Northern Province		Western Province	
	Nyagatare	**Kayonza**	**Nyarugenge**	**Gasabo**	**Kicukiro**	**Nyanza**	**Muhanga**	**Musanze**	**Gicumbi**	**Rusizi**	**Rubavu**
Public institutions and places	UR Campus Nyagatare Modern Market	UR Rukara Campus Kayonza Tax Park	UR Nyarugenge campus Nyarugenge Market	Amahoro Stadium Kimironko Tax Park and Modern Market	IPRC Kicukiro Gikondo UR Headquarters	Nyanza Hospital Groupe Schorair e de Nyanza	Institut Catholique Kabgayi Kabgayi Hospital	Musanze Modern Market Ecole des Sciences de Musanze	Byumba Hospital Groupe Scolaire de la Salle	Rusizi Market Rusizi Car Park	Mbugangari Market & Handcra Border post (petite Barriere)
Prisons	Nyagatare, Nsinda, Ngoma, Ririma		Mageragere			Mpanga, Muhanga, Karubanda		Musanze, Miyove		Rusizi, Rubavu	
Slums[1]			Muhima	Gatsata	Karambo		Ruvumera	Tete Gauche		Cité	
Settlements / centres[2]	Nsheke, Mirama	Gasogoroo, Video					Munyinya Mubiti	Karwasa Kimonyi	Yaramba	Kamembe Airport	Mahoko Byahi
	Gatsibo Refugees camps					Gihembe, Mugombwa Refugees camps					
IDP models	Rwabihamba	Rugeyo	Nyabikiri	Rudakabukirwa	Ayabaraya	Nyabinyenga Mututu	Muyebe Horezo	Umutuzo Gatovu	Kabeza Ruzizi	Murambi Kibangira	Bahimba
Landfills/dumdumping sites	Mirama	Kayonza	Nduba Landfill			Nyanza Landfill	Muhanga land fill	Musanze dumping site	Gicumbi faecal TS	Open dumping	Open dumping
Total	**17**		**14**			**18**		**16**		**15**	

[1] Slums do not have a semi-centralized system. Wastewater and faecal management practices differ from HH to HH, hence 50 households will be randomly selected and surveyed.
[2] Like slums, settlements and centres do not have a centralized system. Wastewater and faecal management practices iffer from hh to hh, hence 50 households will be randomly selected and surveyed.

The investigations were done through field surveys using observations, questionnaires, interviews targeting existing systems and stakeholders of different types of wastewater treatment technologies. Annex 1 and Annex 2 give the template used to collect the information (indicators) from field observation and the questionnaires used.

To check the efficiency of the existing sewage treatment systems and the status of its operationalization, wastewater samples were collected at the outflow of the sewage treatment systems and faecal treatment/disposal systems.

1.4.2 Sampling and Laboratory analyses

To assess the efficiency of wastewater and sludge treatment systems, wastewater and sludge treatment effluents were taken at the outlet of wastewater treatment systems and faecal sludge treatment/disposal systems in real estates of Kigali City (Table 1) and in selected strata across the country (Table 2). Samples were collected, preserved and analyzed following the Standard Methods for the Examination of Water and Wastewater (APHA, 2005). Wastewater Indicators measured are temperature, pH, Electrical conductivity (EC), Total Suspended Solids (TSS), Biological Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), Total Phosphorus (TP), Total Nitrogen (TN), Chloride and E-coli. Temperature, pH, EC, Turbidity and TSS were measured on-site using a Multimeter and a Portable colorimeter DR/890. Other indicators (BOD_5, COD, TP, TN, Chloride and E-coli) were measured in the laboratory. To avoid sample spoilage during transportation, samples were transported in cooler box with ice packs whose temperature is to be maintained at 4°C, to the Laboratory and tested the following day.

Biological Oxygen Demand (BOD_5) was measured by completely filling an airtight bottle of 300 mL and incubates it in darkness at 20°c for 5 days. BOD_5 was calculated as the difference between the initial dissolved oxygen and the dissolved oxygen (DO) after incubation. The DO was measured using the Oxymeter. The Chemical Oxidation demand will be determined using the strong oxidizing agents ($Cr_2O_7^{2-}$ or (Cr^{IV}) and a solution of Ag_2SO_4, H_2SO_4 as a catalyst. The reading of absorbance was done at 600 nm using a UV Spectrophotometer CECIL, CE 2041. The total nitrogen and phosphorus were measured using the UV Spectrophotometer CECIL, CE 2041 (the persulfate digestion method) at specific wavelengths (APHA, 2005). Chloride was determined using Digital Titrator (Titration Method, using a solution of silver nitrate). E-coli test was done using the heterotrophic plate count. Water samples were filtered on through sterile membrane filters (0.45 µm, 47 mm) with a vacuum pump. Filtrates were incubated on Chlomocult Coliform Agar at 37°C for 24 hours. Blue colonies were counted for E-coli (APHA, 2005).

1.4.3 Review of documents related to wastewater and fecal sludge management

1.4.3.1 Review of sanitation policy and legal framework

A number of key documents were reviewed in order to address the various aspects of the assignment. Some of these documents are:

- National Sanitation Policy,
- National Sanitation Policy implementation strategy
- Organic Law N° 04/2005 of 08/04/2005 determining the modalities of protection, conservation and promotion of environment;
- National (RURA, RSB) and international norms and Requirements applicable to wastewater treatment systems, wastewater treatment effluents
- The Economic Development and Poverty Reduction Strategy 2013-2018 (EDPRS 2), Shaping our Development, MINECOFIN, May 2013;
- Rwanda Vision 2020, MINECOFIN;
- Kigali Sanitation Master Plan;
- The Water and Sanitation Sector Strategic Plan 2013-2018, MININFRA, November 2012;

- Lake Victoria Water Supply and Sanitation Program phase II (LV WATSAN II);
- WASH documents from various stakeholders.
- Rwandan Water Law;
- National Policy for water resource management.

1.4.4 Review of existing semi-centralized wastewater treatment technologies and propose their operationalization in Rwanda

The study has critical reviewed the performance and applicability of different wastewater treatment technologies with regard to regulation, social acceptance, affordability, construction and maintenance. The systems include:

- Ecosan
- Septic tanks with soak away pits
- Waste stabilization ponds
- Constructed wetlands
- Biogas systems
- Activated sludge process
- Sequencing batch reactors
- Activated sludge processes
- Ready-to-use packaged sewage systems (Biodiscs, oxyfix, Jet Commercial Sewage Treatment Plant, BioKube, etc).

1.4.5 Review of existing faecal sludge management practices and propose their operationalization in Rwanda

Critical analysis of adaptability of different faecal sludge management practices to Rwandan context (Regulation, social acceptance, affordable, construction and maintenance technically feasible and performance) was undertaken. The practices include, but not limited to:

- Energy recovery through Sludge digestion using Biogas system
- Energy recovery through incineration
- Nutrient recovery through composting
- Drying and land application and land filling

As for the selection of appropriate sewage treatment technologies, the study will identify the best practices in faecal sludge management, applicable to different study strata shown in Table 1, with reference to urban area, rural area, low income, middle income and high-income communities.

1.4.6 Link the study with recent completed master plan of Kigali City and Kigali centralized sewerage system to be located at Giticyinyoni

The study will assess the possible options of linking the semi-centralized wastewater technologies to the centralized wastewater treatment to be constructed soon to Gitikinyoni. The options to be explored include:

- The treatment requirements (quality requirements) of the sewage from semi-centralized wastewater systems, prior to discharge;
  Facilities requirements (e.g. provision of the intermediate semi-centralized systems, sewage storage/pumping/conveyance facilities) to fit in the sewerage profile to Giticynyoni proposed centralized sewage treatment plant.

This will be achieved through:

- Review of the master plan of Kigali City and Kigali centralized sewerage system to be located at Giticyinyoni
- Assessment of adequacy/inadequacy, conflicts between existing or planned semi-centralized wastewater treatment plants and the master plan of Kigali City and Kigali centralized sewerage system to be located at Giticyinyoni

2 REVIEW OF EXISTING INFORMATION ON WASTEWATER TREATMENT TECHNOLOGIES AND SLUDGE MANAGEMENT PRACTICES

2.1 Review of policy, regulations and institutional framework

Water pollution regulations in the form of legislation documents, guidelines or ordinances prescribe the necessary level of treatment, so that the treated effluent meets the requirements for safe disposal or reuse. Effluent may be disposed by discharging into a natural water body or infiltrated in the ground. In addition, regulations mention requirements regarding the design and operation of wastewater systems, as well as the penalties and other measures for their enforcement. Centralized systems are designed, built and operated in order to fulfill the existing regulations. Their management usually is executed by local authorities. In hybrid systems and small centralized systems in towns or rural communities, management can be executed in the same way.

In the case of decentralization at on-site level and clusters of buildings, the whole wastewater system is located within private premises. The costs and responsibility for the design, construction, operation and maintenance is the responsibility of the owner. In many cases specialized companies might execute the operation and maintenance procedures. The local authorities issue permits and may provide support for the operation and management in the form of collecting wastes, issuing certificates/licenses for standardized treatment equipment, or for selected qualified private companies. From regulatory point of view, the control of the quality of treated effluent for reuse, discharge or disposal is entirely the responsibility of local or national government authorities. This might be a challenge if a large number of systems must be controlled and inspected. It is in the owner's interest to operate and maintain the system properly, especially in the case of reuse of the treated effluent. Most often the operational problems are associated with clogging of the treatment facilities as result of irregular removal of the sludge or hydraulic overloading due to increased number of populations served or increased water consumption.

2.1.1 Policy, plan, strategies and legal framework

2.1.1.1 The Constitution of the Republic of Rwanda

The constitution of the Republic of Rwanda as revised in 2015; under Article 21 all Rwandans have the right to good health. Article 22 specifies that everyone has the right to live in a clean and healthy environment, while Article 53 specifies that everyone has the duty to protect, safeguard and promote the environment. The constitution gives ways to many laws, policies and strategies for protecting, safeguarding and promoting the environment.

2.1.1.2 Rwanda Vision 2020 and 2050

The water and sanitation sector is defined one of the priority pillars that aims to ensure high standards of living for all Rwandans, improve quality of life and modern infrastructure as mentioned in the Rwanda Vision 2050 and National Strategy for transformation, NST (2018/19-2023/24). The objective of the Government is that by 2020, it will have built a nation in which the process of environmental pollution and degradation has been reversed; a nation in which the management and protection of environment is more rational and well-regulated for the country sustainable development.
However, sanitation has been identified as a key challenge for the development of the City of Kigali. The strategy to achieve the ambitious target for access to improved sanitation to all Rwandans, it is very important to increase the number of people using flush toiles through upgrading of the informal settlements and implementation of planned urban development with in-built modern sanitation systems and construction of the sewerage system in Kigali and the implementation of the localized sewer systems by house developers will contribute greatly to access to good sanitation in City of Kigali.

2.1.1.3 Economic Development and Poverty Reduction Strategy II 2013-2018 (EDPRS 2)

The objective of the EDPRS 2, is to accelerate progress to middle income status and better quality of life for all Rwandans through sustained average GDP growth of 11.5% and accelerated reduction of poverty to less than 30% of the population". One of the priorities of the EDPRS 2 (Priority 4: Economic transformation) is the full coverage of quality of water and sanitation.

2.1.1.4 Water and Sanitation Policy and its implementation strategies

In line with the Sustainable Development Goals (SDGs), target 6, the Government of Rwanda is committed to achieving universal access to basic sanitation services by 2014, as stipulated in Water and Sanitation Policy and its implementation strategic plan 2018-2024. The Government of Rwanda's commitment is to increase access to sanitation. By 2030 all Rwandans will be using safely sanitation services. To achieve this, the GoR needs to invest in water and sanitation sector and strengthen management systems to ensure water and sanitation are maintained over time. The water and sanitation strategic plan 2018-24, emphasizes on the need to promote waste management in urban and rural areas.
It is in this regard that this study on appropriate semi-centralized wastewater treatment technologies and management of faecal sludge is being undertaken. This will help rehabilitation of semi-centralized sewerage systems in Kigali estates, construction of Kigali centralized sewerage system, construction, construction of faecal sludge treatment facilities and modern landfill in the city of Kigali and secondary cities. This project will contribute to the country ambition for achieving safely managed sanitation services for socio-economic development and to all Rwandans.

2.1.1.5 Norms related to wastewater treatment

Rwanda Standards Board specifies general requirements for structures and equipment for wastewater treatment plants for the treatment of domestic and municipal wastewater (DRS 584:2011). The document institutes many aspects related to wastewater treatment systems with main focus on the requirements of drain and sewer systems outside buildings, odour control and ventilation and safety principles. Wastewater treatment system should have safe access in the form of paths, gangways, bridges, stages and the like shall be provided to allow supervision, operating, servicing, cleaning and maintenance.
Openings shall be provided which allow easy replacement of equipment. The location of operating and maintenance points shall allow for adverse weather conditions and other hazards (e.g. handling of gases, vapours, sludge, oil and grease) and possibility of collapse, squeeze and sheer points. The buildings and access shall be sufficiently large to allow all erecting and dismantling, maintenance and repair operations and replacement of assemblies in an easy manner. In enclosed rooms, the possible existence of damp atmospheres, foul air and the risk of explosions shall be considered. Adequate ventilation shall be provided. Appropriate means shall be provided to deter access by unauthorised persons.

As general requirements for wastewater treatment systems, Rwanda Standards Board specifies that:

- The national regulations shall be observed;
- the discharge limits shall be met;
- be capable of satisfactory treatment of the full range of flows and loads;
- personal safety;
- nuisance, odour, noise and toxicity, aerosols and foam shall be considered and shall meet the relevant requirements;
- danger to operating personnel shall be minimized;
- the required service life and long-term structural integrity shall be achieved, including water and gas;

- tightness;
- provisions shall be made for case of operation and maintenance;
- provision for future extensions or modifications of the plant shall be considered;
- the reliability of operation shall be high and risk of danger and the impact of malfunctions shall be limited;
- be cost effective in respect of total costs (capital and operating costs);
- the energy consumption during construction and operation shall be considered;
- the waste products shall be reduced in quantity and improved in quality as far as reasonably achievable to allow for reuse or safe disposal.

The document is also specific to the design requirements as follows:

- All assemblies that are subject to occasional failure (e.g. pumps and compressors) shall be installed with sufficient stand-by capacity so as to achieve full treatment capacity and efficiency with one assembly out of service. In the case where stand-by assemblies cannot be practically installed, provisions shall be made to replace rapidly by another one kept in stock.
- Where practicable and necessary for maintenance work it shall be possible to bypass every unit or assembly, by either a parallel unit or assembly, channel or pipe.
- Where necessary the inlet to the treatment plant shall include a facility that limits the flow. Such facilities may be balancing tanks and/or storm water overflows as required by the authorities.
- Where power supply is subject to prolonged interruption, wastewater treatment plants shall have emergency power generation or an equivalent facility to provide a sufficient power supply during power failure of the network, e.g. a terminal for easy connection with a readily available mobile power generator. Connected to the emergency power supply shall as a minimum include the measuring and control system, the pumps for waste water and return sludge and any aeration equipment (at a designed minimum capacity).
- When the power supply is restored after an interruption, the treatment plant shall be designed so that normal operating status is resumed automatically.
- Provision shall be made for taking representative samples upstream and downstream of each unit and of any flow whose characteristics are important for operation and supervision.
- The design shall ensure that all information (quantities and qualities) that is important for effective operation of the plant is readily obtainable (e.g. flows, levels, pressures, temperatures, dissolved oxygen concentrations, pH-values, other concentrations).
- The design shall enable cleaning, maintenance and repairs to be carried out easily and safely (e.g. access, flushing connections to pipes, isolation means).
- Appropriate provision shall be made for the case of malfunction or emergency.

With regard to the structures, it is necessary that a structure be:

- stable to bear all loads during construction, operation and maintenance periods, e.g. water pressures, static and dynamic forces being induced by the equipment,
- resistant against chemical and biological attack from wastewater, sludge, air and gas components and against temperatures and temperature changes as appropriate,
- Protected against flotation.

The effluent standards for treated sewage Industrial and domestic effluent are shown in Table 3.

Table 3: Tolerance limits for discharged domestic wastewater (RSB, 2017)

Parameter	Unit	Permissible limits	Test methods
TDS	mg/L	<1500	ISO 6107-2
TSS	mg/L	<50	ISO 11923
pH		5-9	ISO 10523
Nitrates	mg/L	<20	ISO 5663
Nitrites	mg/L	<2	ISO 6777
Total Nitrogen	mg/L	<30	ISO 11905
Total Phosphorus	mg/L	<5	ISO 6878
BOD5	mg/L	<50	ISO 5815-2
COD	mg/L	<250	ISO 6060
Faecal Coliforms	fcu /100ml	<400	ISO 4831
Oil and grease	mg/L	<10	ISO 9377-2
Chlorine		<2	ISO 7393
Sulphate	mg/L	<500	ISO 22743
Color	Pt-Co	<200	ISO 7887
Pesticides	mg/L	Not detectable	ASTM D8025-6
Temperature variation of treated water compared to ambient temperature of water	°C	<3	Thermometer1

2.1.1.6 The National Environmental Law No. 48/2018 of 13/08/2018

The Environmental New Law (No. 48/2018 of 13/08/2018) determining the modalities for protecting, conserving and promoting the environment in Rwanda states, that water from the sewage system as well as any liquid waste must be collected in a treatment plant for purification before being released into a river, a stream, a lake or a pond. It also states that no one is permitted to dispose waste in an inappropriate place, except where it is destroyed from or in a treatment plant and after being approved by competent authorities.

2.1.1.7 Kigali Sanitation Master Plan

The objective of the master plan was to define the appropriate sanitation practices according zones of the Kigali city. Table 4 describes the general guidelines for sanitation in Kigali city.

Table 4: General guidelines of the master plan according the type of sanitation

Type of sanitation	Field and type of infrastructures	Remarks/orientation	Communities Implications
Individual	Private(households) and public (public latrines) ✓ Septic tanks and latrines according to adopted standards	✓ Remain the mode of principal sanitation of the city by 2020, for at the same time technical and financial reasons	✓ Encouragement for the establishment of individual systems recommended
Centralized	Public ✓ Central Sewage Network and sewage treatment plant	✓ Separation of storm and dry sewer systems ✓ Treatment of sewage	✓ Investment and monitoring work of the collective system ✓ Network Operations and recovery
Semi-centralized	Estates/small community ✓ Small drainage waste and system of treatment	✓ Separation of storm and dry sewer systems ✓ To be installed in zones not covered by central sewage system	✓ Strict control of installations and their effluents

Type of sanitation	Field and type of infrastructures	Remarks/orientation	Communities Implications
		✓ Applicable to estates and small community	
Institutions with large pollutants (industries, hotels, companies, administrations)	Private ✓ Small treatment plant system	✓ Installation of the treatment system for heavy polluting institution ✓ For domestic wastewater (sewage), they can directly connect to the central system. ⇨ Respect of the requirements for connection to the central sewage system ✓ *For the institutions not able to connect to the collective network*: ⇨ Respect of the standards for effluent discharge into the natural environment	✓ Ensure the companies in charge of sanitation get technical and financial assistance ✓ Strict control of installations and their effluents

Considering the topography of the Kigali city, the master plan has indicated the zones for possible implementation of centralized, semi-centralized and individual sewage systems in Kigali City (Figure 1).

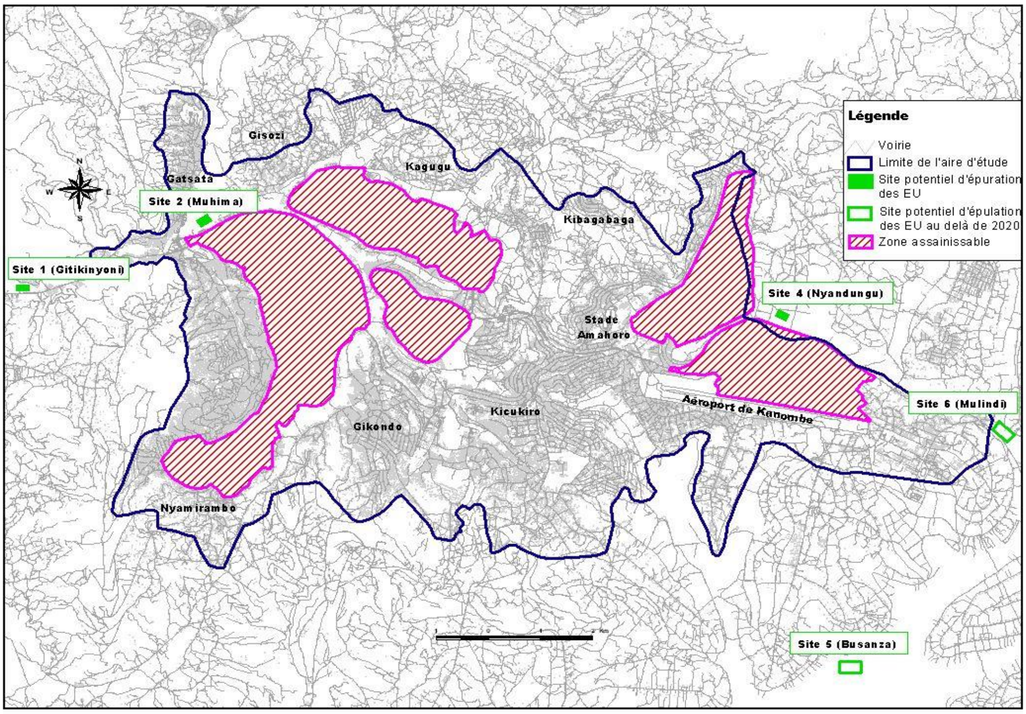


Figure 1: Area possible for the central sewage system (shaded in pink), the remaining of the zone being suitable for individual systems.

The individual sanitation systems recommended by the master plan are **Septic tank latrine, Ecosan, Ventilated Latrine with double pit**. The traditional pit does not form part of the standards recommended in the middle to long term by the master Plan, because of the problems of groundwater pollution. However, the passage to VIP latrine with *tight* pits or to Ecosan latrines, in order to improve the sanitary arrangements and to better protect the environment, could be done only gradually and with a policy of sensitizing and effective encouragement.

2.1.2 Institutional framework

2.1.2.1 MININFRA

The Ministry of Infrastructure (MININFRA) is responsible for developing policies and laws of water/sanitation, energy, transport development, housing and meteorology. MININFRA supervises the functioning of a number of public agencies, including WASAC LTD. This study is initiated by MININFRA

2.1.2.2 WASAC

The Water and Sanitation Corporation Limited WASAC LTD is the public company providing water supply and wastewater collection services to the people of Kigali and other areas in Rwanda. It has been established in 2014 as the result of a division of the previous Energy, Water and Sanitation Authority (EWSA) into a water service provider (WASAC LTD) and a separate energy service provider (REG).

2.1.2.3 RDB

The Rwanda Development Board (RDB) provides support to the development of the private sector, and aims to stimulate business development, investments and innovation in the national economy.

2.1.2.4 REMA

The Rwanda Environmental Management Authority (REMA) is mandated to facilitate coordination and oversight of the implementation of national environmental policy and legislation. It plays a key role in reaching the sustainable development goals as set in out in the Rwanda Development Vision 2020, particularly in terms of addressing urgent environmental issues such as pollution control and preservation of natural resources in sectors and domains such as agriculture, water, mining, forestry, waste and wastewater management.

2.1.2.5 MINECOFIN

The Ministry of Finance and Economic Planning (MINECOFIN) was formed in March 1997 from the joining of the Ministry of Finance and the Ministry of Planning, to better co-ordination between finance and planning. MINECOFIN is the author of the Vision2020.

2.1.2.6 RURA

The Rwanda Utilities Regulation Agency (RURA) was established in 2001. It regulates public utilities including telecommunications and ITC; postal services; energy storage, transport and supply; and water and sanitation. This task includes setting up guidelines; licensing; ensuring compliance with laws and regulations and protecting the consumers' interests.

2.1.2.7 RSB

The Rwanda Standards Board (RSB), a public institution is responsible for the development of Standards, Conformity Assessment and Metrology and providing related services. It issues a wide variety of standards. The standards relevant to Project are wastewater treatment standards; waste disposal standards; occupational health and safety standards.

2.1.2.8 FONERWA

The Environment and Climate Change Fund is a cross-sectoral financing mechanism to achieve development objectives of environmentally sustainable, climate resilient and green economic growth.

2.1.2.9 The Ministry of Environment

The Ministry of Environment is responsible for the development of policies, laws and regulations as well as coordination of all the activities concerned with the management of water, land and forestry.

2.1.2.10 Rwanda Water and Forestry Authority (RWFA)

RWFA is an authority that leads the management of promotion of land and water resources. It is entrusted with supervision, monitoring and to ensure the implementation of issues relating to the promotion and protection of land and water and help citizens live well without pressure that compel them to exert too much strain on the country's natural resources.

2.1.2.11 Ministry of Agriculture (MINAGRI)

MINAGRI has the mission of initiating, develop and manage suitable programs of transformation and modernization of agriculture and livestock to ensure food security and to contribute to the national economy. The Ministry vision is the transformation of Agriculture from subsistence to a productive high value, market-oriented farming that is environmentally friendly and has an impact on other sectors of the economy.

2.1.2.12 Decentralized entities

For better sanitation and environmental management, decentralized entities like Districts are responsible for the implementation of laws, policies, strategies, objectives and programmes related to sanitation, protection, conservation and promotion of the environment in Rwanda.

Decentralized entities are also responsible for collecting and piling domestic wastes. This is carried out in collaboration with institutions, Districts, Towns and Municipalities or associations and authorized competent individuals. Decentralized entities also put much emphasis on the removal of any other waste in any possible way depending on its nature and quantity, supervision and its treatment. Upon advice of the committees responsible for the protection of environment referred to in article 66 of the organic law, consultative committees of Districts, Towns and Municipalities shall determine a hygiene and sanitation service fees.

2.2. Review of Wastewater Treatment Systems

2.2.1 Basic Concepts in Wastewater Treatment

Wastewater treatment is described as a multistage system whose performance depends on the technology involved in each stage. In general, the more stages are involved; the more level of treatment is achieved. The most complex system template for wastewater treatment would comprise four stages: pre-treatment, primary treatment, secondary treatment and tertiary treatment. Each stage could be done by various processes and technologies.

- During pre-treatment or preliminary treatment, big solids are removed, and grits and oil loads are reduced. Preliminary processes prevent problems of equipment clogging or erosion. Therefore, this stage supports and optimizes the subsequent treatment stages.
- The primary treatment involves physical operations mainly sedimentation but may involve chemical process like flocculation/coagulation. These processes are induced in order to remove solid particles not easy to settle. This stage removes up to 25-50% of BOD, 70% of suspended solids (SS) and 65% of grease (Armenante, 1999).
- The secondary stage consists of processes that remove biologically the organic matter. It aims to remove the 90% of the organic matter dissolved and the 80% of the suspended solids (Armenante, 1999).
- The tertiary treatment aims to produce an effluent with very low level of organic matter and suspend solids. This stage is an additional treatment that guarantees quite acceptable quality of effluent. Beside organic matter also toxic compounds, pathogens and odours are removed. Indeed, these processes are the one recommended for a safety reuse of the effluents (in terms of health protection).

2.2.2 Types of wastewater treatment technologies

2.2.2.1 The activated sludge process

The activated sludge process is a type of wastewater treatment process for treating sewage or industrial wastewaters using aeration to activate the biological flocks composed of bacteria and protozoa and oxidize the carbonaceous, nitrogenous and phosphorus in biological matter (Figure 4). The process takes advantage of aerobic micro-organisms that can digest and clump together (by flocculation) the organic matter in sewage to produce a liquid that is relatively free from suspended solids and organic material. The general arrangement of an activated sludge process for removing carbonaceous pollution includes the following items:

- Aeration tank where air (or oxygen) is injected in the mixed liquor.
- Settling tank (usually referred to as "final clarifier" or "secondary settling tank") to allow the biological flocks (the sludge blanket) to settle, thus separating the biological sludge from the clear treated water.

Treatment of nitrogenous matter or phosphate involves additional steps where the mixed liquor is left in anoxic condition (meaning that there is no residual dissolved oxygen).

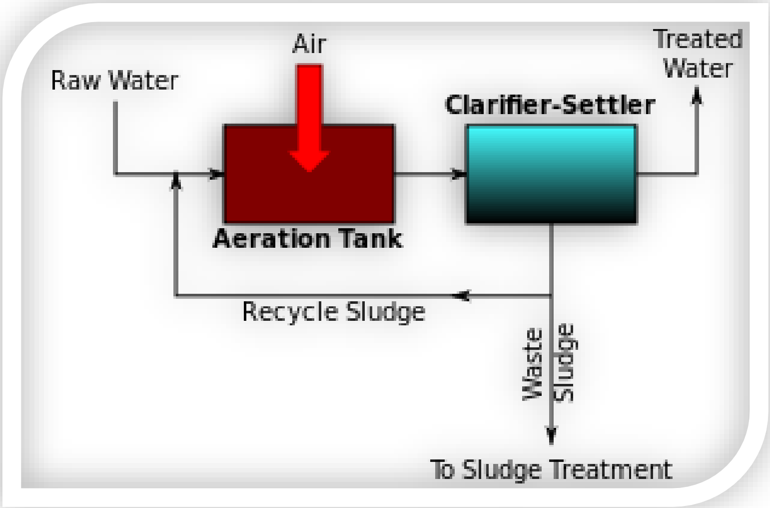


Figure 2: Activated Sludge process

Activated sludge is also the name given to the active biological material produced by activated sludge plants. Excess sludge is called "surplus activated sludge" or "waste activated sludge" and is removed from the treatment process to keep the ratio of biomass to food supplied in the wastewater in balance. This sewage sludge is usually mixed with primary sludge from the primary clarifiers and undergoes further sludge treatment for example by anaerobic digestion, followed by thickening, dewatering, composting and land application.

The amount of sewage sludge produced from the activated sludge process is directly proportional to the amount of wastewater treated. The total sludge production consists of the sum of primary sludge from the primary sedimentation tanks as well as waste activated sludge from the bioreactors. The activated sludge process produces about 70–100 kg of dry solids per mega litre (ML or 10^3 m^3) of waste activated sludge, in addition to about 110–170 kg/ML of primary sludge produced in the primary sedimentation tanks.

2.2.2.2 Adsorption/Bio-oxidation process

The adsorption/bio-oxidation process is a two-stage modification of the activated sludge process. It consists of a high-loaded A-stage and low-loaded B-stage (Figure 3). The process is operated without a primary clarifier, with the A-stage being an open dynamic biological system. Both stages have separate settling tanks and sludge recycling lines, thus maintaining unique microbial communities in both reactors.

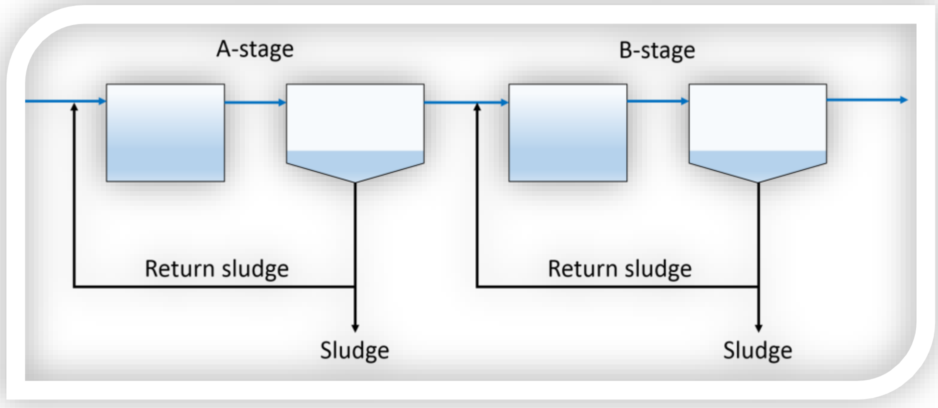


Figure 3: Adsorption/Bio-oxidation process

The A-stage or adsorption stage is the most innovative component of the process. It is not preceded by primary treatment. Influent organic matter is removed in the A-stage mainly by flocculation and sorption to sludge due to the high loading rates (2-10 g BOD • g VSS^{-1} • d^{-1}) and low sludge age (typically 4-10 h). Hydrolysis of complex organic molecules occurs improving biodegradability of the influent of the B-stage.
High loading rates and low sludge age favours development of dynamic biocoenosis with a large fraction of microorganisms present in the exponential growth phase. Diverse sludge biocoenosis increase variety of organic compounds that can be degraded in the A-stage and makes the process more stable towards the shock loads. Altogether, up to 80% of the influent organic matter can be removed in the A-stage. The required reactor volume and oxygen supply are lower if compared to the removal in the conventional activated sludge process.

The B-stage, or bio-oxidation stage, is a typical low-loaded activated sludge process, where biodegradation of the remaining organic material occurs. The B-stage can be designed for nitrogen and/or phosphorus removal by alternating aerobic, anoxic and anaerobic zones in the reactor.

The advantages of adsorption/bio-oxidation process range from lower aeration, energy and volume requirements that makes the able to receive higher organic loads than conventional activated sludge system. The effluent concentrations are more stable because of the two-stage process configuration employed. However, the system suffers from incomplete denitrification, higher sludge production in the A-stage increasing the sludge treatment costs. Phosphorus removal from the secondary effluent of the B-stage can be achieved by coagulation with ferric and aluminium salts, e.g. $FeCl_3$ or $Al_2(SO_4)_3$.

2.2.2.3 Sequencing batch reactor

Sequencing batch reactors (SBR) or sequential batch reactors are a type of activated sludge process for the treatment of wastewater. SBR reactors treat wastewater such as sewage or output from anaerobic digesters or mechanical biological treatment facilities in batches (Figure 4).

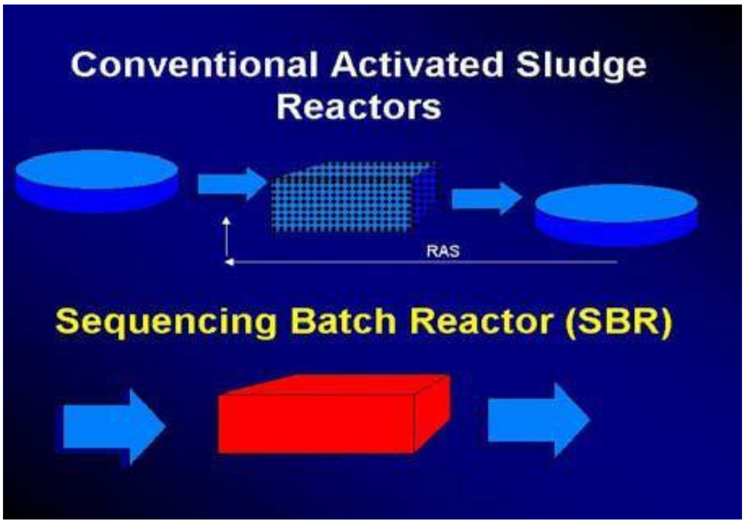


Figure 4: Sequencing Batch Reactor in comparison to the conventional activated sludge reactor

Oxygen is bubbled through the mixture of wastewater and activated sludge to reduce the organic matter (measured as biochemical oxygen demand (BOD) and chemical oxygen demand (COD)). The treated effluent may be suitable for discharge to surface waters or possibly for use on land. While there are several configurations of SBRs, the basic process is similar. The installation consists of one or more tanks that can be operated as plug flow or completely mixed reactors. The tanks have a "flow through" system, with raw wastewater (*influent*) coming in at one end and treated water (*effluent*) flowing out the other. In systems with multiple tanks, while one tank is in settle/decant mode the other is aerating and filling.

In some systems, tanks contain a section known as the bio-selector, which consists of a series of walls or baffles which direct the flow either from side to side of the tank or under and over consecutive baffles. This helps to mix the incoming Influent and the *returned activated sludge* (RAS), beginning the biological digestion process before the liquor enters the main part of the tank. The inlet valve opens and the tank is being filled in, while mixing is provided by mechanical means (no air). This stage is also called the anoxic stage. Aeration of the mixed liquor is performed during the second stage by the use of fixed or floating mechanical pumps or by transferring air into fine bubble diffusers fixed to the floor of the tank. No aeration or mixing is provided in the third stage and the settling of suspended solids starts. During the fourth stage the outlet valve opens and the "clean" supernatant liquor exits the tank.

2.2.2.4 Rotating biological contactor

A rotating biological contactor (RBC) is a biological treatment process used in the treatment of wastewater following primary treatment (Figure 5). The primary treatment process means protection by removal of grit and sand and coarse material through a screening process, followed by a removal process of sediment by settling. The RBC process involves allowing the wastewater to come in contact with a biological medium in order to remove pollutants in the wastewater before discharge of the treated wastewater to the environment, usually a body of water (river, lake or ocean).
A rotating biological contactor is a type of secondary (Biological) treatment process. It consists of a series of closely spaced, parallel discs mounted on a rotating shaft which is supported just above the surface of the waste water. Microorganisms grow on the surface of the discs where biological degradation of the wastewater pollutants takes place.

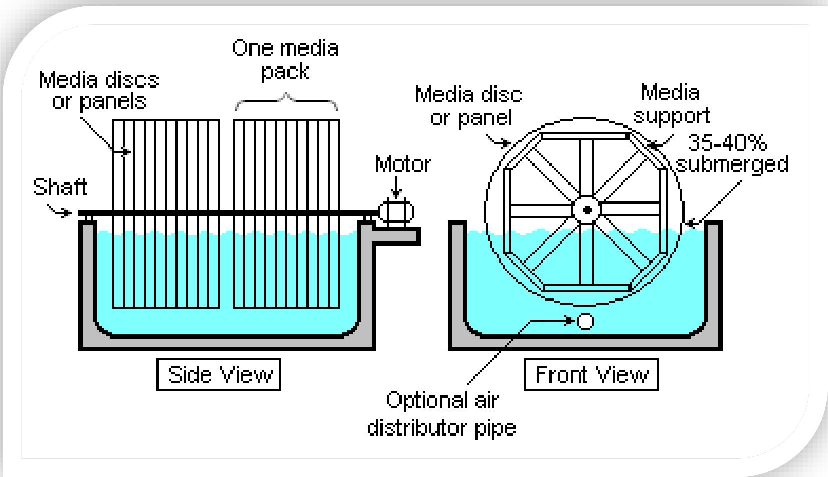


Figure 5: Schematic diagram of a typical rotating biological contactor (RBC)

The rotating packs of disks (known as the media) are contained in a tank or trough and rotate at between 2 and 5 revolutions per minute. Commonly used plastics for the media are polyethylene, PVC and expanded polystyrene. The shaft is aligned with the flow of wastewater so that the discs rotate at right angles to the flow, with several packs usually combined to make up a treatment train. About 40% of the disc area is immersed in the wastewater (*Ronald L. Antonie 2018).*

2.2.2.5 Trickling filter

A typical trickling filter is circular and between 10 meters and 20 meters across and between 2 meters to 3 meters deep (Figure 6). A circular wall, often of brick, contains a bed of filter media which in turn rests on a base of under-drains. These under-drains function both to remove liquid passing through the filter media but also to allow the free passage of air up through the filter media. Mounted in the center over the top of the filter media is a spindle supporting two or more horizontal perforated pipes which extend to the edge of the media. The perforations on the pipes are designed to allow an even flow of liquid over the whole area of the media and are also angled so that when liquid flows from the pipes the whole assembly rotates around the central spindle. Settled sewage is delivered to a reservoir at the centre of the spindle via some form of dosing mechanism, often a tipping bucket device on small filters.

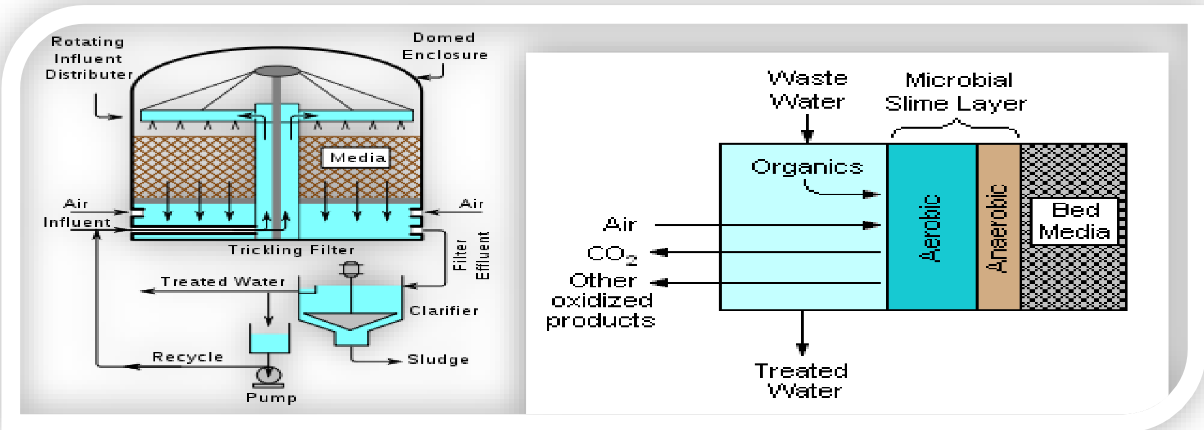


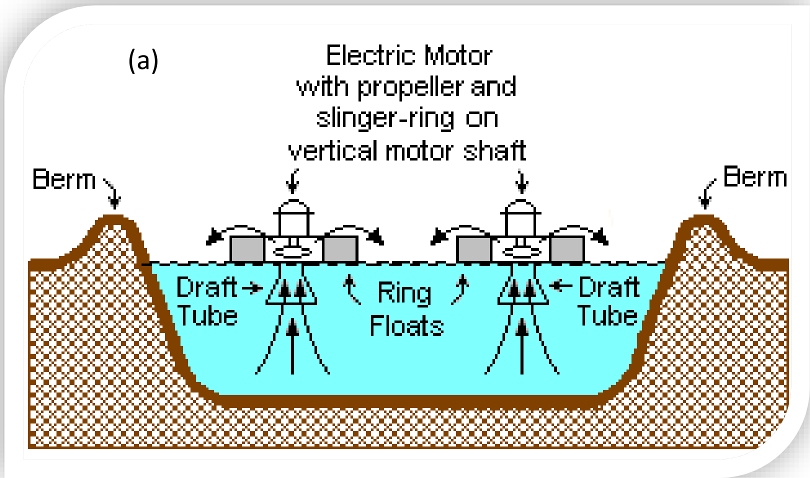
Figure 6: Trickling Filter Configuration

Larger filters may be rectangular and the distribution arms may be driven by hydraulic or electrical systems. It consists of a fixed bed of rocks, lava, coke, gravel, slag, polyurethane foam, sphagnum peat moss, ceramic, or plastic media over which sewage or other wastewater flows downward and causes a layer of microbial slime (biofilm) to grow, covering the bed of media. Aerobic conditions are maintained by splashing, diffusion, and either by forced-air flowing through the bed or natural convection of air if the filter medium is porous. The terms trickle filter, trickling biofilter, biofilter, biological filter and biological trickling filter are often used to refer to a trickling filter. These systems have also been described as roughing filters, intermittent filters, packed media bed filters, alternative septic systems, percolating filters, attached growth processes, and fixed film processes.

The removal of pollutants from the waste water stream involves both absorption and adsorption of organic compounds and some inorganic species such as nitrite and nitrate ions by the layer of microbial bio film. The filter media is typically chosen to provide a very high surface area to volume. Typical materials are often porous and have considerable internal surface area in addition to the external surface of the medium. Passage of the waste water over the media provides dissolved oxygen which the bio-film layer requires for the biochemical oxidation of the organic compounds and releases carbon dioxide gas, water and other oxidized end products. As the bio film layer thickens, it eventually sloughs off into the liquid flow and subsequently forms part of the secondary sludge. Typically, a trickling filter is followed by a clarifier or sedimentation tank for the separation and removal of the sloughed film. Other filters utilizing higher-density media such as sand, foam and peat moss do not produce a sludge that must be removed but require forced air blowers and backwashing or an enclosed anaerobic environment.

2.2.2.6 Aerated lagoon and Oxidation Ditch

An aerated lagoon (or aerated pond) is a simple wastewater treatment system consisting of a pond with artificial aeration to promote the biological oxidation of wastewaters (Figure 7a). Like the activated sludge, trickling filters, rotating biological contactors and biofilters, the aerated lagoon uses of oxygen (or air) and microbial action to reduce the pollutants in wastewaters. The system can operate as suspension mixed lagoons, where there is less energy provided by the aeration equipment to keep the sludge in suspension or as facultative lagoons, where there is insufficient energy provided by the aeration equipment to keep the sludge in suspension and solids settle to the lagoon floor. The biodegradable solids in the settled sludge then degrade as in an anaerobic lagoon. The aeration of the lagoon is done through motor-driven submerged or floating (jet aerators), motor-driven floating surface aerators, motor-driven fixed-in-place surface aerators or injection of compressed air through submerged diffusers.



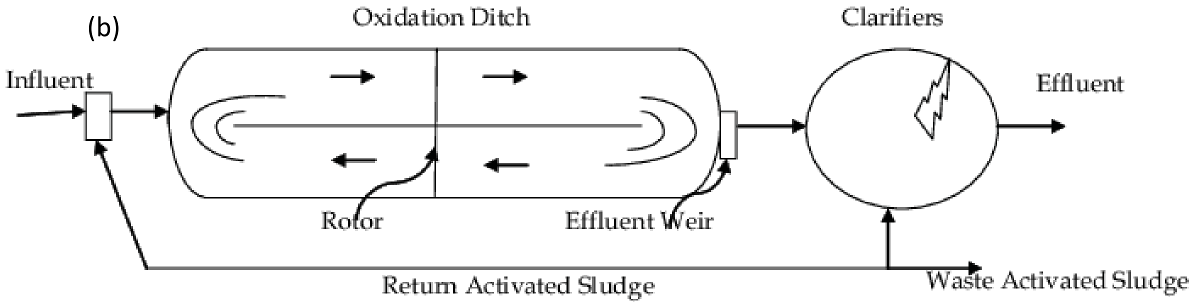


***Figure 7: Aerated Lagoon configuration (a) and* Oxidation Ditch**

Like the aerated lagoon, the oxidation ditch also uses the aeration process to treat the impurities. However, the oxidation ditch is a modification of the complete-mixed extended aeration activated sludge process using a continuous channel or loop reactor (Figure 7b). This process removes BOD at very high efficiency (95-98%). Because of the long detention times, high mixed-liquor suspended solids (large mass of organisms), and efficient aeration, the oxidation ditch can achieve nitrogen removal (nitrification and denitrification). The oxidation ditch has been very effective in the treatment for organic shock loadings because the system contains large mass organisms. The oxidation ditch process is simpler to construct and operate than the conventional activated sludge. The costs for construction are also generally lower than those conventional plants. Nevertheless, because it operates in the extended aeration mode, the process requires more power. The oxidation ditch also requires a large amount of land area. It may not suitable for large scale plants where land is costly and unavailable.

2.2.2.7 Waste stabilization pond

Waste stabilization ponds consist of man-made basins comprising a single or several series of anaerobic, facultative or maturation ponds (Figure 8). The presence or absence of oxygen varies with the three different types of ponds, used in sequence (anaerobic, facultative and aerobic). The main configurations of pond systems are:

- Facultative pond only;
- Anaerobic pond followed by a facultative pond;
- Facultative pond followed by maturation ponds in series;
- Anaerobic pond followed by a facultative pond followed by maturation ponds in series.

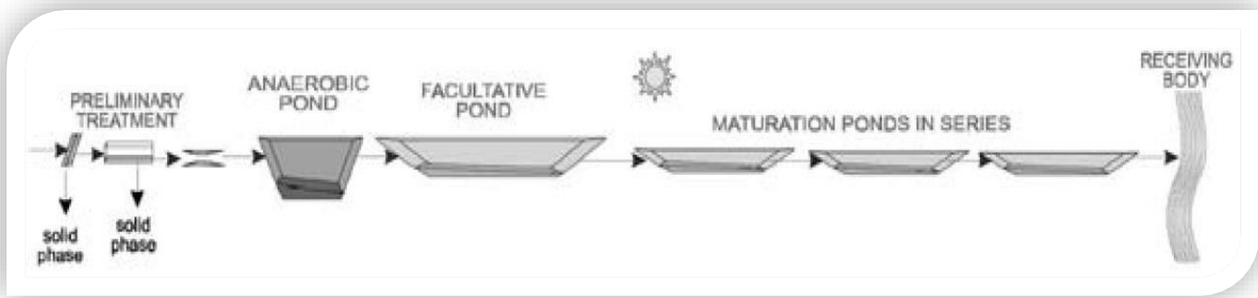


Figure 8: Waste stabilization ponds

If an anaerobic pond is present, part of the suspended solids from the wastewater settles, thus removing the organic matter (BOD) contributed by these solids. Additionally, some of the dissolved organic matter is removed by anaerobic digestion. During the second stage in the facultative pond, most of the remaining BOD is removed mainly by the heterotrophic bacteria that receive oxygen from the photosynthesis undertaken by algae. The main function of the tertiary stage in maturation ponds is the removal of pathogens, although it may also assist in nutrient reduction (i.e. nitrogen).[12] However, nitrogen fixation by algae living in stabilization pond systems may increase nitrogen levels in stabilization pond effluent.

Waste stabilization ponds are very efficient in their primary objective of removing organic matter and, under some conditions, pathogenic organisms. Ponds are simple to design, build, operate and maintain, which is very important in remote areas and in developing countries where sophisticated equipment and highly skilled labor is not easily available. Construction may be done by local contractors in small towns. Waste stabilization ponds work well in nearly all environments and can treat most types of wastewater. They are particularly well-suited for tropical and subtropical countries because the intensity of the sunlight and temperature are key factors for the efficiency of the removal processes. Ponds are used throughout the world. In many countries and regions ponds are the most widely used treatment process. For this reason, they are one of the processes recommended by WHO for the treatment of wastewater for reuse in agriculture and aquaculture, especially because of their effectiveness in removing nematodes (worms) and helminth eggs.

Ponds cannot achieve very high efficiencies in the removal of organic matter, and usually have low capacities for removing nitrogen and phosphorus. The effluent usually has high concentrations of suspended solids, resulting from algal production in the ponds. Therefore, ponds are not a suitable technology in areas where stringent discharge standards exist, unless additional stages of post treatment are included. Since ponds require large areas, they may not be practical in proximity to towns where land is expensive. A suitable topography and a suitable soil structure are also desired, in order to reduce construction costs.

Regarding operation and maintenance, the tasks performed by the operational staff are very simple and do not require special skills. Additionally, there is no energy consumption for aeration, no need of heavy equipment maintenance and no frequent sludge removal, sludge treatment and disposal. The only routine maintenance needed is on the preliminary treatment (cleaning of screens and removal of sand), routine checking of pipes, weirs and other hydraulic structures, and removal of unwanted vegetation growth in embankments *(Sperling, Marcos (2005), von Sperling 2007*.

Sludge accumulates inside the ponds. It needs to be removed only in the interval of several years. This is an important advantage of the system. However, when removal is necessary, it is usually an expensive and labor-intensive operation. Removal is more frequent in anaerobic ponds (every few years), because of their smaller volume and lower capacity to store the sludge, compared with facultative ponds. In facultative ponds, sludge removal may be necessary only in intervals around 15 to 25 years. In maturation ponds, sludge accumulation is

2.2.2.7 Constructed wetland

Constructed wetlands are engineered systems that use natural functions vegetation, soil, and organisms to filter and treat waterborne pollutants found in municipal or industrial wastewater, grey water or storm water runoff (Figure 9). They may also be designed for land reclamation after mining or as a mitigation step for natural areas lost to land development. They can be used after a septic tank for primary treatment (or other types of systems) in order to separate the solids from the liquid effluent. Although, some constructed wetland designs do not use upfront primary treatment, primary treatment is recommended especially when there is a large amount of suspended solids or soluble organic matter (measured as BOD and COD).

Similarly to natural wetlands, constructed wetlands act as a biofilter and/or can remove a range of pollutants (such as organic matter, nutrients, pathogens, heavy metals) from the water. Constructed wetlands are a sanitation technology that have not been designed specifically for pathogen removal, but instead, have been designed to remove other water quality constituents such as suspended solids, organic matter and nutrients (nitrogen and phosphorus). All types of pathogens (i.e., bacteria, viruses, protozoan and helminths) are expected to be removed to some extent in a constructed wetland. Constructed wetlands can be classified as surface or subsurface flow wetlands (Figure 10). Subsurface flow wetlands provide greater pathogen removal than surface wetlands. Some constructed wetlands may also serve as a habitat for native and migratory wildlife, although that is not their main purpose.

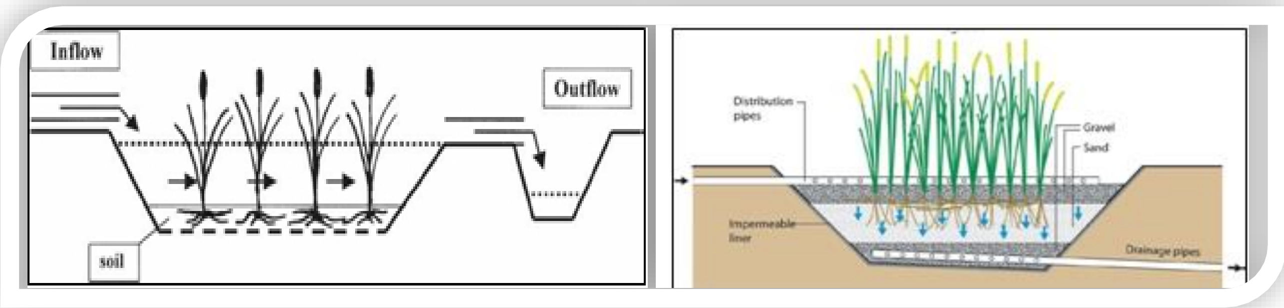


Figure 9: Constructed wetlands (surface flow at left side and subsurface flow at right side)

Constructed wetlands are one example of nature-based solutions and of phytoremediation. Many regulatory agencies list treatment wetlands as one of their recommended "best management practices" for controlling urban runoff. They are more suitable for applications at on-site or at neighborhood level, while stabilization ponds could be a viable alternative for decentralized systems at the level of small towns or rural communities.

Physical, chemical, and biological processes combine in wetlands to remove contaminants from wastewater. Theoretically, wastewater treatment within a constructed wetland occurs as it passes through the wetland medium and the plant rhizosphere. Vegetation in a wetland provides a substrate (roots, stems, and leaves) upon which microorganisms can grow as they break down organic materials. This community of microorganisms is known as the periphyton. The periphyton and natural chemical processes are responsible for approximately 90 percent of pollutant removal and waste breakdown. The plants remove about seven to ten percent of pollutants, and act as a carbon source for the microbes when they decay. Different species of aquatic plants have different rates of heavy metal uptake, a consideration for plant selection in a constructed wetland used for water treatment. A thin film around each root hair is aerobic due to the leakage of oxygen from the rhizomes, roots, and rootlets.

Aerobic and anaerobic micro-organisms facilitate decomposition of organic matter. Microbial nitrification and subsequent denitrification releases nitrogen as gas to the atmosphere. Phosphorus is co-precipitated with iron, aluminium, and calcium compounds located in the root-bed medium. Suspended solids filter out as they settle in the water column in surface flow wetlands or are physically filtered out by the medium within subsurface flow wetlands. Harmful bacteria and viruses are reduced by filtration and adsorption by biofilms on the gravel or sand media in subsurface flow and vertical flow systems.

Limited information on total land requirements for low-cost FS treatment options have been collated to date. Information received and extrapolations made for the systems described above (pond and constructed wetlands treatment) yielded land requirements ranging from 0.02 – 0.07 m2 per capita (Heinss et al., 1998). The figures may serve for order-of-magnitude estimates.

2.2.2.8 Vermifilter

A vermifilter (vermi-digester) is an aerobic treatment system, consisting of a biological reactor containing media that filters organic material from wastewater (Figure 10). The media also provides a habitat for aerobic bacteria and composting earthworms that produce humus. The "trickling action" of the wastewater through the media dissolves oxygen into the wastewater. This is an important feature because bacteria and worms that rapidly decompose organic substances need oxygen to survive. Wastewater is purified by removing pathogens and oxygen demand.

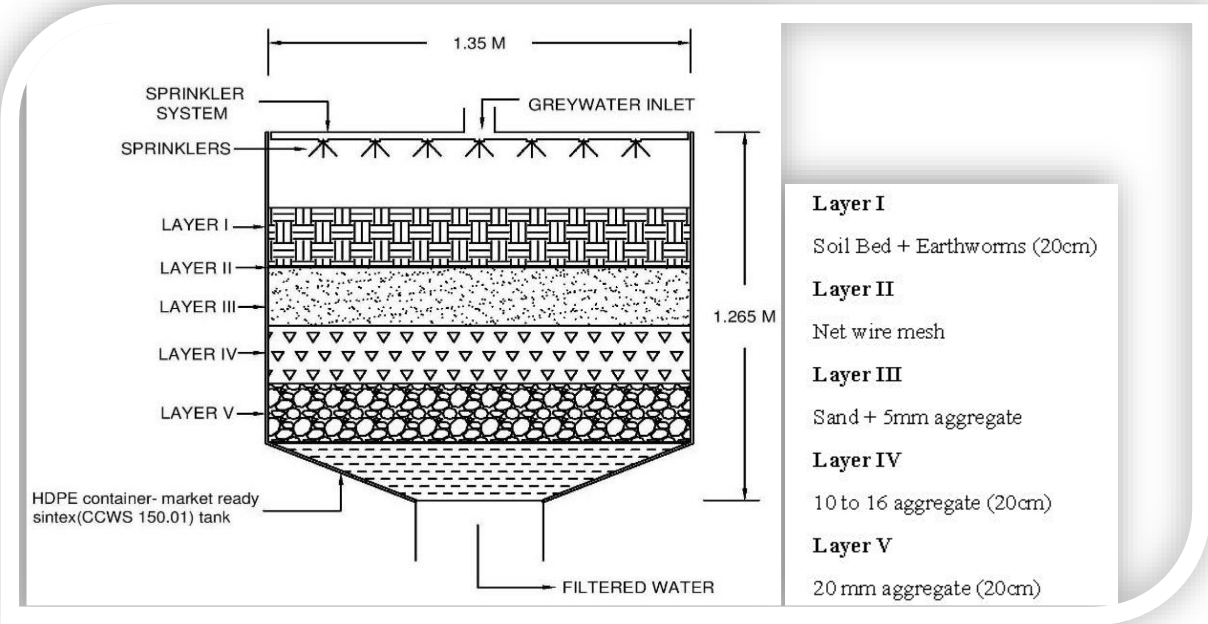


Figure 10: Vermifilter configuration

Vermifilters are most commonly used for sewage treatment and for agro-industrial wastewater treatment. Treatment can take place in either large centralized systems or by smaller on-site sewage treatment. Vermifilters are also used if wastewater requires treatment before it can be safely discharged into the environment. Vermifilters can be used for primary, secondary and tertiary treatment of blackwater and greywater. On-site systems can treat influent from flush toilets (vermifilter toilets). In this case, the treated effluent is disposed of to either surface or subsurface leach fields. Solid material (such as fecal matter and toilet paper) is retained, de-watered and digested by bacteria and earthworms. This converts material into humus. The liquid passes through filtration media to which microorganisms attach themselves and secondary treatment occurs. At that point, organic compounds naturally biodegrade. The oxygen dissolved in the water allows further degradation to take place.

Vermifilters are low cost aerobic wastewater treatment options. Because energy is not required for aeration, vermifilters can be considered "passive treatment" systems (pumps may be required if gravity flow is not possible). Another advantage is the high treatment efficiency given the low space requirement. Drainage within the vermifilter reactor is provided by the filter media. The filter media has the dual purpose of retaining the solid organic material while also providing a habitat suitable for sustaining a population of composting worms. This population requires adequate moisture levels within the media, along with good drainage and aerobic conditions. Common filter packing materials include sawdust, wood chips, coir, bark, peat, and straw for organic packing. Gravel, quartz sand, river bed gravel, pumice, mud balls, glass balls, ceramsite and coal are commonly used for inert packing. Surface area and porosity of filter packing materials influence treatment performance. Thus materials with low granulometry and large surface area may improve the performance of the vermifilter.

A vermifilter has low mechanical and manual maintenance requirements, and where gravity operated requires no energy inputs. Recirculation, if required for improved effluent quality, would require a pump. An annual application of dry organic materials on the top of the filter media may be required for secondary and tertiary treatment vermifilters. The volume of vermicast increases only slowly and occasionally vermicompost needs to be removed from the vermifilter. Solids accumulate on the surface of the organic filter media (or filter packing). The liquid fraction drains through the medium into the sump or equaliser and is either discharged from the reactor or recirculated to the top entry for further treatment. Wastewater is discharged to the surface of the filter packing by direct application or by sprinklers, drippers or tricklers.

2.2.2.9 Enpure wastewater treatment system

The Enpure wastewater treatment system is an advanced waste water purification technology designed to deliver effective sewage treatment forlarge communities. The process provides for full Carbon and Nitrogen removal to produce high quality effluent that is odour free, suitable for reuse such as in irrigation, outdoor washing and safe discharge into water courses. The treatment process includes;

- **Primary Treatment:** - The waste water, both black and grey enter the primary treatment chamber where some solids settle and the liquid effluent is passed through a brush filter to the second tank where more solids are filtered preventing passage to the reactors.
- **Buffer Tank:** The buffer chamber regulates the amount of effluent that is fed into the reactor tanks. The plant runs at maximum efficiency when the effluent stream is at a steady, constant rate.
- **Aeration Reactor:** The effluent enters the reaction chambers where countless bacteria lodged onto the fixed film media breakdown the waste in the presence of oxygen provided by an air blower. This fixed-film media is so designed to ensure that the system works even in the most difficult conditions of overloading, power cuts, downtime, flooding and toxic shock. It also ensures low sludge wastage reducing sludge removal to a minimum thereby saving costs
- **Clarifier Tank:** The effluent then passes to the clarifier tank where sludge settles at the bottom and clear water collects at the top.
- **Storage Tank:** The final product, a clear, odorless and sanitized effluent is collected in this tank ready for discharge either by means of irrigation or onto natural watercourses.

2.2.2.10 Anaerobic Biological Sewage Treatment

Anaerobic treatments on wastewater are normally implemented when treating more concentrated wastewater. The anaerobic sewage contains various groups of microorganisms that work together to convert organic material to biogas via hydrolysis and acidification. Biogas typically consists of 70% methane (CH_4) and 30% carbon dioxide (CO_2) with residual fractions of other gases like H_2 and H_2S. The methane can be used as an energy source. Anaerobic reactors can be implemented in a variety of ways: contact reactor and an upflow reactor (Figure11).

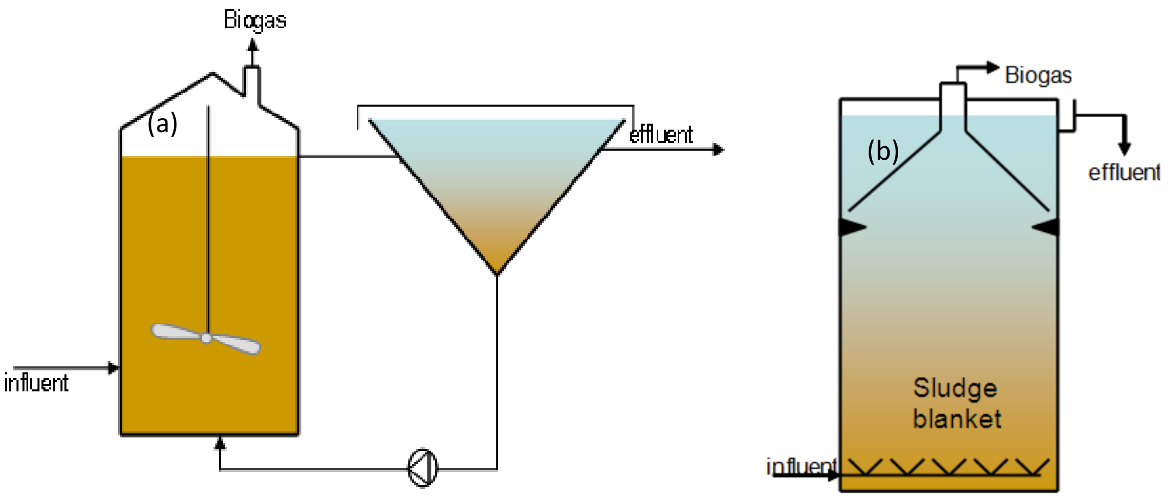


Figure 11: Anaerobic wastewater treatment using the contact reactor (a) and upflow reactor (b)

The contact reactor is comparable with a conventional active sludge system, but under anaerobic conditions. The sludge is mixed with wastewater in the reactor and is then separated in the sedimentation tank and returned to the reactor.

In the anaerobic up flow reactor, the influent is introduced at the bottom of the vertical reactor. The sludge in the reactor is primarily grain shaped and forms a blanket in the reactor, with the most compact sludge grains at the bottom and the lighter grains and heavier sludge floccules above it. Very light sludge floccules will be released by the upward flow, but can potentially be collected in a sedimentation tank. The biogas is collected and disposed of at the top of the reactor, separately from the partly purified water and the sludge.

In addition to the contact reactor and the upflow reactor, other types are:

- Conventional digester primarily implemented for the fermentation of sludge and liquid organic waste. The system is characterised by very low loads and a large volume in order to achieve the longest possible retention time. This type of reactor does not include recirculation of anaerobic sludge.
- Packed anaerobic filter (sludge on carrier), which is filled with carrier material and is normally used as an upflow reactor.
- UASB (upflow anaerobic sludge blanket) or EGSB (expanded granular sludge bed). Both systems are variations of the upflow reactor. The main difference between the two is the increased recirculation of the EGSB reactor. Together with the prominent sludge grain, this enables higher loads in the EGSB (15-30 kg COD/m^3/day).
- Anaerobic membrane reactor: This type of application uses membranes for sludge-water separation. To date, little use has been made of this system. An extra purification phase will often be implemented after anaerobic purification, e.g. for the removal of residual fractions of COD and nutrients N and P. This often involves the use of an aerobic post-purification treatmen

In general, the anaerobic reactor can be implemented for removing:

- COD: On average, the reactor will remove 80-90% of ingoing COD;
- N: Is incorporated into the sludge at a rate of 13g N per 1000g removed COD;
- P: Is incorporated into the sludge at a rate of 3g P per 1000g removed COD.

Approximately 0.35-0.4 Nm^3 biogas is produced per kg COD that is removed from the influent. The caloric value amounts to 20 to 30 MJ/Nm^3. The system can operate with limited_supports aids. However, it is important to collect the biogas to prevent it from escaping into the atmosphere. 60-

75% of the biogas consists of methane, which is a greenhouse gas with an impact that is approximately 20 times greater than carbon dioxide. Despite the biological processes in the anaerobic reactor, this is a fairly simple system and is, in terms of complexity, comparable with conventional aerobic water purification. It can be fully automated, as can aerobic wastewater purification techniques.

2.2.2.11 Vacuum evaporation

Vacuum evaporation is the process of causing the pressure in a liquid-filled container to be reduced below the vapor pressure of the liquid, causing the liquid to evaporate at a lower temperature than normal. Although the process can be applied to any type of liquid at any vapor pressure, it is generally used to describe the boiling of water by lowering the container's internal pressure below standard atmospheric pressure and causing the water to boil at room temperature. Vacuum evaporators are used in industrial wastewater and represent a clean, safe and very versatile technology having low management costs, which in most cases serves as a zero-discharge treatment system.

2.2.2.12 Septic Tanks

A septic tank means any watertight, covered receptacle that is designed and constructed to receive the discharge of sewage from a building sewer or preceding tank, stores liquids for a detention period that provides separation of solids from liquid and digestion of organic matter, and allows the effluent to discharge to a succeeding tank, treatment device, or soil dispersal system (Figure 12). The purpose of the septic tank is to provide an environment for the first stage of treatment in onsite and decentralized wastewater systems by promoting physical settling, flotation, and the anaerobic digestion of sewage. Additionally, the tank allows storage of both digested and undigested solids until they are removed.

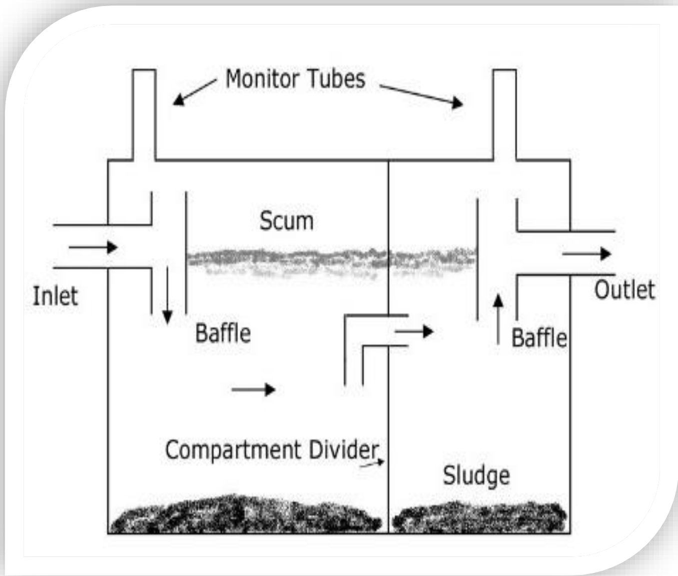


Figure 12: Septic Tank

Septic tanks allow the separation of solids from wastewater as heavier solids settle and fats, greases, and lighter solids float. The solids content of the wastewater is reduced by 60-80% within the tank. The settled solids are called sludge, the floated solids are called scum, and the liquid layer in between is called the clear zone. Although the liquid in the clear zone is not highly treated, it is greatly clarified compared to the wastewater entering the tank, the larger particles having migrated to either the sludge or scum layers. Another important function of the tank is storage of these accumulated solids. The tank is sized large enough to hold solids until maintenance (i.e., tank pumping) is performed. The effluent, that leaves the septic tank comes from the clear zone to minimize the solids loading on the downstream components of the system.

The baffle, tee, or effluent screen at the outlet is designed to draw from the clear zone retaining floatable or settleable solids in the tank. The settling process requires time to occur, so the tank must be large enough to retain the wastewater in a turbulence-free environment for two to four days. Excessive flow and turbulence can disrupt the settling process, so tank volume, size, shape, and inlet baffle configuration are designed to minimize turbulence. Special considerations should be made when designing a septic tank for any establishment. Grease traps should be included in residential or commercial treatment trains that produce high levels of organics and fats, oils, and grease (FOG). Typically, the kitchen waste stream is plumbed to a grease trap while other waste streams are plumbed directly to a septic tank or other treatment tank.

2.2.3 Decentralized and centralized wastewater systems

Decentralized wastewater systems treat, reuse or dispose the effluent in relatively close vicinity to its source of generation. They have the purpose to protect public health and the natural environment by reducing substantially health and environmental hazards. They are also referred as "decentralized wastewater treatment systems" because the main technical challenge is the adequate choice of a treatment and/or disposal facility. A commonly used acronym for decentralized wastewater treatment system is DEWATS.

Decentralized wastewater systems are the most widely applied in well-developed urban environments and the oldest approach to the solution of the problems associated with wastewater. They collect wastewater in large and bulk pipeline networks, also referred as sewerage, which transport it at long distances to one or several treatment plants. Storm water can be collected in either combined sewers or in a separate storm water drains. The latter consists of two separate pipeline systems, one for the wastewater and other for the storm water. The treated effluent is disposed in different ways, most often discharged into natural water bodies. The treated effluent may also be used for beneficial purposes and in this case, it is referred as reclaimed water.

The main difference between decentralized and centralized systems is in the conveyance structure. In decentralized systems the treatment and disposal or reuse of the effluent is close to the source of generation. This results in a small conveyance network, in some cases limited only to one pipeline. In addition, decentralized systems allow for flow separation or source separation, which segregates different types of wastewater, based on their origin, such as: black water, grey water and urine. This approach requires separate parallel pipeline/plumbing systems to convey the segregated flows and the purpose is to apply different level of treatment and handling of each flow and to enhance the safe reuse and disposal of the end products.

Based on the size of the served area, different scales of decentralization could be found:

- Decentralization at the level of a suburb or satellite township in an urban area – these systems could be defined as small centralized systems when applied to small towns or rural communities. But if they are applied only to selected suburbs or districts in medium or large population centres, with existing centralized system, the whole system could be defined as a *hybrid* system, where decentralization is applied to parts of the whole drained area.
- Decentralization at the level of a neighbourhood: this category includes clusters of homes, gated communities, small districts and areas, which are served by vacuum sewers.
- Decentralization at "on-site" level (on-site sanitation) – in these cases the whole system lays within one property and serves one or several buildings.

In locations with developed infrastructure, decentralized wastewater systems could be a viable alternative of the conventional centralized system, especially in cases of upgrading or retrofitting existing systems. Many different combinations and variations of *hybrid* systems are possible. The development of new treatment technologies allows for decentralized solutions, which are technically and aesthetically sound and acceptable.

Decentralized applications are a necessity in cases of new urban developments, where the construction of the infrastructure is not ready or will be executed in future. In many countries and locations, the infrastructure development (roads, water supply and especially wastewater/drainage systems) is executed years after the housing development. In such cases decentralized wastewater facilities are considered as a temporary solution, but they are mandatory, in order to prevent public health and ecological problem.

There is a large variety of wastewater treatment plants where different treatment processes and technologies are applied. Small-scale treatment facilities in decentralized systems, apply similar technologies as medium or large plants. For on-site applications package plants are developed, which are compact and have different compartments for the different processes. However, the design and operation of small treatment plants, especially at neighborhood or on-site level, present significant challenges to wastewater engineers, related to flow fluctuations, necessity of competent and specialized operation and maintenance, required to deal with a large number of small plants, and relatively high per capita cost.

In the specific case of developing countries, where localities with poor infrastructure are common, decentralized wastewater treatment has been promoted extensively because of the possibility to apply technologies with low operation and maintenance requirements. In addition, decentralized approaches require smaller scale investments, compared to centralized solutions.

2.2.4 Proposed centralized sewage system at Giticyinyoni

Wastewater Treatment Plant (WTP) will be constructed at Giticyinyoni near the road crossings Kigali-Musanze and Kigali-Muhanga. It will connect from the sewerage collection from the central part of Kigali of Nyarugenge district in Gitega, Nyarugenge, Muhima, Kimisagara and Kigali sectors, a trunk main to transport the collected wastewater in Kigali and Kimisagara sectors and a pumping station in Muhima sector. Wastewater treatment will involve chemically enhanced primary sedimentation system followed by an activated sludge treatment system with an initial capacity of 12,000 m3 / day and maturation ponds. The plant will also have facilities for sludge digestion and mechanical sludge drying for potential reuse in the agricultural sector, or otherwise disposed of at the Kigali Solid Waste Landfill site. The treated effluent will be discharged in the Nyabugogo River, next to the plant and upstream of the confluence with the Nyabarongo River.

2.3 Fecal sludge management

Fecal sludge management deals with the organization and implementation of this practice in a sustainable way, including collection, transport, treatment and disposal/reuse of fecal sludge from pit latrines and septic tanks (Figure 13).

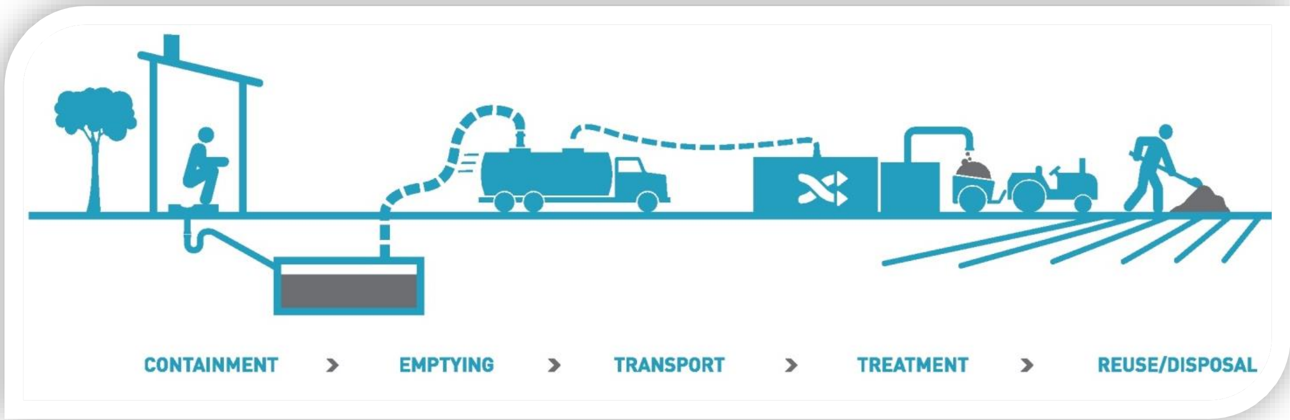


Figure 13**: Sanitation service chain (Water, Sanitation and Hygiene (WSH) program of the Gates Foundation /BMGF, 2015).**

2.3.1 Emptying

In under-developed population centres where no infrastructure is available, is difficult to provide sustainable sanitation measures; e.g. pit latrines/septic tanks need periodic cleansing, usually executed by vacuum trucks, which have to access the latrine and need a basic road for this purpose. Pumping systems that utilize a vacuum have been shown to be effective at removing FS from onsite water-retaining systems. Vacuum pumps may be mounted on heavy duty trucks or trailers, on lighter duty carts or even on human powered carts when smaller volumes are being collected, or for use in dense urban settings not accessible by larger trucks. Vacuum pumps often utilize the truck's transmission to power the system, although independently powered, dedicated motors can also be used. Vacuum trucks are available in a wide variety of sizes and models to accommodate different needs, with the most commonly used having capacities ranging from 200 litres to 16,000 litres.

The operator who comes to collect the FS is often the only person that a resident will interact with regarding their onsite system. As such, the operator has a responsibility not only to perform the tasks properly, but to be able to observe the onsite storage system both when it is full, and when it is empty. They should use this opportunity to assess how well it is functioning, identify repair needs and issues related to proper operation that might increase the life span of the system. As such, they can also troubleshoot and be a source of valuable information about FS management (FSM) in the community in which they work. This is also a good opportunity for service providers to work in conjunction with local governments to disseminate information, such as pamphlets on the proper care of septic tanks, or information on how unimproved latrines might be updated or improved to provide better service.

BREVAC, is one of the specialist vacuum tankers that is used (Figure 14). The equipment was designed to haul a double-compartmental vessel; the first being a 4.3 m3 compartment for sludge, and the second a 1m 3 compartment for service liquid. It is fitted with a high-performance liquid ring vacuum pump with a 0.8 bar suction capacity and 26 m3 /minute air flow rate. The tanker is also fitted with a hydraulic tipping cylinder to incline the vessel and facilitate cleaning after it had been emptied. Small vacuum trucks (EVac) can also be used in slums where road access is a problem.

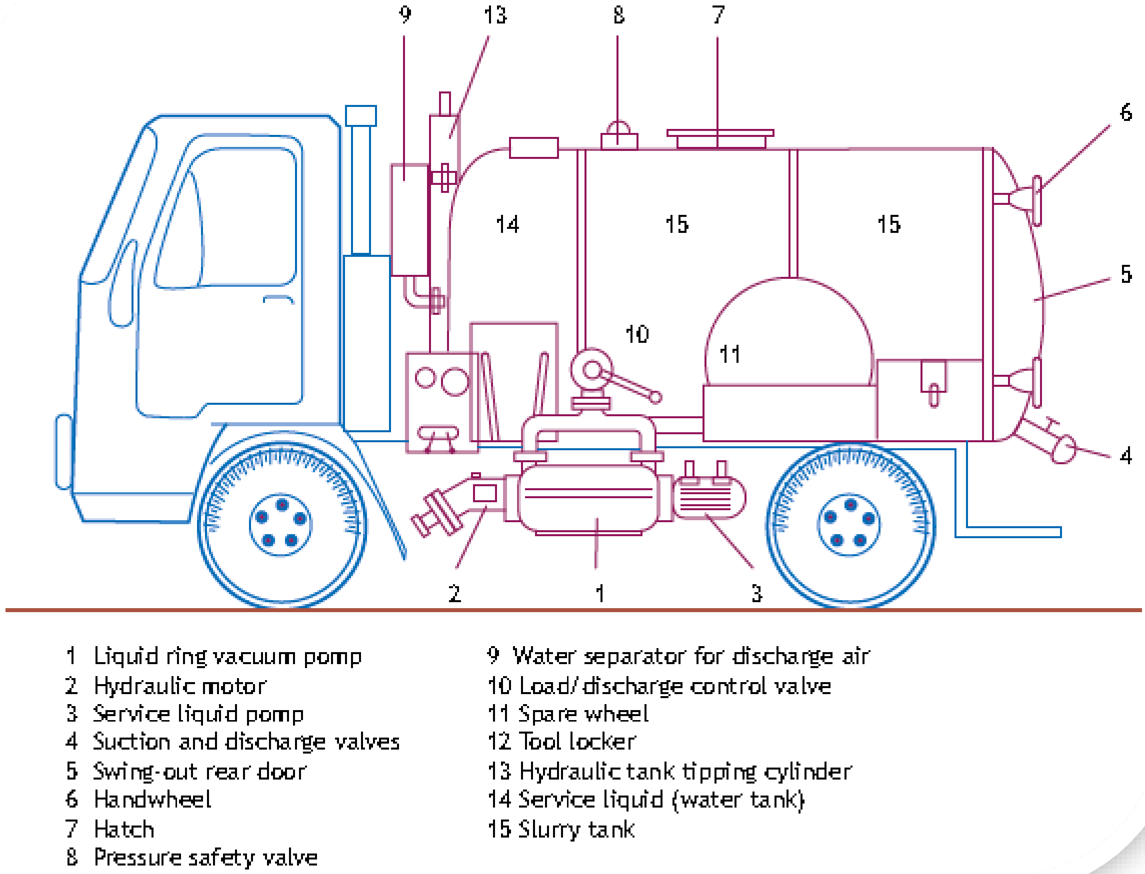


Figure 14: Specialist

2.3.1.1 Options for dealing with trash during pit emptying

The main challenge in mechanized pit emptying is dealing with trash. Trash, such as large pieces of clothing, rope-type materials, bottles, shoes, etc., can clog any tube-based mechanical approach, if the material is bigger than the tube, that is sometimes limited to around 10-12 cm in diameter. There are several approaches to deal with trash in pit latrines, either accept clogging, or use a "fluidization" method, followed by manual "fishing" to remove the trash using manually operated hooks. Fishing is messy and time consuming and can take hours, even half a day, while the subsequent pumping by vacuum pumps take just minutes.
The trash in pit latrines is covered in faecal material, and comes in many forms and sizes, making manual removal unhygienic. Another approach is to "macerate" or somehow reduce the size of trash before they enter the hose or tube. However, to our knowledge, there has not been a single successful application of this technology in real pits. This is because high rotational speeds and a large amount of energy would be needed to chop up material such as cloth, or trash like jeans, shoes, or bottles. Another approach is trash exclusion using screens or other methods preventing trash from being sucked. Trash exclusion seems the best method of dealing with trash.

Trash exclusion

Leaving the trash behind in the pit avoids all these issues. There is no clogging, no fishing, no fluidization needed (which requires addition of large amounts of water), and no messy trash outside the pit that needs to be handled and disposed. There is no need for additional energy for chopping or macerating trash. What happens to the trash left behind? One option is to leave it there. This will decrease the subsequent working volume of the pit. Thus the homeowners will need more frequent pit emptying, which will increase their costs. The other option is for the homeowner to request removal of the trash left behind. Since the contract is for removal of faecal material, this additional service should also be additional cost to the homeowner. In both cases, the higher costs for dealing with trash will lead to the change in behavior that is needed for users to stop using the pit latrine as a trash disposal system.

Separating the trash from faecal material makes downstream treatment of faecal sludge easier. Current FS treatment technologies, such as anaerobic digestion, composting, fermentation, black soldier fly, vermicomposting, and supercritical water oxidation, all require the pre- removal of non biodegradable material such as plastic, clothing, glass bottles, metals, etc. If only faecal sludge needs to be treated, then needed steps, such as pathogen inactivation, become more economical and effective, as the volume of material to be treated is reduced. Other reuse options become more feasible. These include conversion technologies to energy or high-value materials (such as long-chain acids or biofuels).
Separating the trash will lead to efficiencies in collection, since faecal sludge volumes would be lower. The separated trash can be collected separately and transported to a landfill or other trash management facility that is possibly in a different part of town. Alternatively, the trash can be disposed of in a trash pit within the homeowner's property. In any case, the trash management system can be optimized to lower costs of dealing with trash.

To conclude, the removal of only faecal material during pit emptying, and leaving the trash in the pit, is a new approach that has inherent advantages. It is realistic, solves many pit emptying problems, and makes downstream handling and treatment of faecal sludge and trash easier, more hygienic, and more cost-effective.

2.3.2 Transport

When the faecal sludge has been pumped in the tracks, the next step is to transport it to the site of treatment or disposal of the FS. The aspects that need to be considered for the transportation of FS include:

- the safety of the public during the transport;
- the spill management strategies and appropriate equipments to be used in case of spills (shovels, disinfectants, sorbents, and collection bags);
- appropriateness of the vehicle used including its road worthiness, maintenance, licenses and permits, and where it is kept when it is not in service;
- the type of sludge removal equipment, including hoses, pumps, augers, and other tools of the trade;
- the skills of the operator including the training and certifications that might be required to perform the work;
- procedures that need to be followed including rules of the road and activities at the treatment plant;
- Other aspects such as the use of transfer stations, worker health and safety, and emerging technologies.

2.3.3 Delivering faecal sludge to the treatment plant or transfer station

It is becoming more common for larger FSTPs to make use of mechanised receiving stations as shown in Figure 15, where the operator connects the hose from the vacuum truck to the input port, electronically signs in, and discharges the load through the system provided. The receiving station will track the time and date of the load, the volume received, the operator's name, and any other relevant information as required. Mechanised receiving stations can therefore reduce human error and increase the accuracy and accountability of service providers.

Figure 15: Automated FS receiving station at Manila Water's Septage Treatmnt Plant in Philipinnes (photo: WSUP, Sam Parke)

Some advanced transfer stations and vacuum trucks can dewater faecal sludge to some extent, and this water may be placed in sewer lines to be treated in wastewater treatment plants. This allows more sludge to be dealt with more efficiently and may constitute one of the best cases of co-treatment of fecal sludge in wastewater treatment plants.

2.3.3 Treatment

Sludge is solid concentrate removed from liquid sewage. Primary sludge includes settleable solids removed during primary treatment in primary clarifiers. Secondary sludge separated in secondary clarifiers includes treated sewage sludge from secondary treatment bioreactors.

Sludge treatment is focused on reducing sludge weight and volume to reduce disposal costs, and on reducing potential health risks of disposal options. Water removal is the primary means of weight and volume reduction, while pathogen destruction is frequently accomplished through heating during thermophilic digestion, composting, or incineration. The choice of a sludge treatment method depends on the volume of sludge generated, and comparison of treatment costs required for available disposal options. Air-drying and composting may be attractive to rural communities, while limited land availability may make aerobic digestion and mechanical dewatering preferable for cities, and economies of scale may encourage energy recovery alternatives in metropolitan areas.

2.3.3.1 Anaerobic Treatment (Biogas Reactor)

A biogas reactor is an anaerobic treatment technology that produces digested slurry (digestate) that can be used as a fertilizer and biogas that can be used for energy. Biogas is a mix of methane, carbon dioxide and other trace gases which can be converted to heat, electricity or light. A biogas reactor is an airtight chamber that facilitates the anaerobic degradation of Blackwater, sludge, and/ or biodegradable waste (Figure 16). It also facilitates the collection of the biogas produced in the fermentation processes in the reactor. The gas forms in the slurry and collects at the top of the chamber, mixing the slurry a s it rises.
The digestate is rich in organics and nutrients, almost odourless and pathogens are partly inactivated. Biogas reactors can be brick-constructed domes or prefabricated tanks, installed above or below ground, depending on space, soil characteristics, available resources and the volume of waste generated.

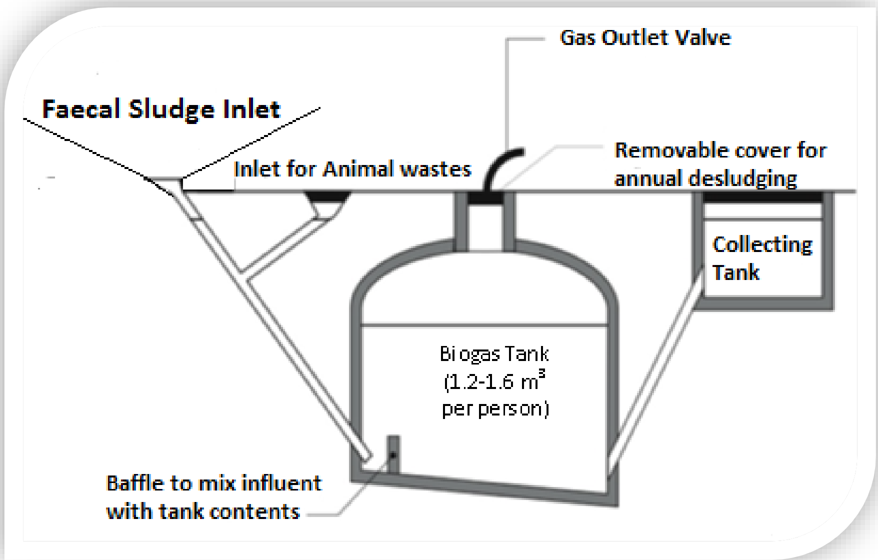


Figure 16: Biogas system

This technology can be applied at the household level, in small neighborhoods or for the stabilization of sludge at large wastewater treatment plants. It is best used where regular feeding is possible. Often, a biogas reactor is used as an alternative to a Septic Tank, since it offers a similar level of treatment, but with the added benefit of biogas. However, significant gas production cannot be achieved if black water is the only input. The advantages of biogas reactor system are: generation of renewable energy; small land area required (most of the structure can be built underground); no electrical energy required; conservation of nutrients; long service life; low operating costs. The disadvantages of the system are:

- It requires expert design and skilled construction;
- Incomplete pathogen removal;
- The digestate might require further treatment;
- Limited gas production below 15 °C.

2.3.3.2 Co-composting with organic wastes

Processes

Composting is the biological decomposition and stabilization of organic substrates, under conditions that allow development of thermophilic temperatures, as a result of biologically produced heat, to produce a final product that is stable, free of pathogens and seeds and that can be beneficially applied to land (Haug, 1993). The process involves the mineralization and humification of organic materials under controlled conditions to achieve stable humus for safe use in agriculture. It reduces the mass and volume of organic materials through microbial degradation of organic matter and C in the form of CO2 (Banegas et al. 2007; Gu et al. 2011; Shan et al. 2013). The composting process generates heat which creates an environment necessary for the deactivation of pathogens and seeds. The temperature profile during biosolid transformation is shown in Figure 17.

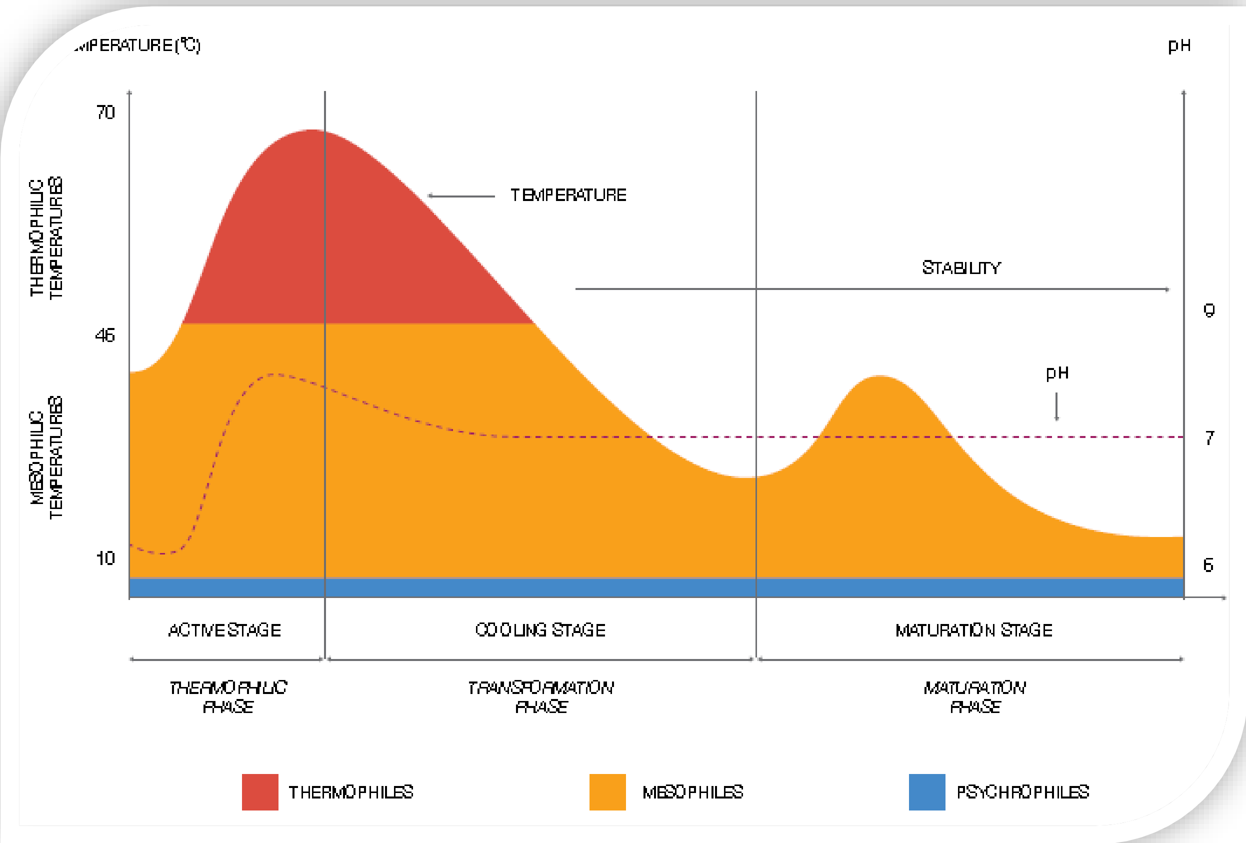


Figure 17: Stages of Biotransformation of biosolids in the composting process

During composting, two main stages are often differentiated: the oxidative phase and the maturation (or curing) phase. In fact, during the aerobic oxidative phase, thermophilic temperatures develop independently of ambient temperatures because of the heat generated in aerobic/exothermic decomposition of waste (Wang et al. 2013). Temperature of a compost pile or inside the compost eactor at this point in time is mainly affected by the material characteristics (moisture content and readily biodegradable organic matter content), or operating conditions (turning frequency, aeration method, size of the compost pile, type of composting device) (Wang et al. 2013).

During the first days of composting, the temperature increases steadily in proportion to the amount of biological activity until equilibrium, until heat loss is reached or the feedstock is used up. With adequate levels of oxygen, moisture, C and N, compost piles can heat up to temperatures in excess of 65 °C (Chen et al. 2010; Wang et al. 2013). Such high temperatures have a negative impact on microbial activity and can become lethal at 70 °C (Bernal et al. 2009; Luangwilai et al. 2011; Singh et al. 2012). This explains why temperatures must be reduced at this point in time, e.g., through turning or forcing air through the compost heap and humidification. The quality of the final compost depends on the control of various factors during composting which are: nutritional composition of the feedstock, C: N ratio, particle size, pH, temperature, moisture content, aeration and operational parameters such as turning frequency and monitoring. Understanding and appropriate application of these factors are major prerequisites for successful composting (UNEP 2005).

Compost inputs

Composting can include a wide variety of biosolids and organic wastes (Table 5). In farming, composting of crop residues mixed with manures from livestock production was and is a common practice on a global scale. However, co-composting of fecal sludge (FS) with organic solid wastes is less widespread to date and replication of this recycling option will depend largely on country-specific context and socio-cultural conditions. Co-composting of FS is considered as a low-cost and appropriate technology to enhance sanitation and waste management in low income countries, especially in urban areas where on-site storage of FS is the main sanitation option for most households but proper treatment of removed sludge is often lacking.

Feedstock materials for composting should be selected according to availability, cost and quality aspects and properties that favor the biotransformation process such as carbon and water content and appropriate C:N ratio. Carbon content should be at least 50% dry weight. Preferably, the material should be amenable to microbial decomposition and cost effective to use (e.g. locally available), but also suited to the proposed or applied composting technology.

Due to the FS compactness and high moisture content, in most cases addition of a bulking agent is required to provide structural support, e.g. to create voids between particles that facilitate the composting process (Doublet et al. 2011). The types of bulking agent used have little effect on the level of organic matter stabilization and availability in the final compost, but the time to reach organic matter stability is significantly influenced by the type of bulking agent used (Doublet et al. 2011). Additionally, the particle size of the bulking agent in the final mixture is an important factor to enhance the sludge composting process and mainly controls aeration (Wong et al. 1995).

Table 5: Compost input material

SOURCE OF MATERIALS	TYPE OF WASTE
Residences and gardens	Garden trimmings, leaves, grass cuttings
Restaurants and canteens	Raw peelings and stems, rotten fruits and vegetables and leftover food
Market	Organic waste of vegerable and fruit markets
Agro-industries	Food waste, bagasse, organic residues
Parks and road verges	Grass clippings, branches, leaves
Municipal areas	Residential solid wastes, human and animal excreta
Dumping sites	decomposed garbage
Animal excreta	cattle, poultry, pig dung from urban and peri-urban farms
Slaughterhouses	contents of digestive system

In 1987, Obeng and Wright of the World Bank and the United Nations Development Programme (UNDP) reviewed available literature and prevailing practices on the co-composting of human waste together with organic solid wastes. They highlighted key issues for consideration in planning for co-composting in developing countries. They are available waste materials, market for compost, type of technology, scale of composting, as well as benefits and justification for co-composting (Obeng and Wright 1987).

Composting turnover frequency and period

Cofie and Koné (2009) conducted in-depth research on the process dynamics of co-composting of fecal sludge and organic solid waste for agriculture and presented various options and performance data for combined treatment of FS and municipal solid waste (SW) through co-composting. The objectives were to investigate the appropriate SW type, SW/FS mixing ratio and the effect of turning frequency on compost maturity and quality. Solid waste from markets (MW) and households (HW) was combined with dewatered FS in mixing ratios of 2:1 and 3:1 by volume and aerobically composted for 90 days.

The compost has been tested for its impact on the germination capacity and early growth of selected vegetables commonly grown in the urban and peri-urban areas (tomato, sweet pepper, lettuce, cabbage, spring onion and carrot). The germination capacity varied between 70-100% for all vegetables, which is an acceptable range. Some of the compost was given to selected urban farmers from the Gyenyasi Farmers Association in Kumasi for its application on their farms. The feedback received was encouraging. There was no difference in performance between this compost and poultry manure for lettuce production. Furthermore, the compost was tested on a demonstration field with maize and compared with a control field without compost application. The field with compost achieved a significantly higher crop yield than the control field. The compost has been used to grow cereals and vegetables. Also, the composting plant operators use it for their ownproduction. This is a demonstration plant to convince policy makers, researchers, farmers, city planners and waste managers of the merits of compost production from faecal sludge.

Fecal Sludge Pretreatment for co-composting with organic wastes

Depending on the source of FS, some form of pretreatment will be needed prior to co-composting. Usually human excreta from public toilets and septic tanks are too high in moisture content (95-97%) and need to be dewatered prior to composting with organic solid waste to ensure aerobic composting. This requires the use of solid-liquid separation systems such as unplanted drying beds, constructed wetlands or thickening/settling tanks. The effluent from these systems must be treated (for example in facultative and maturation ponds, constructed wetlands) to meet discharge guidelines before being discharged into receiving water bodies. The effluent can also be used for watering the compost windrows at the early stages of composting or as irrigation water in peri-urban farming provided its quality meets the standards set for unrestricted irrigation. Nikiema et al. (2014) provide more information on selected solid-liquid separation technologies.

Solid Waste Sorting

As solid wastes could have negative impacts on the final compost quality, it is important to ensure proper separation of organic from inorganic and especially hazardous materials. Usually an organic fraction of household waste, market waste or agro-industrial waste is recommended for use in co-composting. The solid waste should be mixed with the pretreated (e.g., dewatered FS) in the appropriate proportion to ensure an optimal composting process (Cofie et al. 2009).

Technologies

Two main types of composting systems are generally distinguished: 1) open systems such as windrows and static piles and 2) closed 'in-vessel' systems. These in-vessel or 'reactor' systems can be static or movable closed structures where aeration and moisture are controlled by mechanical means. Such systems usually require an external energy supply, either by electricity or through decentralized electricity generators, whereas the latter is often provided by diesel engines. In general, in vessel or reactor systems require higher investment compared with static systems and are also more expensive to operate and maintain. Static composting systems on the other hand, require much lower investments and are hence the preferred option for composting in developing countries. Among them, windrow composting is the most commonly applied system. The identification of the best-suited option for composting depends on numerous parameters. The main choices to be made are related to a) scale (household, community, commercial), b) input materials, c) business models (public, private or combined), d) demand and market situation, e) investment and operation cost, f) technology option and equipment, f) standards and legal framework and g) environmental and health concerns as shown in Figure 5. Decision-making has to be done on a case-by-case basis aiming at the highest possible cost- and co-benefits and sustainability level for the operator, community, stakeholder and the environment.

Enrichment of Compost

Compared to inorganic fertilizers, compost is typically low in nutrients which results in high application rates, often more than 10 t ha-1. Most of the total N in compost is in organic form (>90%) and hence not readily available for plant use (Doublet et al. 2011).

Due to the low mineralization rate, large quantities of compost in the range of 12-48 t ha-1 are required to achieve agronomic N efficiency of 6-22% (Murrilo et al. 1995). Enriching compost with inorganic fertilizer (for both macro and micro nutrients) is recommended. Enrichment with bacterial inoculants, such as Azotobacter and Pseudomonas, as well as other organic nutrient sources such as poultry waste, urine and vermicompost have also been reported (Biswas and Narayanasamy 2006; Kavitha and Subramanian 2007).

Mixing of compost and inorganic fertilizer (e.g., urea) was tested to sanitize the product because inorganic fertilizer can kill pathogens that are present in the co-compost (Vinnerås et al.2003; Vinnerås 2007). Combining co-compost and inorganic fertilizer can also enhance application efficiency since such substrate can supply simultaneously high organic matter to the soil as well as the needed nutrients to increase crop yields (Han et al. 2004; Ahmad et al. 2008), and minimize work load for application (Ahmad et al.2007b). The synergistic effect provided by the organic matter from compost and the inorganic fertilizer contributes to:

- Storing nitrogen in the soil—N is gradually made available to plants over time (Ahmad et al. 2007b);
- Gradually releasing plant nutrients thereby increasing nutrient uptake (Ahmad et al. 2007b; Ahmad et al. 2008);
- Reducing N losses by up to 90 percent and P losses by up to 75 percent; and
- Mitigating soil erosion and subsoil leaching by improving the physic-chemical properties of soil through increased organic matter and biomass generation (Soumare et al. 2003; Adediran et al. 2004).

2.3.3.3 Fecal Char Briquette

The developing world faces dual crises of escalating energy demand and lack of urban sanitation infrastructure that pose significant burdens on the environment. Faecal material from the septic tank and latrines can be pumped out when full and transported using appropriate tracks to the plant site. At the plant, the sludge is discharged into drying beds in a greenhouse, and left to dry for two to three weeks. The greenhouse heat reduces the moisture content from around 95 percent to below 20 percent, to prepare it for carbonisation. The dried-out sludge is then treated at temperatures of about 700 degrees Celsius, with the accompanying sawdust carbonized at 300 degrees Celsius. Next, the carbonized materials are ground into fine particles using a hammer mill, before being mixed together in an equal ratio using motorized equipment. Molasses is added as a binder, before the mixture is transformed into small, round balls in a rotating drum and produce a briquette (Figure 18).

An alternative to the above technology is to use concentrated sunlight to process fecal sludge at high -temperature and low oxygen conditions and transforms it into useful and pathogen-free biochar. The reactor uses pyrolysis, the thermal decomposition of organic matter in the absence of oxygen, to reduce the fecal feedstock into biochar and high-energy gas. The resulting briquette is the charcoal free of odor, and can burn cleaner than charcoal, but it also burns longer. Fecal chars made at 300 °C were found to be similar in energy content to wood chars and bituminous coal, having a heating value of 25.6 ± 0.08 MJ/kg, while fecal chars made at 750 °C had an energy content of 13.8 ± 0.48 MJ/kg.

Figure 18: Faecal char briquette (Nakuru Water and Sanitation Services Company/NAWASSCO)

The biochar byproduct of pyrolysis contains inorganic materials, carbonized residue of organic components, potentially unconverted organic solids and combustible gases like CO, CH_4, H_2, C_2H_6, and C_2H_4. Pyrolysis is used in this technology because it offers relatively quick, high-temperature pathogen destruction, and reduces waste volume by 90%. Collection and use of biogas and use of biochar as a nutrient source for agricultural is also an option of value chain for toilet byproducts.

2.3.3.4 Other faecal sludge treatment options

Apart from energy and nutrient recovery from the fecal sludge, other systems for sludge treatment are constructed wetlands, drying beds, co-treatment with wastewater in ponds, settling and thickening (Figure 19).

Sludge drying beds, if suitably designed and operated, can produce a solids product, which may be used either as soil conditioner or fertilizer in agriculture, or deposited in designated areas without causing damage to the environment. In most cities, the solids removed from the drying beds after a determined period (several weeks to a few months) require further storage and sun drying to attain the hygienic quality for unrestricted use. Where dried sludge is used in agriculture, helminth (nematode) egg counts should be the decisive quality criterion in areas where helminthic infections are endemic. A maximum nematode (roundworm) egg count of 3-8 eggs/g TS has been suggested by Xanthoulis and Strauss (1991).

Although drying bed treatment is usually not classified as a solids-liquid separation process, it serves to effectively separate solids from liquids and to yield a solid concentrate. Gravity percolation and evaporation are the two processes responsible for sludge dewatering and drying. In planted beds, evapotranspiration provides an additional effect. Unplanted and planted sludge drying beds.

Figure 19: Sludge treatment by drying beds (a), thickening (b), composting (c) and constructed wetlands (d)

Sedimentation/thickening tanks require a much smaller per-capita area than sludge drying beds, as the process of separating settable solids requires relatively short hydraulic retention. The space required to store the separated solids bears little on the area requirement. In contrast to this, dewatering and drying of thin layers of sludge on sludge drying beds call for comparatively long retention periods. Organic and solids loads in the percolate of drying beds are significantly lower than in the effluent of sedimentation/thickening tanks. Hence, less extensive treatment is necessary. Percolate (underdrain) flows from drying beds will amount to 50-80 % of the raw fecal sludge deliveries only, whereas the supernatant flows from settling/thickening tanks amount to 95 %, approximately, of the raw sludge discharged into the tanks.

2.4 Case studies on best practices on semi centralized sewage faecal sludge

Amoatey and Bani (2011) conducted a study on appropriate sanitation systems in Ghana. The study findings showed that Individual and community/residential based septic tanks were the most preferred. However, septic tanks have the disadvantages that they partially treat sewage, and the effluent is still rich in organic material. The septic tank has to be emptied from time to time and the disposal of the septic sludge causes severe public health and environmental particularly in urban area. Other sewage treatment systems considered include waste stabilization ponds, trickling filters and activated sludge processes.

Stabilization ponds have also been very well due to the convenient climatic conditions. They usually flow under gravity from one pond to the other and mostly do not require any pumping. They are less energy dependent thus plant activities cannot be interrupted due to power cuts. Their disadvantages however include odour problems and require a large area of land to function properly. In 2010 there were 21 stabilisation ponds in Ghana mainly in Accra and Kumasi. Later, the majority of systems broke down or worked sub-optimally, large quantities of wastewater was discharged directly into the recipient, causing a negative impact on the environment (Kvernberg, E.B., 2012).

A combination of technical, institutional and financial issues were reported to be the major causes of poor performance. The technical issues include damage and wear and tear on physical components of the plants, blocked sewer lines, power cuts and more. The institutional issues are related to inadequate operation and maintenance activities, lack of qualified personnel, lack of commitment of the authorities in charge and a general lack of motivation among workers. The financial issues deal with lack of funds to buy items for maintenance and repair works and poor remuneration of workers at the plants.

3 ASSESSMENT OF CURRENT SITUATION OF WWTP AND FEACAL SLUDGE MANAGEMENT SYSTEMS

3.1 Important definitions related to wastewater treatment and fecal sludge management

a. Type of system

- **Decentralized or Individual systems** are on-site systems that handle wastewater from small communities, buildings and dwellings, individual, public or private properties with one single or a certain number of households with a maximum capacity of up to 20 persons. The system treats reuses or disposes the effluent in relatively close vicinity to its source of generation.

- **Semi-centralized systems** are defined in various ways in the literature. They can generally be categorized by their number of connections of households, or by the outline of the sewer system relative to the central sewerage system (Obermann and Sattler, 2014). For the first option, the numbers of connected households to semi-centralized systems vary greatly in the literature, ranging from several dozens to several tens of thousands. For this study, semi-centralized systems were defined as systems that collect wastewater from small villages, real estates or communities of more than 20 households that not exceeding 10,000 people. They were also defined as sanitation systems that would be connected to central sewer systems.

- **Centralized systems** are off-site systems that collect, transport wastewater from a large area and large communities to a centralized wastewater treatment plant. Centralized systems generally have a wide range and high number of people connected, normally more than PE >50,000. Sewerage and flush systems are required, as well as high capacities for construction and maintenance.

b. Status of the structure of the system

- Fit: Aesthetic, intact, not damaged, perfectly working system
- Fair: Old system, less aesthetic, not perfectly working
- Inadequate: Damaged, unaesthetic, failing or a system out of service

c. System size

- Adequate: System with sufficient enough size to handle the sewage load
- Small: System with insufficient size to handle the sewage load

d. Status Drainage system

- Adequate: Aesthetic, intact and perfectly working system
- Inadequate: Damaged system, unaesthetic, failing or out of service

e. Nuisance to the surrounding

- Offensive odors: bad smells or stench, causing someone to feel resentful, upset, or annoyed.
- Objectionable discharge: unaesthetic effluent with remarkably high turbid, intense colour or bad smells.
- Flies & scavengers : unaesthetic environment with flies, cockroaches, moose, worms, etc
- No nuisance to the surrounding: Clean environment that does not cause the inconvenience or annoyance.

3.2 Current situation of semi-centralized wastewater treatment systems in Kigali City Estates

3.2.1 Mountain Ridge Estate

Estate Name:	Mountain Ridge Estate	**Number of Households:**	49
Location	District:	Gasabo	
	Sector:	Rusororo	
	Cell:	Kabuga	
Treatment technology:	**Activated Sludge Treatment**	**Treatment capacity (PE):**	294

Brief Description of treatment system

Waste water from this estate is designed to use the activated sludge process. The process refers to a multi-chamber reactor unit that makes use of highly concentrated microorganisms to degrade organics and remove nutrients from wastewater to produce a high-quality effluent. To maintain aerobic conditions and to keep the activated sludge suspended, a continuous and well-timed supply of oxygen is required, and it is working with electrical power.

The system was constructed by ECO-Protection Ltd, and it is designed for a domestic sewage flow from 46 households in the estate. The design capacity of the facility is 30m^3/day.

At the time of visit, the system was not yet operational because houses were not yet occupied, and all indicators were satisfactory.

Indicators of the status of the wastewater treatment system

Type of system:	**Semi-centralized**
Operation cost	**-**
Source of operation Cost	**Estate Developer**
Status of the structure of the system:	**Fit**
System sizing:	**Adequate**
Drainage system:	**Adequate**
Nuisance to the surrounding:	**No**
Sludge treatment & disposal;	**Existing**
Effluent disposal	**Cesspool**

Criteria for the proper operation of the system

Although not yet operational, it is worth to underline that the susccess of the system will depend on the availability and efficient operation and maintenance of the system. The most basic thing is securing of the budget for the proper operation and maintenance of the system.

3.2.2 Kabuga hillside housing estate

Estate Name:	Kabuga hillside housing estate	**Number of Households: 79**
Location	District:	Gasabo
	Sector:	Rusororo
	Cell:	Nyagahinga
Treatment technology:	**Jet loop Aerobic treatment**	**Treatment capacity (PE):474**

Brief Description of treatment system

The Estate relies on Jet-Loop System which is a modification of a full activated sludge process. Jet-Loop System is a new and revolutionary process for biological wastewater treatment, in using atmospheric oxygen as source for oxidation of the raw organic loads, driven to the effluents by ejectors devices specially designed and assembled in an innovative matter. The system receives the influent from household by gravity and its working with electrical power to be provided by estate's Contractor (Real Contractor).

The plant is well designed, operated and maintained with easy access to all sewage compartments. The effluent is discharged in open soak a way pit right beside the outlet of the plant. Being open, the soak away pit can cause accidents to people and animals and nuisance to the surrounding. At the time of visit, the system was operated by two technician working day and night. However, the technicians were not regularly paid in time.

Indicators of the status of the wastewater treatment system

Type of system:	**Semi-centralized**
Power operation cost	**200,000 Rwf per month**
Source of operation Cost	**Estate Developer**
Status of the structure of the system:	**Fit**
System sizing:	**Adequate**
Drainage system:	**Adequate**
Nuisance to the surrounding:	**No**
Sludge treatment & disposal;	**Existing**
Effluent disposal	**Cesspool**

System illustrative Photo

Effluent quality

According to WASAC effluent test results (WASAC 2017), most of measured parameters complied with National Tolerance Limits for domestic effluent discharge except total nitrogen and faecal coliforms which exceed the standards. This means that nitrogen removal and disinfection were not efficiently done during treatment.

Table 6: Effluent quality of Kabuga hillside housing estate

Nº	Parameter	Unit	Influent	Effluent	Efficiency (%)	Limits[1]
1.	Turbidity	NTU	61.3	36.2	59	
2.	Total Dissolved Solids (TDS)	mg/l	495	779		<1500
3.	Total Suspended Solids (TSS)	mg/l	75	62	17.3	<50
4.	Total Nitrogen (TN)	mg/l	66	34	48.5	<30
5.	Total Phosphorus (TP)	mg/l	18.4	4.54	75.3	<5
6.	DO initial	mg/l	0.20	1.41		
7.	BODs	mg/l	69	33	52.2	<50
8.	COD	mg/l	139	82	41	<250
BACTERIOLOGICAL ANALYSIS						
9.	Fecal Coliforms	Cfu/100 ml	>50x10^3	>30x10^3		<400

Criteria for the proper operation of the system

For the proper operation of the system, it is very important to design the appropriate drain field for receiving the effluent or to cover to avoid flies and mosquito breeding environment. The monthly cost of operation and maintenance services was estimated at 12,700 Rwf Rwf per household (WASAC 2017).

3.2.3 Gate Hills Estate I (Sekimondo)

Estate Name:	Gate hills Estate I	**Number of Households: 28**	
Location	District:	Kicukiro	
	Sector:	Nyarugunga	
	Cell:	Kanombe	
Treatment technology:	**Common Septic Tank**	**Treatment capacity (PE): 168**	

Brief Description of treatment system

Wastewater from estate building is discharged in Aerated common septic tank by gravity. The effluent from septic tank is discharged into cesspool. The operation and maintenance of the system is still done by the estate developer.

Indicators of the status of the wastewater treatment system

Type of system:	**Semi-centralized**
Operation cost	**-**
Source of operation Cost	**Estate Developer**
Status of the structure of the system:	**Fit**
System sizing:	**Adequate**
Drainage system:	**Adequate**
Nuisance to the surrounding:	**No**
Sludge treatment & disposal;	**Existing**
Effluent disposal	**Cesspool**

System illustrative Photo

Criteria for the proper operation of the system

Although the treatment performance of the septic tank is low, the septic tank can operate effectively, if properly designed, operated and maintained, with regular and professional desludging, transport, treatment, reuse/recycle or disposal of the septic sludge. It is important for the sewage operator to maintain the proper operation, maintenance of the system for continuation of good services.

3.2.4 Gate Hills Estate II (Sekimondo)

Estate Name:	Gate hills Estate I	**Number of Households:**	78
Location	District:	Kicukiro	
	Sector:	Nyarugunga	
	Cell:	Kanombe	
Treatment technology:	**Jet loop Aerobic treatment**	**Treatment capacity (PE):**	546

Brief Description of treatment system:

Gate Hills Estate II uses the jet loop aerobic wastewater treatment plant. The system consists of a pre-treatment compartment, bioreactor, settling compartment, and clear liquid known as effluent is then discharged through the baffled outlet to the groundwater. The atmospheric oxygen is supplied into the wastewater by subsurface jet aerators. The Jet-Loop System is a new and revolutionary process for biological wastewater treatment, in using atmospheric oxygen as source for oxidation of the raw organic loads, driven to the effluents by ejectors devices specially designed and assembled in an innovative matter. The surveyed receive the influent from household by gravity and its working with electrical power to be provided by estate developer until the end of guarantee period. Gate Hill Sewerage system looks nice and satisfies all the observation and other feeling senses (no bad odors, no nuisance, no objectionable discharge).

Indicators of the status of the wastewater treatment system

Type of system:	**Semi-centralized**
Operation cost	**70,000 Rwf per month**
Source of operation Cost	**Estate Developer**
Status of the structure of the system:	**Fit**
System sizing:	**Adequate**
Drainage system:	**Adequate**
Nuisance to the surrounding:	**No**
Sludge treatment & disposal;	**Existing**
Effluent disposal	**Cesspool**

System illustrative Photos

Criteria for the proper operation of the system

For the improved operation of the system, it is very important to strengthen the operation and maintenance services of the system and regular monitoring of the effluent characteristics. The monthly cost for the proper operation and maintenance services was estimated at 2,219 Rwf per household (WASAC 2017).

3.2.5 Masaka Hill View Estate

Estate Name:	Masaka Hill view estate	**Number of Households:**	28
Location	District:	Kicukiro	
	Sector:	Masaka	
	Cell:	-	
Treatment technology:	**Jet loop Aerobic treatment**	**Treatment capacity (PE):**	-

Brief Description of treatment system

Estate was designed to have Jet loop Aerobic treatment as waste water treatment plant. The system worked well at begging but failed after the estate was fully occupied following the lack of maintenance. While the house occupants said the system was designed with critically low capacity, the system provider pointed out that the occupants failed to pay the requested 5,000 Rwf per household per month. Currently, each household is relying on individual septic tank.

Indicators of the status of the wastewater treatment system

Type of system:	**Semi-centralized**
Operation cost	**-**
Source of operation Cost	**Estate owner**
Status of the structure of the system:	**Failed**
System sizing:	**Inadequate**

Drainage system:	**Adequate**
Nuisance to the surrounding:	**No**
Sludge treatment & disposal;	**Existing**
Effluent disposal	**Cesspool**

System illustrative Photos

Criteria for the proper operation of the system

For the proper operation of the system, it is very important to rehabilitate the sewer system and sensitize the occupants on the need for the proper operation and maintenance of the system. The most basic need is securing of the budget for the proper operation and maintenance of the system and hiring a technician in charge ot the day to day operations.

The monthly cost of operation and maintenance services was estimated at 13,600 Rwf Rwf per household (WASAC 2017).

3.2.6 Sunset Estate

Estate Name:	Sunset estate	**Number of Households:**	24
Location	District:	Gasabo	
	Sector:	Kimironko	
	Cell:	kibagabaga	
Treatment technology:	**Common open pit/tank**	**Treatment capacity (PE):**	-

Brief Description of treatment system

Sewage from the estate is conveyed into a common septic tank. However, the system was supposed to rely on the activated sludge process whose installation was not complete.

While the well completed sewer system suffered from the lack of maintenance and has clogged some years ago, the sewage treatment system never worked. Some components of the sewage treatment systems (air compressor and electric cabin) were installed, but the construction of subsequent effluent tank have not been completed. This means that there was treatment at all even though some of the equipment were installed. Waste water from the estate is discharged untreated to the environment through the clogged manholes and open pits.

Indicators of the status of the wastewater treatment system

Type of system:	**Semi-centralized**
Operation cost	**-**
Source of operation Cost	**Estate owner**
Status of the structure of the system:	**Failed**
System sizing:	**Inadequate**
Drainage system:	**Adequate**
Nuisance to the surrounding:	**Bad odor and presence of flies**
Sludge treatment & disposal;	**Existing**
Effluent disposal	**Cesspool**

System illustrative Photos (Clogged manhole on the left side and some installed equipments on right side)

Criteria for the proper operation of the system

For the proper operation of the system, it is very important to rehabilitate the sewer system and complete the effluent tank. It is also of prime importance to provide all requirements for the proper operation and maintenance of the system. The most basic requirement is securing of the budget for the proper operation and maintenance of the system. The monthly cost of operation and maintenance services was estimated at 27,600 Rwf Rwf per household (WASAC 2017).

3.2.7 Umucyo Estate

Estate Name:	Umucyo Estate	**Number of Households:**	300
Location	District:	Gasabo	
	Sector:	Kinyinya	
	Cell:	Gacuriro	
Treatment technology:	Activated Sludge Treatment	**Treatment capacity (PE):**	1800

Brief Description of treatment system

Waste water from this estate was supposed to be treated by an activated sludge process. It is the process with multi-chamber reactor with highly concentrated microorganisms to degrade organics and remove nutrients from wastewater to produce a high-quality effluent. To maintain aerobic conditions and to keep the activated sludge suspended, a continuous and well-timed supply of oxygen is required, and it is working with electrical power. The influent from household was proposed to flow by gravity.

The system was working well before it was handed over to the occupants, but later started failing. The cause of the system failure is the lack of maintenance following the lack of will from the estates occupants to take the responsibility of its operation and maintenance. Currently, the system is no longer functional. The installed air compressor or aerator is out of service due to technical problems. The tanks which were initially designed to be used as aeration tanks are now used or working as septic tanks. Nowadays, the Estate owners are organizing themselves for proper management of the system.

Indicators of the status of the wastewater treatment system

Type of system:	**Semi-centralized**
Operation cost	-
Source of operation Cost	**Estate Owner**
Status of the structure of the system:	**Failed due to lack of maintenance**
System sizing:	**Adequate**
Drainage system:	**Adequate**
Nuisance to the surrounding:	**Bad odor**
Sludge treatment & disposal;	**Not Existing**
Effluent disposal	**Cesspool**

System illustrative Photo

Criteria for the proper operation of the system

For the proper operation of the system, it is very important to provide the proper operation and maintenance requirements of the system. The requirement range from the system components repairs to illegal connection of storm runoff and provision of the system operation and maintenance cost. The monthly cost of operation and maintenance services was estimated at 622,500 Rwf or 2,219 Rwf per household (WASAC 2017).

3.2.8 Kacyiru Estate

Estate Name:	Kacyiru Estate	**Number of Households:**	100
Location	District:	Gasabo	
	Sector:	Kacyiru	
	Cell:	-	
Treatment technology:	**Activated Sludge Treatment**	**Treatment capacity (PE):**	600

Brief Description of treatment system

Indicators of the status of the wastewater treatment system

Type of system:	**Semi-centralized**
Operation cost	**-**
Source of operation Cost	**Estate Owner**
Status of the structure of the system:	**Fit**
System sizing:	**Adequate**
Drainage system:	**Adequate**
Nuisance to the surrounding:	**no**
Sludge treatment & disposal;	**Existing**
Effluent disposal	**Storm water drainage**

Effluent characteristics

As show in the table below (WASAC 2017), the plant performance is not satisfactory compared to the standards set by Rwanda Standard Board (RS 109-2009) related to domestic wastewater effluent standards. This may be due to insufficient aeration, irregular desludging of settlers and low residence time in the final settling tank. The high concentration of faecal coliforms (3.5x103 CFU/1ml) was also detected in the effluent of the plant compared to the discharge limits.

Table 7: Effluent quality of Kacyiru Estate

Nº	Parameter	Unit	Influent	Effluent	Efficiency (%)	Standards
1.	DO	mg/l	1.27	0.14	88.97	
2.	COD	mg/l	312.2	287	8.0	≤250
3.	BOD_5	mg/l	128.4	72.3	43.92	≤50
4.	TDS	mg/l	389	446	-	≤1500
5.	TSS	mg/l	237	256	-	≤50
6.	Total Nitrogen	mg/l	74.1	75.44	-	≤30
7.	Total Phosphorus	mg/l	15	12.5	16.66	≤5
8.	Feacal coliforms	Cfu/1ml	$32x10^3$	$3.3x10^3$	23.80	≤400

Criteria for the proper operation of the system

For the proper operation of the system, it is very important to provide the proper operation and maintenance requirements of the system. The requirement range from protecting the system from illegal storm water connerction to securing the budget for the proper operation and maintenance services of the system. RSSB staff in charge of the sewage systems, have indicated that the required cost of operation and maintenance services amonts at 7,000 Rwf per household per month while WASAC estimated that cost at 10,000 per household per month.

3.2.9 Vision 2020 Estate

Estate Name:	Vision 2020 Estate	**Number of Households:**	300
Location	District:	Gasabo	
	Sector:	Kinyinya	
	Cell:	Gacuriro	
Treatment technology:	**Activated Sludge Treatment**	**Treatment capacity (PE):**	1800

Brief Description of treatment system

Waste water from this estate is treated by an activated sludge. The process refers to a multi-chamber reactor unit that makes use of highly concentrated microorganisms to degrade organics and remove nutrients from wastewater to produce a high-quality effluent. To maintain aerobic conditions and to keep the activated sludge suspended, a continuous and well-timed supply of oxygen is required and it is working with electrical power. The influent from household was proposed to flow by gravity.

The system was working well after its commissioning. Currently the system carries both sanitary sewage and large part of storm water from the estate houses. This unnecessarily increases the burden of the system that was designed to handle the sewage of $300m^3$. In addition, the system lacks the appropriate and regular operation and maintenance services. The occupants were not willing to take the responsibility of the system operation and maintenance. The good news is that now the owners are organizing themselves for proper management of the system.

Indicators of the status of the wastewater treatment system

Type of system:	**Semi-centralized**
Operation cost	**-**
Source of operation Cost	**Estate Owner**

Status of the structure of the system:	**Failed due to lack of maintenance**
System sizing:	**Adequate**
Drainage system:	**Adequate**
Nuisance to the surrounding:	**Bad odor**
Sludge treatment & disposal;	**Not Existing**
Effluent disposal	**Storm water Drainage**

System illustrative Photo

Effluent characteristics

The data from WASAC in the report of the assessment of the performance of semi-centralized sewerage systems in Kigali estates for domestic discharge wastewater in Rwanda (WASAC 2017) are used as indicators of the system performance and are here below presented.

Table 8: Effluent quality of Vision 2020 Estate

Nº	Parameter	Unit	Influent	Effluent	Overall Efficiency (%)	Standards
1.	DO	mg/l	0.06	0.66	-	
2.	COD	mg/l	356	289.4	18.70	≤250
3.	BOD_5	mg/l	157.65	110.82	29.70	≤50
4.	TDS	mg/l	495	511	-	≤1500
5.	TSS	mg/l	240	108	55	≤50
6.	Total Nitrogen	mg/l	76.5	48.6	36.47	≤30
7.	Total Phosphorous	mg/l	25	18	28	≤5
8.	Faecal coliforms	cfu/1ml	$23x10^4$	$3x10^3$	57.69	≤400

From the above results, the effluent quality does not comply with the domestic wastewater effluent standards of Rwanda Standard Board (RS 109-2009) for most of parameters. This was attributed to faults in the processes of aeration and required residence time.

Criteria for the proper operation of the system

For the proper operation of the system, it is very important to provide the proper operation and maintenance requirements of the system. The requirement range from protecting the system from illegal storm runoff to providing the budget for the proper operation and maintenance services of the system. The monthly cost of operation and maintenance services was estimated at 2,062,500 Rwf or 6,875 Rwf per household (WASAC 2017).

3.2.10 Kagugu Villas Housing Estate

Estate Name:	Kagugu villas housing estate	**Number of Households:**	21
Location	District:	Gasabo	
	Sector:	Kinyinya	
	Cell:	Gacuriro	
Treatment technology:	**Sequencing Batch Reactor (SBR)**	**Treatment capacity (PE):**	180

Brief Description of treatment system

Kagugu Villas sewerage and wastewater treatment system is designed for a domestic sewage from 21 buildings located in the estate. The wastewater treatment plant has a design capacity of 180 Population Equivalent and may treat up to 36m3/day. Currently, the plant also receives storm water due to households' illegal connections. Kagugu Villas' estate WWTP consists of two preliminary sedimentation tanks in series, a SBR (Sequencing Batch Reactor) reactor, a storage tank for the final effluent and soak away pits for effluent discharge. SBR reactors treat wastewater such as sewage or output from anaerobic digesters or mechanical biological treatment facilities in batches. Oxygen is bubbled through the mixture of wastewater and activated sludge to reduce the organic matter (measured as BOD and COD). The treated effluent may be suitable for discharge to surface waters or possibly for use on land. For this estate, influent from household is conveyed by drainage system up to treatment by gravity. The treated effluent was disposed into cesspool by using pump.

Sequencing Batch Reactor system is used in this estate house for treating grey water and black water. The operation and maintenance are in charge of the estate occupants, where each household contribute amount of 100,000Rwf per year for operation power and maintenance.
During our survey, we realized that some households have illegally connected the sewer network to storm sewer. Not all sewage produced within the estate reaches the treatment plant, but discharge into the environment. Also, the system was not working properly due to pump collapse. The preliminary sedimentation tanks are full of sludge hindering the optimization of biological treatment.

Indicators of the status of the wastewater treatment system

Type of system:	**Semi-centralized**
Operation cost	**8,500 Rwf /household/ month**
Source of operation Cost	**Estate Owner**
Status of the structure of the system:	**Failed due to lack of spare part**
System sizing:	**Adequate**
Drainage system:	**Adequate**
Nuisance to the surrounding:	**Over flow due failure of pumping system**
Sludge treatment & disposal;	**Not Existing**
Effluent disposal	**Cesspool**

System illustrative Photos


Effluent characteristics

Data previously collected by WASC 2017, before the pump collapse, showed that many parameters complied with National Tolerance Limits for domestic effluent discharge except total phosphorus and faecal coliforms which exceeded the standards (see Table below). This means that phosphorus removal and disinfection were not efficient during treatment.

Table 9: Effluent quality of Kagugu Villas Housing Estate

Nº	Parameter	Unit	Influent	Effluent	Efficiency (%)	Limits
1.	Total Dissolved Solids (TDS)	mg/l	352	365		<1500
2.	Total Suspended Solids (TSS)	mg/l	64	39	39	<50
3.	Total Nitrogen (TN)	mg/l	73.1	17	76.7	<30
4.	Total Phosphorus (TP)	mg/l	27.4	5.7	57.5	<5
5.	DO initial	mg/l	6.03	7.1		
6.	BOD_5	mg/l	74	24.7	66.6	<50
7.	COD	mg/l	108	76	29.6	<250
BACTERIOLOGICAL ANALYSIS						
8.	Fecal coliforms	Cfu/100ml	$29X10^3$	$18X10^3$	38	<400

Criteria for the proper operation of the system

For the proper operation of the system, it is very important to replace the pumping system, respect the desludging frequency, protecting the the sewer system from storm water and comply to the proper operation and maintenance requirements of the system. The monthly cost of operation and maintenance services was estimated at 47,700 Rwf or 6,875 Rwf per household (WASAC 2017).

3.2.11 Juru Estate

Estate Name:	Juru Estate	**Number of Households:**	102
Location	District:	Gasabo	
	Sector:	Remera	
	Cell:	Nyarutarama	
Treatment technology:	**Waste water stabilization pond**	**Treatment capacity (PE):**	Unknown

Brief Description of treatment system

During construction of Nyarutarama Juru estate, the waste water stabilization pond was proposed and constructed at its downstream marshland for wastewater treatment to reduce the organic content and remove pathogens from wastewater. The waster stabilization pond has standard component of stabilization pond such as facilitative pond, aerobic pond and maturation pond.

The sewage treatment system for Juru Estate is wastewater stabilisation pond (WSP). The system is no longer working for some three years ago, due to lack of maintenance of the sewer pipelines and the ponds. The sewer pipeline and manholes have been damaged and the WSP do anymore receive the sewage. Fresh faecal material is discharged untreated into environment, causing bad odor, presence flies and diseases to the surrounding population.

Indicators of the status of the wastewater treatment system

Type of system:	**Semi-centralized**
Operation cost	-
Source of operation Cost	-
Status of the structure of the system:	**Failed**
System sizing:	-
Drainage system:	**Inadequate**
Nuisance to the surrounding:	**Bad odor, presence of flies**
Sludge treatment & disposal;	**Not existing**
Effluent disposal	**Environment**

System illustrative Photos

Criteria for the proper operation of the system

The requirements for the proper operation of WSP range from repairs of the sewer system (pipeline and manholes) to the complete rehabilitation of the whole system and securing the budget for the proper operation and maintenance of the WSP. The budget for the proper operation and maintenance of the WSP was estimated at 7,200 FRw per household per month.

3.2.12 Kami Executive Apartment

Site Name:	Kami Executive Apartment	**Number of Rooms:**	18
Location	District:	Gasabo	
	Sector:	Kinyinya	
	Cell:	Kagugu	
Treatment technology:	**Activated Sludge Treatment**	**Treatment capacity (PE):**	-

Brief Description of treatment system

Waste water from this estate is supposed to be treated by an activated sludge process. This process refers to a multi-chamber reactor unit that makes use of highly concentrated microorganisms to degrade organics and remove nutrients from wastewater to produce a high-quality effluent. To maintain aerobic conditions and to keep the activated sludge suspended, a continuous and well-timed supply of oxygen is required and it is working with electrical power.

During our visit, the system was periodically failing due to the fault in installation and inadequate maintenance and operation services. The plant electric cabin is off service the tank supposed to be an aeration tank is used as a septic tank for black water and grey water.

Indicators of the status of the wastewater treatment system

Type of system:	**Semi-centralized**
Operation cost	**-**
Source of operation Cost	**Estate Developer**
Status of the structure of the system:	**Fit**
System sizing:	**Adequate**
Drainage system:	**Adequate**
Nuisance to the surrounding:	**No**
Sludge treatment & disposal;	**Not existing**
Effluent disposal	**Reused for irrigation**

System illustrative Photos

Criteria for the proper operation of the system

For the proper operation of the system, it is very important to fix the problems in different components of the system. It is also of prime importance to put in place a system for operation and maintenance of the system, by securing of the budget and qualified staff in charge. The monthly cost of operation and maintenance services was estimated at 56,600 Rwf Rwf per household (WASAC 2017).

3.2.13 Landmark Apartment

Site Name:	Landmark Apartment	**Number of Rooms:**	36
Location	District:	Gasabo	
	Sector:	Kinyinya	
	Cell:	Kagugu	
Treatment technology:	**Activated Sludge Treatment**	**Treatment capacity (PE):**	-

Brief Description of treatment system

Waste water from this estate is treated by an activated sludge process with attached growth. This process refers to a multi-chamber reactor unit that makes use of highly concentrated microorganisms to degrade organics and remove nutrients from wastewater to produce a high-quality effluent. To maintain aerobic conditions and to keep the activated sludge suspended, a continuous and well-timed supply of oxygen is required and it is working with electrical power.

The influent from four high raised apartments of 36 rooms as well as influent from Kitchen and laundry flows by gravity up to waste water treatment. The system is operated by part time technician and Treated water is pumped out into cesspool where the sludge is pumped out to municipal land fill.

During our survey, the plant physical layout was in good conditions and all visual and feeling indicators (no smells, no flies, no objectionable discharge) were satisfactory.

Indicators of the status of the wastewater treatment system

Type of system:	**Semi-centralized**
Operation cost	**-**
Source of operation Cost	**Estate Developer**
Status of the structure of the system:	**Fit**
System sizing:	**Adequate**
Drainage system:	**Adequate**
Nuisance to the surrounding:	**No**
Sludge treatment & disposal;	**Not existing**
Effluent disposal	**Cesspool**

System illustrative Photos

Criteria for the proper operation of the system

For the improved proper operation of the system, it is very important to rearrage the system in such away to allow the easy access to all components of the system and make a routine monitoring of the effluent. It is also important to strenghen the operation and maintenance activities and securing of the required budget for the operation and maintenance.

The monthly cost of operation and maintenance services was estimated at 1,000,000, equivalent to 28,000 per apartment (WASAC 2017).

3.2.14 Home Comfort Estate

Estate Name:	Home comfort Estate	**Number of households:**	30
Location	District:	Kicukiro	
	Sector:	Rebero	
	Cell:	-	
Treatment technology:	**Individual and common septic tank**	**Treatment capacity (PE):**	-

Brief Description of treatment system:

The estate house is constructed in two parallel line, one-line upper side have been designed to have individual septic tank and cesspool for waste water treatment and disposal where downward the block line has been designed to have common septic tank and cesspool. The system is under construction during our survey.

Indicators of the status of the wastewater treatment system

Type of system:	**Individual and common septic tank**
Operation cost	**-**
Source of operation Cost	**Estate Developer**
Status of the structure of the system:	**Under construction**
System sizing:	**-**
Drainage system:	**-**
Nuisance to the surrounding:	**No**
Sludge treatment & disposal;	**Not existing**
Effluent disposal	**Cesspool**

System illustrative Photo

Criteria for the proper operation of the system

Although the system is still under construction, it is very important for the Estate manager to put in place a system (budget and technical staff) for proper operation and maintenance of the system. The treatment performance of the septic tank is known to be low. However, if properly designed, operated and maintained, with regular and professional desludging, transport, treatment, reuse/recycle or disposal of the septic sludge, the septic tank can operate effectively.

3.2.15 Vision City Estate

Estate Name:	Vision city estate	**Number of Households: 504**	
Location	District:	Gasabo	
	Sector:	Kinyinya	
	Cell:	Gacuriro	
Treatment technology:	**Sequencing Batch Reactor (SBR)**	**Treatment capacity (PE):**	3528

Brief Description of treatment system

SBR reactors treat wastewater such as sewage or output from anaerobic digesters or mechanical biological treatment facilities in batches. Oxygen is bubbled through the mixture of wastewater and activated sludge to reduce the organic matter (measured as BOD and COD). The treated effluent may be suitable for discharge to surface waters or possibly for use on land. For this estate, influent from household is conveyed by drainage system up to treatment by gravity. The treated effluent was disposed into storage tank and to be reused.

During survey the system was completed and waiting for commissioning. Regarding the proper operation and maintenance, system will be operated by WASAC and permanent technician will be on site.

Indicators of the status of the wastewater treatment system

Type of system:	**Semi-centralized**
Operation cost	**-**
Source of operation Cost	**Estate Owner**
Status of the structure of the system:	**Fit**
System sizing:	**Adequate**
Drainage system:	**Adequate**
Nuisance to the surrounding:	**Over flow due failure of pumping system**
Sludge treatment & disposal;	**Not Existing**
Effluent disposal	**Reused for irrigation**

System illustrative Photo

Criteria for the proper operation of the system

Although the system is still new, it is very important for the Estate manager to put in place a system with good budget and technical staff for the proper operation and maintenance of the system. Monitoring of the treatment performance (effluent quality, structure integrity, smells in the surroundings, etc) should integral part of the system operation.

3.2.16 Cooperative COHAKI Estate

Estate Name:	Cooperative COHAKI	**Number of households:**	46
Location	District:	Gasabo	
	Sector:	Kinyinya	
	Cell:	Gasharu	
Treatment technology:	**Common septic tank**	**Treatment capacity (PE):**	-

Brief Description of treatment system

The Estate was developed to have common septic treat all waste water from household but the construction common septic tank and reticulation system was stopped due to contract problem between developer and contractor. Household in the estate dispose black and grey water in soak pit premise on each household.

Indicators of the status of the wastewater treatment system

Type of system:	**Common septic tank**
Operation cost	**-**
Source of operation Cost	**-**
Status of the structure of the system:	**Under construction**
System sizing:	**-**
Drainage system:	**Not existing**
Nuisance to the surrounding:	**No**

Sludge treatment & disposal;	**Not existing**
Effluent disposal	**-**

System illustrative Photo

Criteria for the proper operation of the system

COHAKI Estate will be using a common septic tank which is still under construction. There are lot of criticism concerning the low treatment performance of the septic tank. However, it is very important to comply with the proper operation and maintenance of the septic tanks. Septic tank can operate effectively, if properly designed, operated and maintained, with regular and professional desludging, transport, treatment, reuse/recycle or disposal of the septic sludge.

3.2.17 Urukumbuzi Estate

Estate Name:	Urukumbuzi Estate	**Number of households:**	166
Location	District:	Gasabo	
	Sector:	Kinyinya	
	Cell:	Gasharu	
Treatment technology:	**Individual and Common septic tank**	**Treatment capacity (PE):**	-

Brief Description of treatment system

The Estate relies on individual septic tank and pits for lower raised building, and a semi-centralized septic tank and a pit for the raised building for only the black water, while the grey water is conveyed to the storm drainage channel where it may have negative impacts on environment and the public. The operational cost for emptying and maintaining septic tank and cesspool is under the Estate house Owners. The raised building in the estate is sharing the common septic and cesspool.

Indicators of the status of the wastewater treatment system

Type of system:	**Individual and Common septic tank**
Operation cost	**-**
Source of operation Cost	**Estate owners**
Status of the structure of the system:	**Fair**
System sizing:	**Fair**
Drainage system:	**Not existing**
Nuisance to the surrounding:	**No**
Sludge treatment & disposal;	**Not existing**
Effluent disposal	**-**

System illustrative Photos

Criteria for the proper operation of the system

For the proper operation of the system it is worth to consider connecting the grey water to sewage system and compliance to the proper operation and maintenance. The septic tanks systems can operate effectively, if properly designed, operated and maintained, with regular desludging of septic sludge. They should also serve for the designed flow. When a system is poorly maintained (not pumped out on a regular basis), solids build up in the septic tank, then flow into the leaching system, clogging it. It is also important to consider hiring the qualified personal to carry out regular operation and maintenance activities and apply sewerage tariffs to users for the sustainability of the system.

The budget for the proper operation and maintenance of the WSP was estimated at 4,000 FRw per household per month.

3.2.18 Izuba City Estate

Estate Name:	Izuba City Estate	**Number of households:**	150
Location	District:	Gasabo	
	Sector:	Kinyinya	
	Cell:	Batsinda	
Treatment technology:	**Enpure Waste water treatment**	**Treatment capacity: (PE): 1,100**	

Brief Description of treatment system

The Enpure wastewater treatment system is an advanced waste water purification technology designed to deliver effective sewage treatment for large communities. The process provides for full Carbon and Nitrogen removal to produce high quality effluent that is odor free, suitable for reuse such as in irrigation, outdoor washing and safe discharge into water courses. The treatment process follows the components of the system in this order: **Primary Treatment, Buffer Tank, Aeration Reactor**, **Clarifier Tank**, **Storage Tank.**

The system is under construction, concrete works is ongoing and reticulation works was completed during our survey.

Indicators of the status of the wastewater treatment system

Type of system:	**Semi-centralized**
Operation cost	**-**
Source of operation Cost	**-**
Status of the structure of the system:	**Under construction**
System sizing:	**Adequate**
Drainage system:	**Not existing**
Nuisance to the surrounding:	**No**
Sludge treatment & disposal;	**Not existing**
Effluent disposal	**To be reused**

System illustrative Photos

Criteria for the proper operation of the system

Although the system is still under construction, it is very important for the Estate manager to put in place a system with enough budget and committed technical staff for the proper operation and maintenance of the system. Monitoring of the treatment performance (effluent quality, structure integrity, smells in the surroundings, etc) should integral part of the system operation.

3.2.19 Gate Hills Estate III

Estate Name:	Gate hills Estate III	**Number of houses:**	52
Location	District:	Gasabo	
	Sector:	Ndera	
	Cell:	Masaro	
Treatment technology:	**Individual septic tank**	**Treatment capacity (PE):**	-

Brief Description of treatment system

The estate was developed to have septic tank and cesspool as technology for treating waste water and disposal. Two septic tanks were constructed in one and to be shared by two household and each household has its cesspool for effluent from septic tank.

Indicators of the status of the wastewater treatment system

Type of system:	**Individual septic tank**
Operation cost	**-**
Source of operation Cost	**Estate owners**
Status of the structure of the system:	**Under construction**
System sizing:	**Fit**
Drainage system:	**Not existing**
Nuisance to the surrounding:	**No**
Sludge treatment & disposal;	**Not existing**
Effluent disposal	**Cesspool**

System illustrative Photos

Gate hills Estate III will be using the individual septic tank which is still under construction. Despite valid criticisms concerning the low treatment performance of the septic tank, it is very important to note that septic tanks can operate effectively, if properly designed, operated and maintained, with regular and professional desludging, transport, treatment, reuse/recycle or disposal of the septic sludge.

3.2.20 Garden Estate

Estate Name:	Garden estate	**Number of houses:**	16
Location	District:	Gasabo	
	Sector:	Kinyinya	
	Cell:	-	
Treatment technology:	**Individual septic tank**	**Treatment capacity (PE):**	-

Brief Description of treatment system

The estate was developed to have individual septic tank and cesspool as technology for treating waste water and disposal. However, the system is still under construction.

Indicators of the status of the wastewater treatment system

Type of system:	**Individual septic tank**
Operation cost	**-**
Source of operation Cost	**Estate owners**
Status of the structure of the system:	**Under construction**
System sizing:	**Fit**
Drainage system:	**Not existing**
Nuisance to the surrounding:	**No**
Sludge treatment & disposal;	**Not existing**
Effluent disposal	**Cesspool**

Criteria for the proper operation of the system

Garden estate will be using the individual septic tanks which are still under construction. Despite valid criticisms concerning the low treatment performance of the septic tank, it is very important to note that septic tanks can operate effectively, if properly designed, operated and maintained, with regular and professional desludging, transport, treatment, reuse/recycle or disposal of the septic sludge.

3.2.21 Stip Estate / Gaposho Estate

The consultant failed to visit the Stipp Estate/Gaposho Estate due to the denied access by the manager. However, the previous survey by WASAC (2017) showed that the wastewater treatment system of the Estate was designed for a domestic sewage flow from 26 houses of the estate. This estate has been constructed in 2005. The wastewater treatment consists of anaerobic septic systems, on-site sanitation facilities which only receive greywater and black water. The solids tend to accumulate and biodegrade in septic tank, while the fluids infiltrate into deeper soil. Scum and sludge must be pumped periodically and should never enter the drain field. Septic tanks provide preliminary treatment for the entire wastewater stream by allowing solids to settle to the bottom of the tank, and soils and fats to float to the top to form a scum layer. Unfortunately, a septic tank provides low treatment efficiency (exceeding the national standards) and does not remove nutrients and pathogenic agents. When filled, these septic tanks at Stippestate are regularly emptied and sludge is disposed at Nduba dumping site while the effluent is discharged into the soak ways pit. Note that storm water is conveyed in storm water drainage channels.

From the WASAC report (WASAC 2017), the system looked well and septic tanks were in good conditions. However, it is worth to note that septic tanks have low sewage treatment efficiency.

Criteria for the proper operation of the system

The septic tanks systems can operate effectively, if properly designed, operated and maintained, with regular desludging of septic sludge. They should also serve for the design flow. When a system is poorly maintained (not pumped out on a regular basis), solids build up in the septic tank, then flow into the leaching system, clogging it. Therefore, the proper operation of the system, it is worth to comply with the strict proper operation and maintenance requirement otherwise consider the replacement of septic tanks by another modern sewage treatment system. The budget for the proper operation and maintenance of the WSP was estimated at 21,200 FRw per household per month (WASAC 2017).

3.2.22 BNR Estate

Estate Name:	BNR Estate	**Number of households:125**
Location	District:	Kicukiro
	Sector:	Kimisange
	Cell:	Rebero
Treatment technology:	**Individual septic tank**	

Brief Description of treatment system:

BNR wastewater treatment system was designed for a domestic sewage flow from125 houses located in the estates. The system does not include a semi-centralized sewerage system, but each household possesses its own anaerobic septic tank which receives grey water and black water.

Unfortunately, some of these septic tanks have been sealed to the extent that having access to them becomes impossible while others are overloaded. Some households have connected grey water to storm water drainage channel.

Indicators of the status of the wastewater treatment system

Type of system:	**Individual septic tank**
Operation cost	**-**
Source of operation Cost	**Estate owners**
Status of the structure of the system:	**System sealed**
System sizing:	**Fit**
Drainage system:	**Not existing**
Nuisance to the surrounding:	**No**
Sludge treatment & disposal;	**Not existing**
Effluent disposal	**Cesspool**

Criteria for the proper operation of the system

The septic tanks systems can operate effectively, if properly designed, operated and maintained, with regular desludging of septic sludge. They should also serve for the design flow. When a system is poorly maintained (not pumped out on a regular basis), solids build up in the septic tank, then flow into the leaching system, clogging it.

Therefore, for the proper operation of the system, it is worth to comply with the strict proper operation and maintenance requirements, by educating people on how to use it, otherwise consider the replacement of septic tanks by another modern sewage treatment system. The budget for the proper operation and maintenance of the WSP was estimated at 5,300 FRw per household per month (WASAC 2017).

3.2.23 Rujugiro Estates

Estate Name:	Rujugiro Estates	**Number of households:58**
Location	District: Kicukiro	Kicukiro
	Sector:	Gikondo
Treatment technology:	**Individual septic tank**	**Treatment capacity (PE):**

Brief Description of treatment system:

The estate was developed to have individual septic tank and cesspool as technology for treating waste water and disposal. When filled, the sludge is emptied and disposed at Nduba dumping site. During our survey the septic tanks were in good status.

Indicators of the status of the wastewater treatment system

Type of system:	**Individual septic tank**
Operation cost	**-**
Source of operation Cost	**Estate owners**
Status of the structure of the system:	**Fit**
System sizing:	**Fit**
Drainage system:	**Not existing**
Nuisance to the surrounding:	**No**
Sludge treatment & disposal;	**Not existing**

Criteria for the proper operation of the system

Rujugiro Estates rely on individual septic tanks. Despites their low treatment efficiency, septic tanks systems can satisfactorily work, if properly designed, operated and maintained, with regular desludging of septic sludge. When a system is poorly maintained (not pumped out on a regular basis), solids build up in the septic tank, then flow into the leaching system, clogging it. For the proper operation of the system, it is worth to comply with the strict proper operation and maintenance requirement otherwise consider the replacement of septic tanks by another modern sewage treatment system.

The budget for the proper operation and maintenance of the WSP was estimated at 11,500 FRw per household per month (WASAC 2017).

3.2.24 Niboye Estate

Estate Name:	RSSB Kacyiru apartment	**Number of stakeholders: 50**	
Location	District:	Kicukiro	
	Sector:	Niboye	
Treatment technology:	**Activated sludge process**		-

Brief Description of treatment system:

Waste water from this estate will be treated using the activated sludge process. This process refers to a multi-chamber reactor unit that makes use of highly concentrated microorganisms to degrade organics and remove nutrients from wastewater to produce a high-quality effluent. To maintain aerobic conditions and to keep the activated sludge suspended, a continuous and well-timed supply of oxygen is required, and it is working with electrical power.

The influent from household was supposed to flow by gravity but the system is not yet operational because houses were not yet occupied.

Indicators of the status of the wastewater treatment system

Type of system:	**Activated sludge process**
Operation cost	**-**
Source of operation Cost	**Estate owners**
Status of the structure of the system:	
System sizing:	**Fit**
Drainage system:	**Not existing**
Nuisance to the surrounding:	**No**
Sludge treatment & disposal;	**Not existing**
Effluent disposal	**Storm water drain**

System illustrative Photo

Criteria for the proper operation of the system

Although the system is still new and not yet operational, it is very important for the Estate manager to put in place a system with good budget and technical staff for the proper operation and maintenance of the system. Monitoring of the treatment performance (effluent quality, structure integrity, smells in the surroundings, etc) should integral part of the system operation.

3.2.25 Highland Apartment & Suites

Estate Name:	Highland Apartment	**Number of rooms: 44**	
Location	District:	Gasabo	
	Sector:	Remera	
	Cell:	Nyarutarama	
Treatment technology:	**Activated Sludge Treatment**	**Treatment capacity (PE):**	-

Brief Description of treatment system:

Waste water from this estate is treated by an activated sludge which is the process refers to a multi-chamber reactor unit that makes use of highly concentrated microorganisms to degrade organics and remove nutrients from wastewater to produce a high-quality effluent. To maintain aerobic conditions and to keep the activated sludge suspended, a continuous and well-timed supply of oxygen is required, and it is working with electrical power.

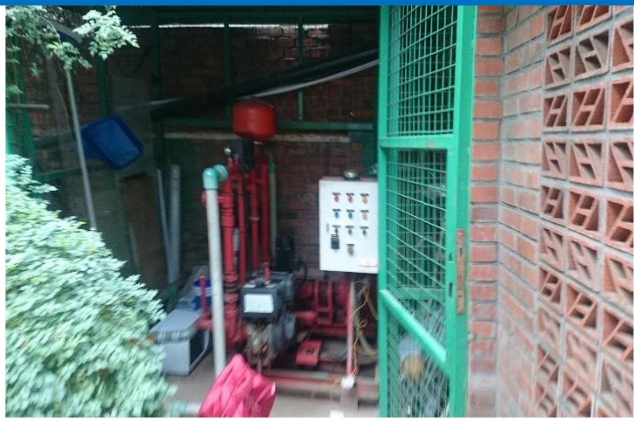
The influent from household was proposed to flow by gravity to the activated sludge, but the system is not yet operational as houses are not yet occupied.

Indicators of the status of the wastewater treatment system

Type of system:	**Centralized**
Operation cost	**-**
Source of operation Cost	**Estate Developer**
Status of the structure of the system:	**Fit**

System sizing:	**Adequate**
Drainage system:	**Adequate**
Nuisance to the surrounding:	**No**
Sludge treatment & disposal:	**Not Existing**
Effluent disposal	**Cesspool**

System illustrative Photo

Criteria for the proper operation of the system

Although the system is still new, it is very important for the Estate manager to put in place a system with enough budget and committed technical staff for the proper operation and maintenance of the system. Monitoring of the treatment performance (effluent quality, structure integrity, smells in the surroundings, etc) should be integral part of the system operation.

3.2.26 Goboka Estate

Estate Name:	Goboka Estate	**Number of households:**	
Location	District:	Gasabo	
	Sector:	Kibagabaga	
	Cell:	Kimironko	
Treatment technology:	Individual septic tank	**Treatment capacity (PE):**	-

Brief Description of treatment system:

The estate was developed to have individual septic tank and cesspool as technology for treating waste water and disposal. However, the system is not yet operational as it is still under construction.

Indicators of the status of the wastewater treatment system

Type of system:	**Individual septic tank**
Operation cost	**-**
Source of operation Cost	**Estate owners**

Status of the structure of the system:	**Under construction**
System sizing:	**Fit**
Drainage system:	**Not existing**
Nuisance to the surrounding:	**No**
Sludge treatment & disposal;	**Not existing**
Effluent disposal	**Cesspool**

Criteria for the proper operation of the system

Goboka Estates will be using the individual septic tanks which are still under construction. Despite valid criticisms concerning the low treatment performance of the septic tank, it is very important to note that septic tanks can operate effectively, if properly designed, operated and maintained, with regular and professional desludging, transport, treatment, reuse/recycle or disposal of the septic sludge. When a system is poorly maintained (not pumped out on a regular basis), solids build up in the septic tank, then flow into the leaching system, clogging it. Therefore, for the proper operation of the system, it is worth to comply with the strict proper operation and maintenance requirements, by educating people on how to use it, otherwise consider the replacement of septic tanks by another modern sewage treatment system. The budget for the proper operation and maintenance of the WSP was estimated at 5,300 FRw per household per month (WASAC 2017).

3.3 Status of operationalization of wastewater treatment systems and fecal sludge management in Kigali City Estates

3.3.1 Performance indicators of existing WWTPs

3.3.1.1 Results from field survey (observation and interviews)

Field surveys (observation, interviews) to different estates in the City of Kigali helped to understand the status of wastewater and faecal sludge treatment systems. Figure 20 shows that 56% of sewage treatment systems are operational (in service), 22% are under construction, 7% are waiting for commissioning, 15% are out of service. Only 67% of the sewage treatment systems have adequate system structure (fit).

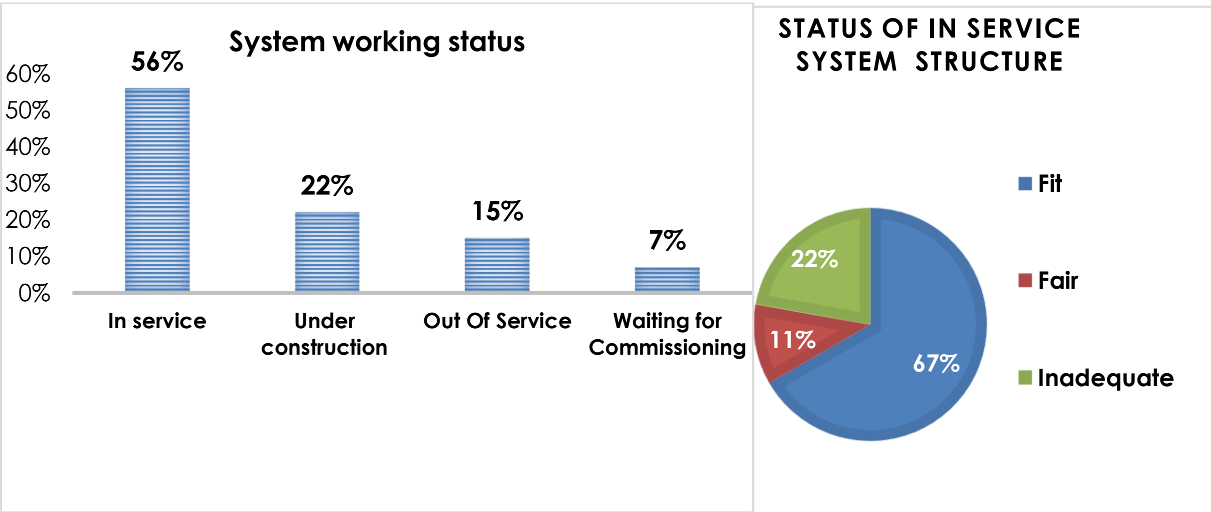


Figure 20: Status of operation of sewage treatment systems in real estates of the City of Kigali

The study has shown that 41% of sewage treatment systems in real estates in Kigali City consist of individual septic tanks against 59% of Semi-centralized systems. The use individual septic tanks challenges the sustainability of sludge management as this requires frequent pumping out of septic faecal sludge for the additional treatment. With regards to the type of treatment technology used, a big number used septic tanks, activated sludge and sequencing (26%) batch reactor (7%) (Figure 21).

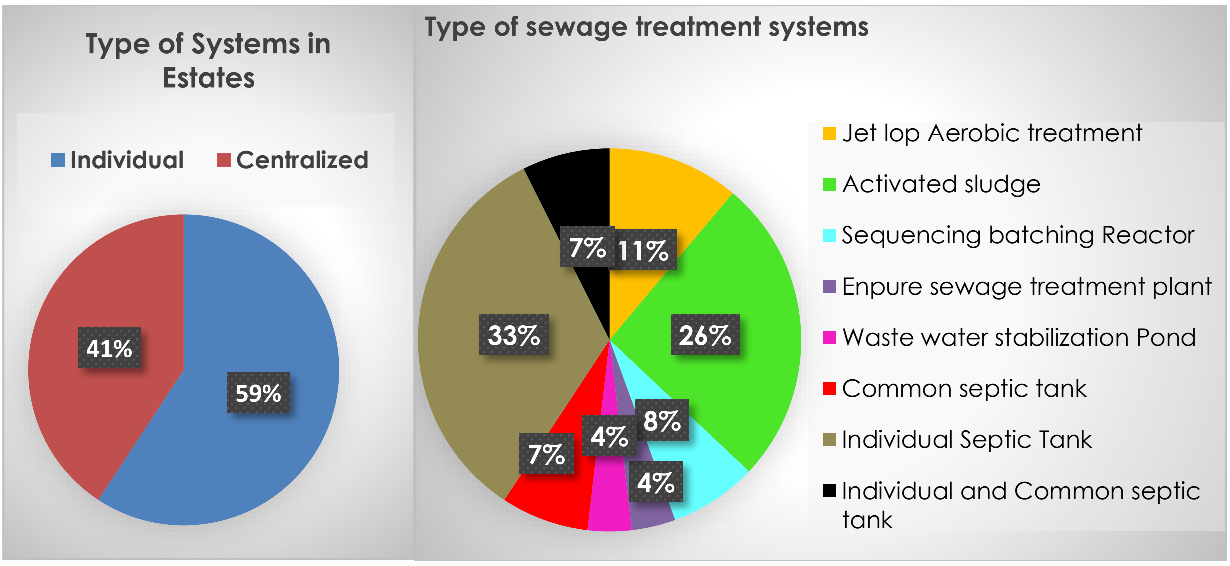


Figure 21: Type of sewage treatment system

With regards to system sizing, the majority (78%) was adequately sized. In terms of the system operation/maintenance responsibility, 37% of the systems were under the responsibility of the owners, 26% under the estate developer, 15% under the contractor, 22% without any person or institution in charge (Figure 22).

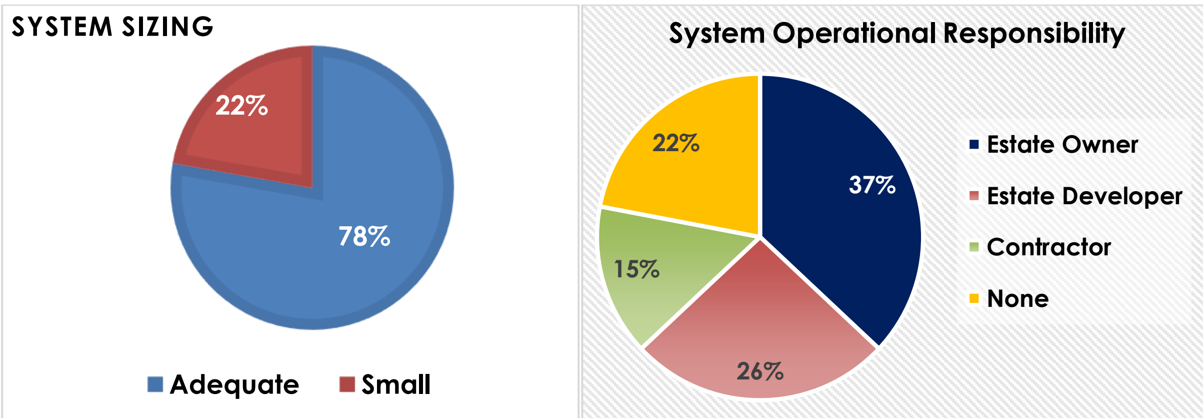


Figure 22: System sizing and responsibility of the system operation & maintenance

About the status of sewer drainage pipeline, only 63% had sound sewer pipeline system, while 15 % had collapsed. About the nuisance state to the surrounding, 70% of all systems had no nuisance to the surrounding (Figure 23).

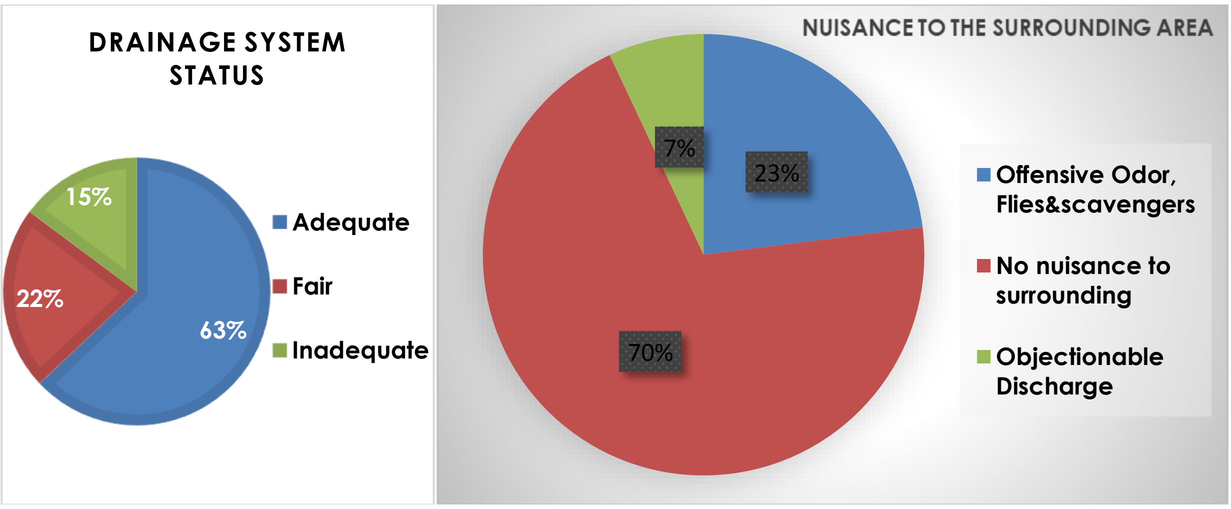


Figure 23: Status of sewage drainage systems and nuisance to the surrounding

About the discharge of wastewater treatment effluent, the majority (70%) of systems discharged their effluent in pits and cesspool. Other systems discharge their effluents in nearby rivers/wetlands (4%) and storm sewers (7%). Others recycled their effluents for irrigation (7%) or for other uses (11%) (Figure 24).

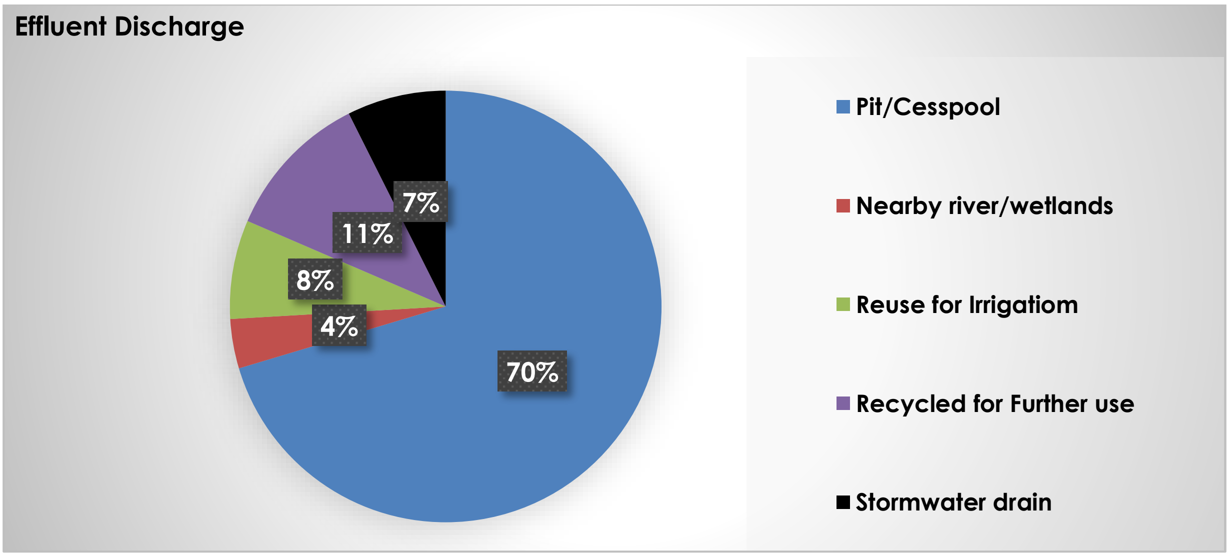
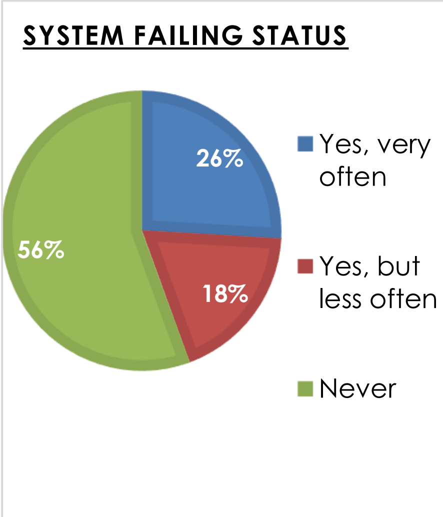


Figure 24: Wastewater treatment effluent discharge environment

With regards to the status of failing of sewer systems, the system owners responded that 56% of all sewage system never failed, 18% fails but less often, and 26% fails very often. The cause for the system failure for most systems was associated with operational and maintenance incapacity: lack of operation and maintenance skills (56%), lack of spare parts (7%) and higher cost of operation and maintenance (4%) (Figure 25).



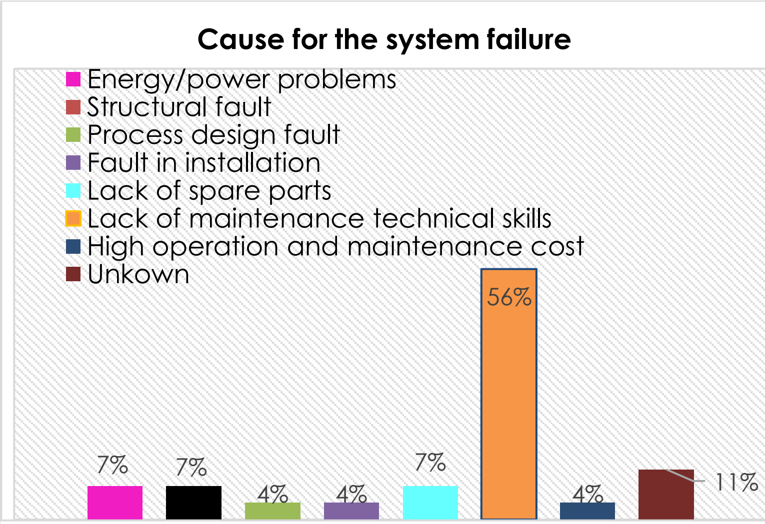


Figure 25: Causes for failing of the Sewage systems

3.3.1.2 Results from Laboratory tests

To complement the operational performance indications from field observations and interviews, samples were taken in the effluent of wastewater treatment plants and collected samples were analyzed in the WASAC Central Laboratory. Note that for some wastewater treatment systems (damaged or out of service or without access to the effluent) the sampling was not done because there was no need or access to do sampling. Sampling was only done for 9 real estates as shown in the sampling plan below (Table below).

Table 10: Sampling plan in different real estates in the City of Kigali

No	Estates and type of sewage treatment plant	Location (District, sector, cell)	Comments on sampling
1	Kabuga hillside housing estate (Jet loop Aerobic treatment)	Gasabo, Rusororo, Nyagahinga	Sampling done
2	Gate Hills Estate I (Sekimondo) (Common Septic Tank)	Kicukiro, Nyarugunga, Kanombe	Sampling done
3	Kacyiru Estate (Activated sludge process)	Gasabo Kacyiru	Sampling done
4	VISION 2020 ESTATE (activated sludge)	Gasabo, Kinyinya, Gacuriro	Sampling done
5	Vision city estate (SBR)	Gasabo, Kinyinya, Gacuriro	Sampling done
6	Kagugu villas housing (Sequencing Batch Reactor/SBR)	Gasabo, Kinyinya, Gacuriro	Sampling done
7	Kami Executive Apartment (Activated sludge process)	Gasabo, Kinyinya, Kagugu	Sampling done
8	Highland Apartment & Suites (individual septic tank)	Gasabo, Remera, Nyarutarama	Sampling done
9	Highland Hotel 1	Gasabo, Remera, Nyarutarama	Sampling done

No	Estates and type of sewage treatment plant	Location (District, sector, cell)	Comments on sampling
10	Gate Hills Estate Ii (Sekimondo) Jet loop Aerobic treatment	Kicukiro, Nyarugunga, Kanombe	No need for sampling as the system was out of service at the time of operation
11	Landmark Apartment (Activated sludge process)	Gasabo, Kinyinya, Kagugu	No need for sampling as the system was out of service at the time of operation
12	Stippestate/Gaposho (septic tanks)	Gasabo, Gisozi	No sampling was done as the access was denied
13	Mountain Ridge Estate (Activated Sludge Treatment)	Gasabo, Rusororo, Kabuga	No need for sampling as the system is not operational as houses are not yet occupied
14	Masaka Hill view estate (Jet loop Aerobic treatment)	Kicukiro, Masaka	No need for sampling as the system is out of service (now individual septic tanks)
15	Sunset estate (Common open pit)	Gasabo, Kimironko, Kibagabaga	No need for sampling as sewage system is damaged and fresh sewage is flowing to the environment
16	Umucyo Estate (Activated sludge process)	Gasabo, Kinyinya, Gacuriro	No need for sampling as the system is not functional
17	Juru Estate (Waste stabilization pond)	Gasabo, Remera Nyarutarama	No need for sampling as the sewage system is damaged and fresh sewage is flowing to the environment
18	Home comfort Estate (Septic tank)	Kicukiro, Rebero	No need for sampling as the system is under construction and not yet functional
19	Cooperative COHAKI (Common septic tank)	Gasabo, Kinyinya, Gasharu	No need for sampling as the system is not yet constructed (now using individual soak way pits)
20	Urukumbuzi Estate (Septic tanks)	Gasabo, Kinyinya, Gasharu	No need for sampling as the system not yet constructed (now using individual soak way pits)
21	Izuba City Estate (Enpure wastewater treatment system)	Gasabo, Kinyinya, Batsinda	No need for sampling as the system is under construction
22	Gate hills Estate III (Individual Septic tanks)	Gasabo, Ndera, Masaro	No need for sampling as the system is under construction
23	Garden estate (Individual Septic tanks)	Gasabo, Kinyinya	No need for sampling as the system is under construction
24	BNR Estate (Individual septic tank)	Kicukiro, Kimisange, Rebero	Sampling is not possible because the system is sealed (no access)
25	Rujugiro Estates (Individual septic tank)	Kicukiro, Gikondo	Sampling is not possible because the system is sealed (no access)
26	Niboye RSSB Kacyiru apartment (Activated sludge process)	Kicukiro, Niboye	No need for sampling because the system is not yet operational (houses not yet occupied)
27	Goboka Estate (Individual septic tank)	Gasabo, Kibagabaga, Kimironko	No need for sampling because the system is not yet operational as it is still under construction

The results from laboratory analysis are shown in the following Tables. In general only one wastewater treatment system (Vision City Estate), complied with National Standards Requirement for tolerance limits for discharged domestic wastewater for all measured parameters (pH, Electrical conductivity (EC), Total Suspended Solids (TSS), Biological Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), Total Phosphorus (TP), Total Nitrogen (TN), Chloride and E-coli).

Other systems were partially compliant as follows:

- Vision City Estate was fully compliant to all parameters
- Highland apartment was uncompliant for E-coli;
- Highland Hotel 1 was uncompliant for E-coli, and TN
- Kami Executive Apartment was uncompliant for only for E-coli and COD;
- Gate hill Estate was uncompliant for E-coli, TSS and TN;
- Kabuga Hillside Estate was uncompliant for E-coli, TSS, TP and TN;
- Vision 2020 was uncompliant for E-coli, TSS, BOD_5, COD, TP and TN;
- Kagugu Villa Estate was uncompliant for E-coli, TSS, COD, TP and TN
- Kacyiru Estate complied only for E-coli, TSS, BOD_5, COD, TP and TN.

More details are shown in the following Tables 11-19 and Annex 4.

Table 11: Results of the characteristics for wastewater treatment plant effluent of Vision City Estate (HICE Consult, 2019).

Parameters	Unit	Effluent	Standards Requirements	Method used
E. Coli	MPN/100ml	1	-	EPA SM 9223
COD	mg/l	64	250	EPA 410.3
BOD_5	mg/l	4.77	50	EPA SM 5210B
PH		8	5.0-9.0	EPA 150.1
TSS	mg/l	4.0	50	HACH 8006
Electrical Conductivity	µS/cm	0.19	-	HACH 8160
Total Nitrogen (TN)	mg/l	12	30	HACH 10072
Total Phosphorus (TP)	mg/l	4.6	5	HACH 8190
Chloride	mg/l	34	-	HACH 8507

Table 12: Results of the characteristics for wastewater treatment plant effluent of Vision 2020 Real Estate (HICE Consult, 2019).

Parameters	Unit	Effluent	Standards Requirements	Method used
E. Coli	MPN/100ml	>2419.6	-	EPA SM 9223
COD	mg/l	256	250	EPA 410.3
BOD_5	mg/l	104	50	EPA SM 5210B
PH		7	5.0-9.0	EPA 150.1
TSS	mg/l	91	50	HACH 8006
Electrical Conductivity	µS/cm	0.19	-	HACH 8160
Total Nitrogen (TN)	mg/l	37	30	HACH 10072
Total Phosphorus (TP)	mg/l	11	5	HACH 8190
Chloride	mg/l	45	-	HACH 8507

Table 13: Results of the characteristics for wastewater treatment plant effluent of Kagugu Villa Estate (HICE Consult, 2019).

Parameters	Unit	Effluent	Standards Requirements	Method used
E. Coli	MPN/100ml	>2419.6	-	EPA SM 9223
COD	mg/l	256	250	EPA 410.3
BOD_5	mg/l	31.2	50	EPA SM 5210B
PH		7	5.0-9.0	EPA 150.1
TSS	mg/l	145	50	HACH 8006
Electrical Conductivity	µS/cm	574	-	HACH 8160
Total Nitrogen (TN)	mg/l	43	30	HACH 10072
Total Phosphorus (TP)	mg/l	6.6	5	HACH 8190
Chloride	mg/l	29	-	HACH 8507

Table 14: Results of the characteristics for wastewater treatment plant effluent of Kami Executive Apartment (HICE Consult, 2019).

Parameters	**Unit**	**Effluent**	**Standards Requirements**	**Method used**
E. Coli	MPN/100ml	>2419.6	-	EPA SM 9223
COD	mg/l	384	250	EPA 410.3
BOD_5	mg/l	3.12	50	EPA SM 5210B
PH		7	5.0-9.0	EPA 150.1
TSS	mg/l	10	50	HACH 8006
Electrical Conductivity	µS/cm	0.13	-	HACH 8160
Total Nitrogen (TN)	mg/l	2.76	30	HACH 10072
Total Phosphorus (TP)	mg/l	3.34	5	HACH 8190
Chloride	mg/l	22	-	HACH 8507

Table 15: Results of the characteristics for wastewater treatment plant effluent of Highland Apartment (HICE Consult, 2019).

Parameters	**Unit**	**Effluent**	**Standards Requirements**	**Method used**
E. Coli	MPN/100ml	>2419.6	-	EPA SM 9223
COD	mg/l	96	250	EPA 410.3
BOD_5	mg/l	10.4	50	EPA SM 5210B
PH		7	5.0-9.0	EPA 150.1
TSS	mg/l	36	50	HACH 8006
Electrical Conductivity	µS/cm	567	-	HACH 8160
Total Nitrogen (TN)	mg/l	8.21	30	HACH 10072
Total Phosphorus (TP)	mg/l	4.3	5	HACH 8190
Chloride	mg/l	20	-	HACH 8507

Table 16: Results of the characteristics for wastewater treatment plant effluent of Gate Hill Estate (HICE Consult, 2019).

Parameters	**Unit**	**Effluent**	**Standards Requirements**	**Method used**
E. Coli	MPN/100ml	>2419.6	-	EPA SM 9223
COD	mg/l	96	250	EPA 410.3
BOD_5	mg/l	13.5	50	EPA SM 5210B
PH		7	5.0-9.0	EPA 150.1
TSS	mg/l	139	50	HACH 8006
Electrical Conductivity	µS/cm	568	-	HACH 8160
Total Nitrogen (TN)	mg/l	60.2	30	HACH 10072
Total Phosphorus (TP)	mg/l	4.9	5	HACH 8190
Chloride	mg/l	35	-	HACH 8507

Table 17: Results of the characteristics for wastewater treatment plant effluent of Kabuga Hillside Estate (HICE Consult, 2019).

Parameters	**Unit**	**Effluent**	**Standards Requirements**	**Method used**
E. Coli	MPN/100ml	>2419.6	-	EPA SM 9223
COD	mg/l	64	250	EPA 410.3
BOD_5	mg/l	15.75	50	EPA SM 5210B
PH		7.5	5.0-9.0	EPA 150.1
TSS	mg/l	131	50	HACH 8006
Electrical Conductivity	µS/cm	140.1	-	HACH 8160
Total Nitrogen (TN)	mg/l	110.4	30	HACH 10072
Total Phosphorus (TP)	mg/l	5.41	5	HACH 8190
Chloride	mg/l	45	-	HACH 8507

Table 18: Results of the characteristics for wastewater treatment plant effluent of Highland Hotel 1 (HICE Consult, 2019).

Parameters	**Unit**	**Effluent**	**Standards Requirements**	**Method used**
E. Coli	MPN/100ml	>2419.6	-	EPA SM 9223
COD	mg/l	192	250	EPA 410.3
BOD_5	mg/l	15.9	50	EPA SM 5210B
PH		7.5	5.0-9.0	EPA 150.1
TSS	mg/l	30	50	HACH 8006
Electrical Conductivity	µS/cm	524	-	HACH 8160
Total Nitrogen (TN)	mg/l	32.9	30	HACH 10072
Total Phosphorus (TP)	mg/l	4.32	5	HACH 8190
Chloride	mg/l	25	-	HACH 8507

Table 19: Results of the characteristics for wastewater treatment plant effluent of Kacyiru Estate (HICE Consult, 2019).

Parameters	**Unit**	**Effluent**	**Standards Requirements**	**Method used**
E. Coli	MPN/100ml	>2419.6	-	EPA SM 9223
COD	mg/l	256	250	EPA 410.3
BOD_5	mg/l	115.6	50	EPA SM 5210B
PH		7	5.0-9.0	EPA 150.1
TSS	mg/l	304	50	HACH 8006
Electrical Conductivity	µS/cm	637	-	HACH 8160
Total Nitrogen (TN)	mg/l	54	30	HACH 10072
Total Phosphorus (TP)	mg/l	12	5	HACH 8190
Chloride	mg/l	0.53	-	HACH 8507

3.3.1.3 Discussion of results of wastewater treatment effluent characteristics from laboratory tests

The results from laboratory tests for wastewater treatment effluents for real estates in the City of Kigali have shown that only one system complied with the National Standards Requirement for tolerance limits for discharged domestic wastewater for all measured parameters (pH, Electrical conductivity (EC), Total Suspended Solids (TSS), Biological Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), Total Phosphorus (TP), Total Nitrogen (TN), Chloride and E-coli).
Note that the uncompliant effluent to the National Standards Requirement for tolerance limits for discharged domestic wastewater has serious consequences to the environment and humans.

- pH out of the guidelines degrade the quality of water for domestic and agricultural uses, destroys the biological properties and microflora and fauna in soil and water and stresses some types of biodiversity that are not adaptive to low or high pH conditions;
- TSS out of the guideline is unaesthetic to the receiving water, reduce the level of dissolved oxygen in water bodies and lead to clogging of fish gills;
- Nitrogen out of the guideline accelerates eutrophication in water bodies and becomes toxic to aquatic life and humans;
- Phosphorus out the guideline accelerate the eutrophication in water bodies;
- BOD and COD out the guideline reduce the level of dissolved oxygen in water bodies that leads to bad smells and toxicity to aquatic life;
- EC and chloride lead to the salinity of water and soil that further degrade the fertility of soil and stress to some types of biodiversity.

The results by WASAC (2017) showed that:

- Only one system (septic tanks for the Stippestate/Gaposho with the effluent disposed in pits) did not have any operational and maintenance problems;
- Two systems (Kabuga Hillside Estate and Kagugu Villa Estate) complied with many parameters for tolerance limits for discharged domestic wastewater, except for TP and faecal coliforms (Kagugu Villa Estate) and TN and faecal coliforms (Kabuga Hillside Estate).
- Some systems (Landmark apartment and Rujugiro Estates) had inaccessible inlets and outlets;
- Some (Vision 2020, Kacyiru Estates and Sekimondo/Gate Hill Estates) were illegally carrying the storm water;
- BNR Estate and Urukumbuzi Estate had sewage systems with operational and maintenance problems; ranging from Storm water illegal connection, discharge of untreated grey water to the storm drains or malfunction of some components
- Umucyo Estate, Juru Estate, Sunset estate, Gate Hill Estate, Kami Executive apartment and Masaka Hill view Estate were not operational due to lack of ownership and regular maintenance, while grey water from Urukumbuzi, houses were directly discharged into the storm water drainage;
- Others were not operational or under constuction (Mountain Ridge estate, Comfort Home Estate, Cooperative Cohaki Estate, Gahanga Complex Apartment, Karumeyi Village Estate).

In the time of our sampling (2019), the Vision City, which was under construction during the WASAC study (2017), was the sole estate with a wastewater treatment system, fully compliant with the environmental discharge. Note also that Kagugu Villa Estate that was uncompliant for only two parameters (TP and E-Coli) became, uncompliant for five parameters (E-coli, TSS, COD, TP and TN) in 2019. Similarly, Kabuga Hillside Estate that was uncompliant for only two parameters (TN and E-coli) during the WASAC study (2017), became uncompliant for four parameters (E-coli, TSS, TP and TN) during our study in 2019). This explains well the need for regular monitoring to ensure the continuous of performance of wastewater treatment systems.

It is also shocking that systems like Juru Estate and Sunset estate that were discharging untreated faecal material in 2017 during WASAC study were still discharging them two years later (2019). This point out the lack of ownership and enforcement of sanitation strategies and environmental laws.

3.3.2 Performance indicators of existing fecal sludge management in Real Estates of CoK

Sewage treatment systems produce the treated effluent and residues that need appropriate disposal. The field survey has shown that only 50% of real estates reused the treatment plant residue as compost for gardening and for small scale agricultural production (Figure 26a). 25% of the real estates disposed the residues in pits, 13% transferred them to Nduba Dumping site, while the remaining 12% remains in the treatment system. With regard to the suggested management technologies for the fecal sludge, 44% of the real estate operators have suggested fecal sludge should be reused in agriculture, 19% as biomass fuel, 15% for biogas production, 11% contained in pits, 7% transported to landfill (Figure 26b).

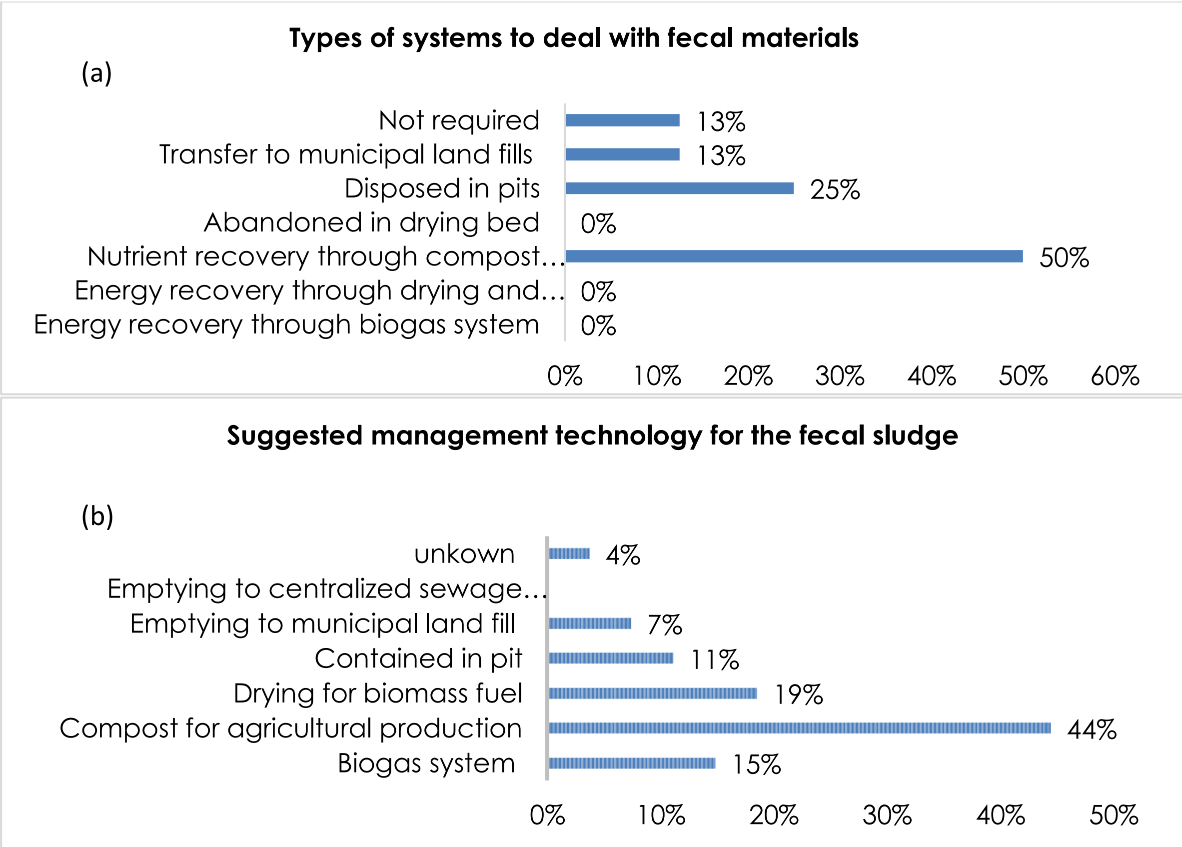


Figure 26: Existing management practices of fecal sludge in real estates of CoK (a) and suggested fecal sludge management practices (b)

3.3.3 Comparison of the performance of sewage treatment technologies in estates based on system structural integrity and presence or absence of hygiene and offensive odors

Based on visual judgement, the survey has shown that some systems are structurally fit, have adequate drainage, do not have no objectionable discharge, odours and flies. All these are the Activated sludge reactor. The estates with those systems were:

- Kabuga hillside estate (Activated sludge reactor; Figure 27)
- Kacyiru Estate (Activated sludge reactor)
- Mountain Ridge Estate (Activated sludge reactor)
- Gate hills Estate II (Activated sludge reactor)
- Land mark apartment (Activated sludge reactor)
- Vision City Estate (Sequencing Batch Reactor)

Figure 27: Kabuga hillside estate well operating sewage treatment system

Other estates had systems that often had operational problems ranging from inappropriate design, poor system maintenance, and lack of spare parts, objectionable effluent discharge, odours and flies. Estates with systems fairly working or fail sometimes are:

- Vision 2020 Estate (Activated sludge reactor/Mixture of storm and dry flow)
- Umucyo estates (Activated sludge reactor/Lack of maintenance technical skills)
- Kagugu villas Housing Estate (Sequencing Batch Reactor/fairly working with objectionable discharge, lack of spare parts and maintenance services)
- Kami Executive apartment (Activate sludge treatment plant/objectionable odours and flies due probably to process design fault and inadequate maintenance)
- Nduba Dumping site (open pits/objectionable odours, flies, etc

There were estates with systems out of service. These are:

- Masaka Hill view estate (Activated sludge reactor/Poor design, lower capacity)
- Sunset Estate (Common open pit/tank/lack of maintenance)
- Juru Estate (sewer system destroyed, no maintenance services for the sewer and Waste water Stabilization Pond)

While Masaka Hill view estate wastewater system was designed with critically lower capacity (≈4 households of the 29 households it is hosting; Figure 28), Sunset and Juru estates suffered from lack of maintenance services (Figure 29, Figure 30). At the time of survey, the sewer systems for Sunset and Juru had collapsed and fresh faecal materials were discharged in open space. At the time of survey (August 2018) Masaka Hill view estate was relying on household individual septic tanks.

Figure 28: Masaka Hill view estate sewage treatment system out of service

Figure 29: Sunset untreated wastewater discharge in ponds

Figure 30: Juru estate Fresh faecal material discharge to open environment

The survey has identified Estates that rely on individual septic tanks and soak away pits with regular sludge emptying. Those are:

- Urugero Etate
- Gate hills I
- Comfort home Estate (under construction but objectionable odours and flies from the temporal system)
- Cooperative COHAKI Estate (inadequate common septic tank)
- Urukumbuzi Estate
- Garden Estate

3.4 Status of other wastewater treatment systems across the country

3.4.1 Current situation

3.4.1.1 Public institutions and places

- **Modern market and tax parks**

Pour flush toilet, ventilated improved latrines and flush toilets connected to the soak away pits and were found the most used systems in modern markets and tax parks (Figure 31a). Only Musanze and Nyarugenge markets used modern on-site wastewater treatment systems (activated sludge treatment or sequencing batching reactor) (Figure 31b).

Figure 31: Septic tank for toilet at Muhanga Tax Park (a) and WWTP Found at Musanze Modern market (b)

Private operators do the emptying of faecal sludge from pit and septic tanks manually or mechanically using vacuum pumps mounted within the emptying trucks. The emptied faecal sludge is disposed in landfill, agricultural lands or in unknown places.

- **Schools and Hospitals**

Similarly, to markets and tax parks, wastewater either black or grey water from Schools and hospitals were mostly disposed in septic tank or soak pits (Figure 32). Few buildings have onsite package sewage treatment systems (Figure 33). The emptying service of faecal sludge is done manually or mechanically. The University of Rwanda has his own suction truck for this service. Other institutions have a one-year contract service for emptying services.

Figure 32: Septic Tank for wastewater pre-treatment at UR Nyarugenge

Figure 33: Jet lop Treatment system under construction at Byumba Hospital

3.4.1.2 Prisons

All surveyed prisons had biogas system as a treatment technology for the black water (Figure 34). The types of toilets used are pour flush toilet draining in reticulation system connected to biogas digester. The biogas sludge is discharged to pit for settling and separation of supernatant liquid and sludge. The supernatant liquid (effluent) is discharged to cesspool/pits and reused for agriculture purpose or discharged to open space. The operation and maintenance of biogas systems is in charge of Rwanda Collection Service. There were no adequate technologies for treating the grey water or discharged to open space or in pit. The exception is at Mageragere prison where the grey water was discharged to constructed wetland. Most of system structures were in good condition.

Figure 34: Biogas System at Miyove Prison in Gicumbi District (a), sludge Drying bed in Nsinda prison (b), open dying be at Nsinda prison and Wastewater reused for Crop irrigation at Rubavu prison (c)

a. NYARUNGENGE PRISON

Estate Name:	Nyarugenge prison	**Number of Population:** 8,700	
Location	District:	Nyarugenge	
	Sector:	Mageragere	
	Cell:		-
Treatment technology for Black water:	Biogas System	**Treatment capacity (PE):** 10,000	
Treatment technology for Grey water	Constructed wetland	**Treatment capacity (PE):**	-

Brief Description of treatment system

Black water from toilets is conveyed by drainage system up to 10 biogas digesters of sewage capacity of 1000 persons (Figure 35). At inside of digester, bacteria convert organic waste into methane gas through the process of anaerobic digestion. The methane gas is used for cooking purpose where Effluent and sludge from biodigester are discharged to desludging tank effluent and sludge separation. Sludge are used as agriculture manure where effluent water is discharged to Cesspool.

Waste water from kitchen and showers is conveyed into constructed wetlands, designed to receive and treat water from showers and kitchen separately before it is discharged into environment. Sludge from primary treatment tank and from grit removal chamber is removed and composted for agriculture purpose. The efficiency of constructed wetland was low as the effluent was very turbid and smelt. This inefficiency is due to the system low detention time. Note the constructed wetlands were also designed to receive effluent from Biogas system, but the system has not yet received it.

Indicators of the status of the wastewater treatment system

Type of system:	**Semi-centralized**
Operation cost:	**Under defect liability period**
Source of operation Cost	**RCS**
Status of the structure of the system:	**Fit**
System sizing:	**Adequate**
Drainage system:	**Adequate**
Nuisance to the surrounding:	**No**
Sludge treatment & disposal;	**Existing**
Effluent disposal	-

System illustrative Photos

Figure 35: Components of Mageragere sewage treatment system: Constructed wetland (a), Series of Biogaz Digestor tank(b), effluent receiving pit before to be discharged into environment (c) and Influent receiving tank (d)

b. MPANGA PRISON

Site Name:	MPANGA PRISON	**Number of populations:**	7069
Location	District:	Nyanza	
Treatment technology for Black water:	**Biogas System**	**Treatment capacity (PE):**	1000
Treatment technology for Grey water	**No treatment**		

Indicators of the status of the wastewater treatment system

Type of system:	**Semi-centralized**
Operation cost	**-**
Source of operation Cost	**Rwanda Correction Services**
Status of the structure of the system:	**Fit**
System sizing:	**Adequate**
Drainage system:	**Adequate**
Nuisance to the surrounding:	**No nuisance to the surrounding**
Sludge treatment & disposal;	**Existing**
Effluent disposal	**Biogas system**

System illustrative Photo

Figure 36: Sewage treatment in Mpanga prison

c. MUHANGA PRISON

Site Name:	MUHANGA PRISON	**Number of population:**	5842
Location	District:	Muhanga	
	Sector:	Nyamabuye	
	Cell:	Gitarama	
Treatment technology:	Biogas systems	**Treatment capacity (PE):**	1,000 cum

Brief Description of treatment system

The Prison has a skilled and permanent technician for the biogas system. Cow dung and faecal materials are mixed together to produce the biogas. However, the system has low sewage handling capacity.

Indicators of the status of the wastewater treatment system

Type of system:	**Semi-centralized**
Operation cost	**-**
Source of operation Cost	**Rwanda Correction Services**
Status of the structure of the system:	**Inadequate**
System sizing:	**Adequate**
Drainage system:	**Adequate**
Nuisance to the surrounding:	**No nuisance to the surrounding**
Sludge treatment & disposal;	**Existing**
Effluent disposal	**Biogas system**

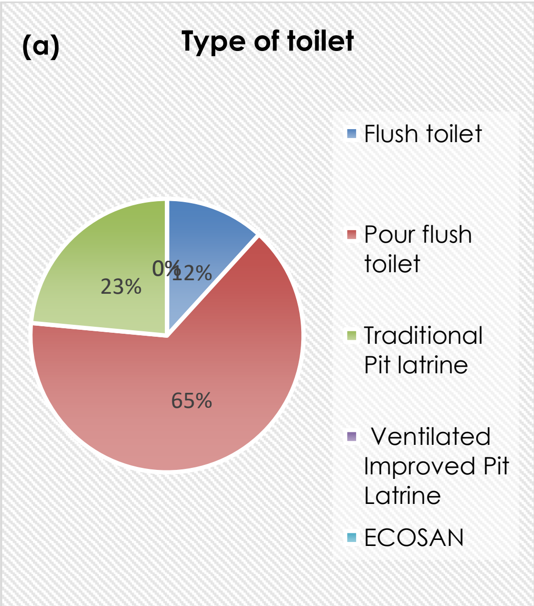
System illustrative Photo

Figure 37: Biogas system in Muhanga prison

3.4.2 Performance indicators of existing wastewater treatment systems across the country

3.4.2.1 IDP Model Villages

Pour flush toilets were the most used (65%) toilets in IDP Model Villages (Figure 38a). Other systems are traditional pit latrines (23%) and flush toilets (12%). As shown in Figure 40b, the fecal material from toilets were discharged into soak away pits (53%), pit latrines (18%), biogas system (18%) and septic tanks connected to leaching pits.



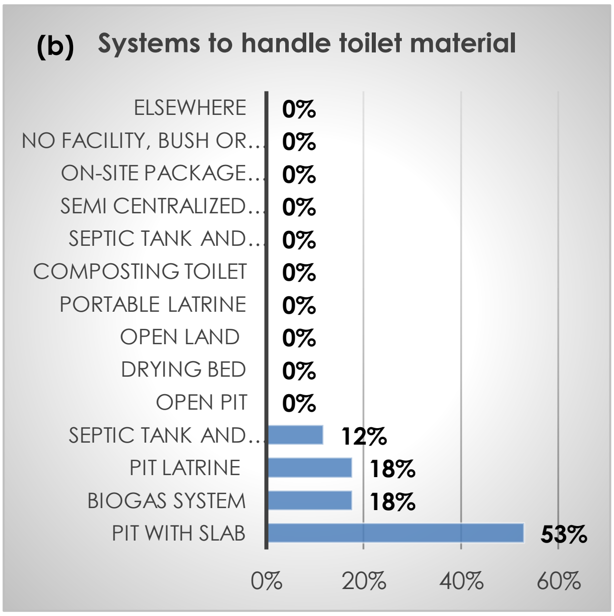


Figure 38: Types of toilets (a) and systems to handle faecal material from toilets (b) in IDP Model Villages across the country

3.4.2.2 Slums

Traditional pit latrines were the most used (65%) toilets in slums (Figure 39a). Other types of systems are flush toilets (15%), pour flush toilets (11%) and ventilated improved latrines (9%)(Figure 39a). As shown in Figure 39b, the fecal material from the toilets were disposed in pit latrines (78%), pits covered with concrete slab (15%) and septic tanks connected to leaching pits (7%).

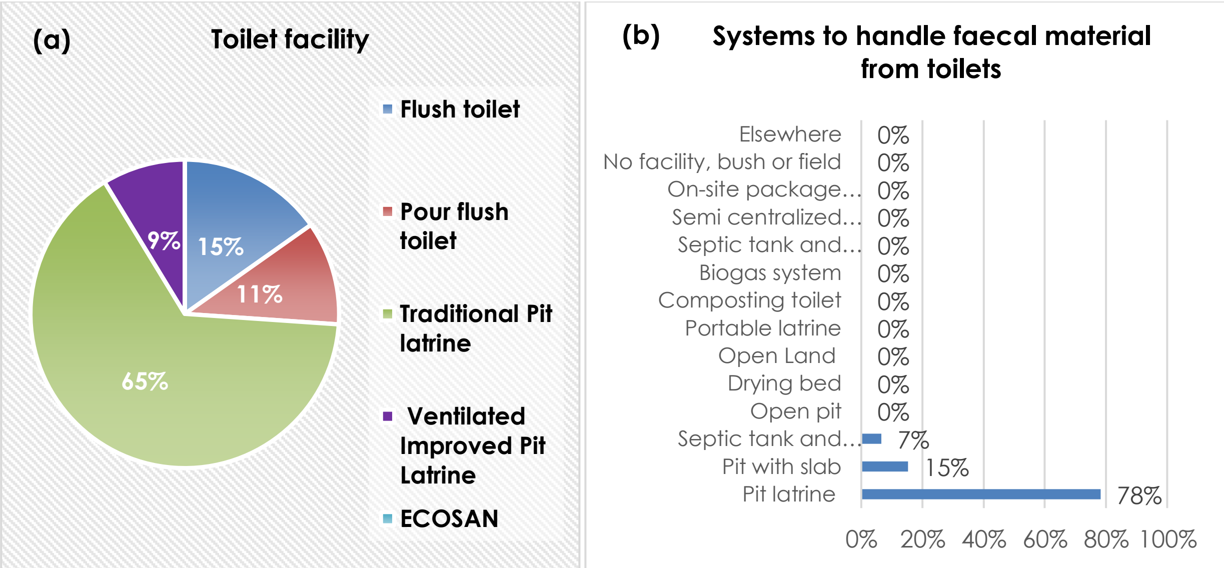


Figure 39: Types of toilets (a) and systems to handle faecal material from toilets (b) in slums across the country

3.4.2.3 Settlement and centers

The most used types of toilets in settlements and centres were traditional pit latrines (53%). They were followed by pour flush toilets (27%), flush toilets (13%) and ventilated improved latrines. Systems to handle/dispose fecal material from toilets are pit latrines (73%), septic tank and leaching pits (13%) and pits covered with slab (Figure 40).

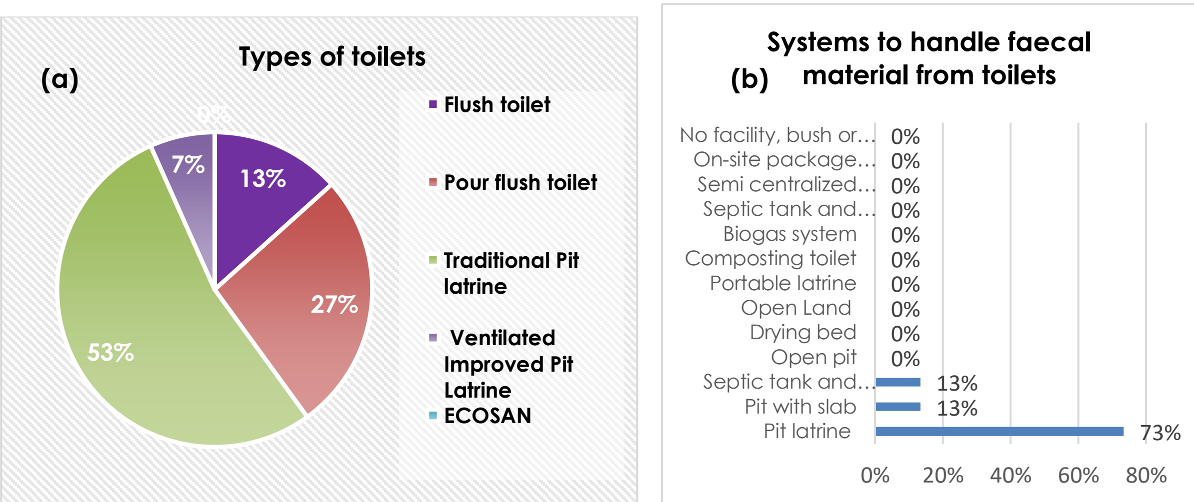


Figure 40: Types of toilets (a) and systems to handle faecal material from toilets (b) in settlements and centres across the country

3.4.2.3 Public Institutions and markets

The most used types of toilets in public institutions and markets were pour flush latrines (47%) and flush toilet (41%) (Figure 41a). Other types of systems are ventilated improved latrines (12%) and ECOSAN latrines (6%). The majority (70%) of public places used septic tanks to treat fecal material from toilets. The activated sludge process and sequencing batch reactor were used in 13% and 7% of public places respectively. The rotating batch reactor was used in 7% of public places (Figure 41b).

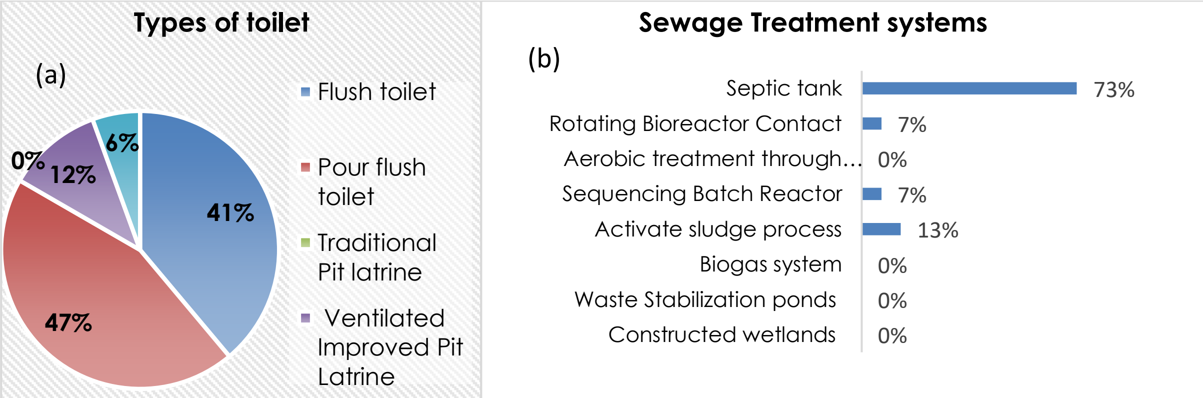


Figure 41: Types of toilets (a) and systems to handle faecal material from toilets (b) in public places

The survey has shown that 50% of the public places use on-site Semi-centralized systems, 33% individual and 17% a combination of Semi-centralized and individual systems (Figure 42a). With regards to the status of system, 50% was sanitation systems was structurally fit, 33% structurally fair, 17% inadequate (Figure 42b). With regards to the system sizing, 70% of sanitation systems was adequately sized (Figure 42c). With regards to the status of the sewer pipelines (drainage system), 50% of the sewage system was inadequate; against 28% that was fair and 22% inadequate (Figure 42d).

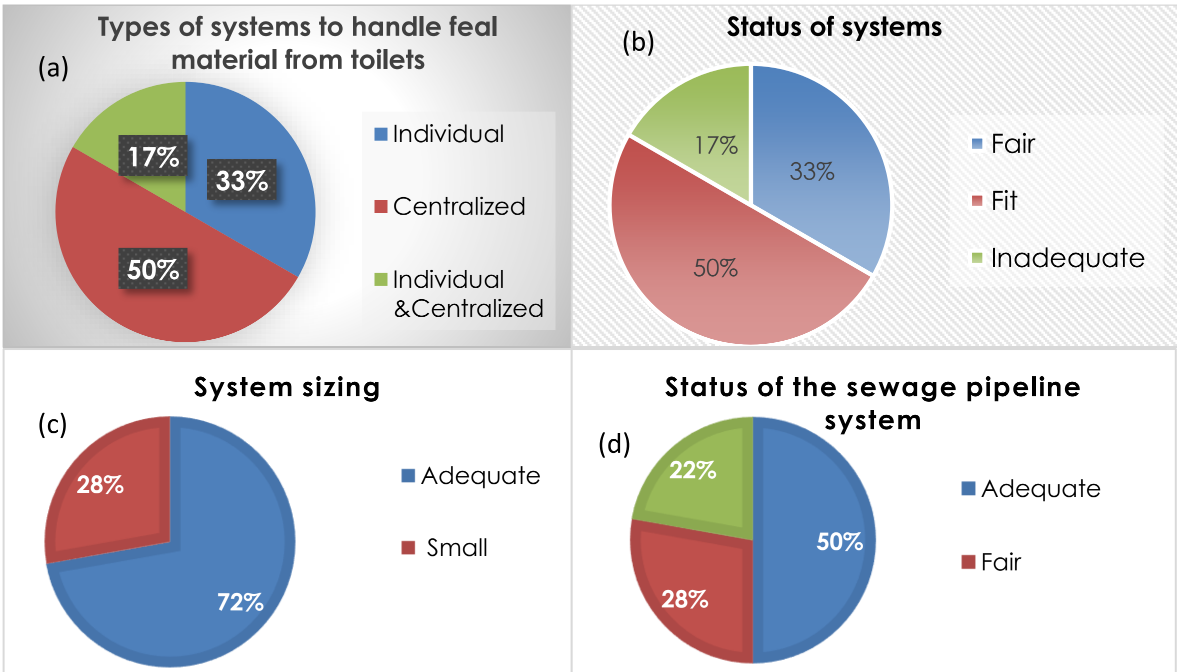


Figure 42: Types and status of sewage systems in public places

With regard to the system nuisance to the surrounding, 61% of the public places sewage systems did not have any nuisance to the surrounding environment (Figure 43). 22% had offensive odors, 11% had flies and scavengers while 6% had objectionable discharge.

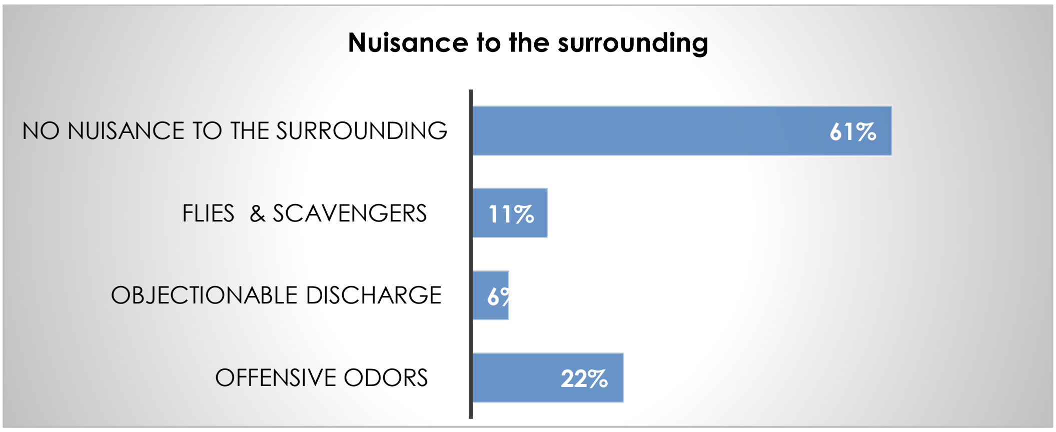


Figure 43: System Nuisance to the surrounding

Pumping out to the landfill was the most important practice (47%) used to dispose the fecal sludge from the public places (Figure 44b). Other practices are disposal in pits (29%), composting (12%) and agricultural land application (12%).

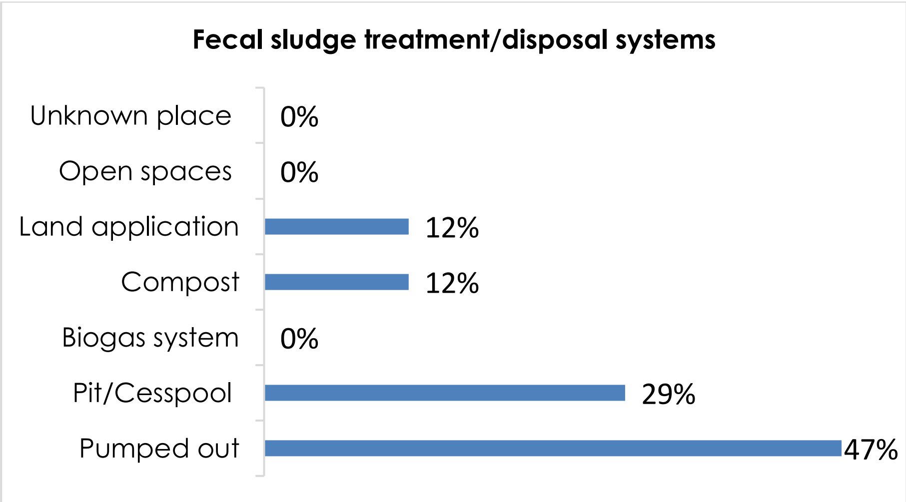


Figure 44: Faecal sludge treatment and disposal systems

3.4.2.4 Prisons

Most of surveyed system (75%) was structurally fit. The remaining 25% unfit suffered from the lack of maintenance services. Some had observed to have small of the size compared to available population. Looking on the pie chart 63% has adequate size where 37% has inadequate system sizing.

3.4.3 Comparison of sewer treatment system across the country

Apart from estates in the City of Kigali, countrywide field surveys (observations and interviews) were conducted at different places. Field observation and interview with the operators indicated that some sewage treatment systems were apparently satisfactorily working, others failing, irrespective to the types of sewage systems. Note that no sampling and laboratory tests for effluents from wastewater treatment systems were done. Therefore, the performance given here below takes into account the system structural integrity, presence or absence of hygiene, flies and offensive odours.

Apparently, the systems found to be satisfactorily working are listed below, with types of system and some key problems in parenthesis.

- Amahoro national stadium (Septic Tank)
- Nyagatare prison (Biogas system)
- Nyagatare (Mirama Landfill, Lamella sewage treatment system)
- Ayabaraya Model Village I (VIP Latrines, maintenance services hardly available)
- Ayabaraya Model Village II (Septic tank and leaching pits, fairly available maintenance services)
- Ayabaraya Model Village/MINADEF Funded (VIP Latrines, fairly available maintenance services)
- Rebero Estate (Septic tank and leaching pits)
- Rebero Cubelion Estate (Septic tank and leaching pits)
- Comfort Home Estate (Septic tank and leaching pits)
- Umutuzo Model Village/Musanze (Biogas system)
- Musanze Modern Market (Activated Sludge Reactor)
- Umutuzo Model Village/Musanze (Biogas system)
- Mpanga Prison (Biogas system, reuse of sludge as a compost)
- Rubavu Prison/Nyakiriba (Biogas system)
- Bahimba Model Village/Rubavu (VIP latrines with soak away pits, but maintenance services fairly available)
- One Stop Border Post/Rubavu (Septic tank with soak away pits)
- Byumba hospital (Septic tank and leaching pits)

The systems that are fairly working are:

- IPRC / Kigali (Inadequate sewer system, objectionable discharge, high operation and maintenance cost related to sewer system, Septic Tank/leaching pits);
- UR-CBE, Gikondo Campus (small system with Septic tank and leaching pits, lack of spare parts/higher maintenance cost, unaesthetic environment during septic sludge pumping out
- Nyabiheke refugees camp (VIP latrines, pit with slab, small system, high operation and maintenance cost, bad odours and diseases during faecal sludge pumping out)
- Nyagatare market (Septic tank)
- Mirama Village/Nyagatare (traditional pit latrines)
- IDP RwabiharambA/Nyagatare
- Muhima slum (fairly to poorly installed and maintained septic tank/soak away pits & traditional pit latrines, Offensive odors, higher emptying or replacement cost)
- Gatsata slum (fairly to poorly installed and maintained septic tank/soak away pits & traditional pit latrines, Offensive odors, higher emptying or replacement cost)
- Musanze prison (fair biogas and sewer systems, High operation and maintenance cost)
- Tete Gauche Slum/Musanze (traditional pit latrines, objectionable discharge, offensive odors, not sludge emptying practices/ pit closing)
- Nyanza Hospital (Small sized septic tank and leaching field, inadequate sewer system, faecal sludge material pumped out to open space
- G.S Nyanza (Septic tank and leaching pits, inadequate sewer system)
- Ruvumera slum (traditional pit latrine, septic tanks/soak away pits)
- Mahoko Trading Center (VIP latrine system, offensive odors, lack of maintenance technical skills)
- Handcraft Phase II (Septic Tanks, structure fairly adequate)
- Handcraft Phase II (Septic Tanks, structure fairly adequate)

- IDP Kabeza (septic tanks/soak away pits, Inadequate sewer system, offensive odors and flies, maintenance services fairly available)
- Miyove Prison (Biogas, small system, faults in Structure, inadequate sewer system, maintenance services hardly available)

The inadequate systems:

- UR/CST, Nyarugenge campus (very old and small sized septic tanks/leaching pits, offensive odours during routine septic tank operation and emptying , high operation and maintenance cost)
- Kimironko Modern market (Ecosan, small, fault in installation, offensive odours and Flies)
- Nyabinyenga IDP model /Nyanza (individual septic tanks/cesspool, process design fault, offensive odours, inadequate sewage drainage
- Nsheke Village/Nyagatare (Collapsed some pit latrines, Flies & scavengers)
- Byahi Centre/Rubavu (Inadequate Pit Latrines, Flies & Scavengers)
- Mbugangari Market/Rubavu (Inadequate Pit latrines, Flies & scavengers)

3.5 Current situation of feacal sludge management in Kigali City and other provinces

3.5.1 Nduba Dumping site

Site Name:	Nduba municipal Landfill	
Location	District:	Gasabo
	Sector:	Nduba
	Cell:	Muremure
Treatment/recycling/reuse/disposal technology:	**None**	

3.5.1.1 Description of disposal system

This is the only landfill in Kigali city. It is located at North East of Kigali at Gasabo District, Nduba Hill at Muremure cell at 10 Km from Kigali Center. It receives all solid and liquid waste collected in Kigali city.

Pumped sewage from septic tank, toilet, soak away pits is disposed into series of pits shown in Figure 45. These pits are located on the top of the hill and if it rains heavily, they are likely to overflow and spread into the neighbourhood and contaminate water and crops. This can lead to spread of disease to the neighbouring population. The system of collection in pits does not give a fair and sustainable solution as many pits are required to accommodate that liquid waste.

Nduba Dumping site receives fifteen suction trucks of 20 cubic meters per day and each truck is charged the amount of 5,000 Rwf for discharging. There is no sewage treatment system at the place but four open ponds. These ponds alternately receive and treat the sewage merely through percolation and evaporation.

3.5.1.2 Indicators of the status of the wastewater treatment system

Land fill operator:	**Reserve force**
Status of the structure of the system:	**Not fit**
System sizing:	**Not enough**
Drainage system:	**Inadequate**
Nuisance to the surrounding:	**Offensive odours**
Sludge treatment & disposal;	**Not Existing**

Effluent disposal	**Pit**

System illustrative Photos


Figure 45: Nduba municipal Landfill components

3.5.1.3 Criteria for the proper operation of the system

One of the challenges for the proper operation of the Nduba sewage system is higher trash load. Leaving the trash behind in the pit or provide a system for screening the trash at the reception could avoid messy trash at the Nduba sewage offloading site. It is possible to put in place a vacuum system to dewater faecal sludge to some extent to prepare sludge to be dealt with more efficiently in subsequent treatment stages like co-composting with other biodegradable organic wastes and Char Briquette making. More details about composting processes are found in section 2.3.3.2 and 2.3.3.3. The biogas production from faecal sludge is another option to be explored, provided that the biogas could be efficiently usable and cost effective.

3.5.2 Fecal Sludge Management in Nyanza, Nyagatare, Kayonza and Gicumbi Landfills

3.5.2.1 Description of the systems

Under the Lake Victoria Water Supply and sanitation Program Phase II, Construction of fecal sludge treatment plant was implemented in cities of Nyagatare, Kayonza , Nyanza and Gicumbi (under construction) landfills. In these landfills, the fecal sludge is treated though a number of stages involving (Figure 46):

- **Pretreatment** (Screening and Grit removal);
- **Thickening (**Screw press or Disc thickener);
- **Liquid phase treatment** (Lamella compact system or equivalent);
- **Solar Drying beds** (green house in polycarbonate);
- **Evacuation** (composting area for treated sludge and infiltration pit for wastewater) and leachate treated phase.

3.5.2.2 Indicators of the status of fecal sludge treatment systems

Land fill operator:	**WASAC**
Status of the structure of the system:	**Fit**
System sizing:	**Adequate**
Nuisance to the surrounding:	**Bad odor**
Effluent disposal	**Pit**

Nyagatare landfill is managed by the District where received feacal sludge is treated to get manual for agriculture purpose and dewatered water is treated and discharged into infiltration pit. Nyagatare District is planning to procure for private operator for the fecal waste treatment plant management, development, operation and maintenance of the installed plant as well as collection and transportation of fecal waste from the households. Kayonza landfill construction works were completed during our survey but it was not yet receiving feacal sludge for treatment. We get information that district was procuring for private operator to manage this land fill. During our survey Nyanza land fill was at the end of construction but waiting for commissioning. Gicumbi land fill was under construction.

System illustrative Photo

Figure 46: Components of Faecal sludge treatment systems for Nyagatare, Kayonza, Nyanza and Gicumbi landfills including grit removal (a), Screw press for thickening sludge(b), Green house for solar drying bed (c), infiltration pit for wastewater (d), Waste water treatment chamber (e), Treated and stabilized Sludge (f).

3.5.2.3 Criteria for the proper operation of the system

One of the challenges for the proper operation of sewage systems in landfills of Cities of Nyagatare, Kayonza, Nyanza and Gicumbi is the lack of required technical skills and budget for the running and maintaining the systems in sustainable ways. To be sustainable, the systems should be cost effective through the production of marketable and economic products like biogas production, co-composting with other biodegradable organic wastes and char briquette making. More details about composting processes are found in sections 2.3.3.1, 2.3.3.2 and 2.3.3.3. The biogas production is also another option of the management of the faecal sludge provided that the biogas could be efficiently usable and cost effective.

4 SELECTION OF APPROPRIATE SEWAGE AND FAECAL SLUDGE TREATMENT TECHNOLOGIES

4.1 Selection process

The methodology adopted when selecting the appropriate technologies for sewage and faecal sludge treatment is summarized in Figure 47. The process starts through literature review aiming at setting the criteria to evaluate different technologies. Weights are assigned to each indicator according its magnitude or importance (Table 3). For each technology, weights of the considered indicators will be summed up and technologies ranked and screened according their relative scores. The selected appropriate technology will be the one with the highest score.

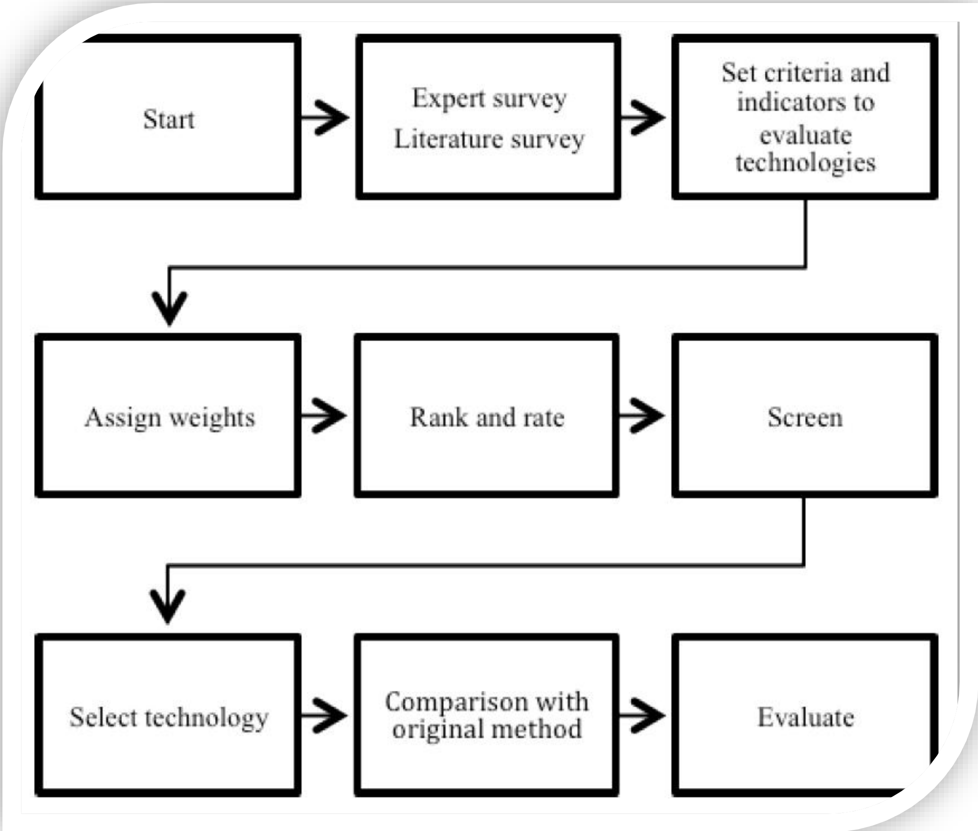


Figure 47: *Process for selection of the best sewage and faecal sludge treatment technology*

4.2 Multi-criteria decision analysis

Selecting the most suitable wastewater treatment technology is not only about providing the best technical solution at the lowest cost. It is also about sustainability (including social and environmental acceptance) and institutional feasibility. Because of the complexity of the task, a multi-criteria decision analysis technique was used to compare and rank the wastewater treatment technology alternatives against the identified technical, socio-economic, and environmental objectives.

The Multi Criteria Analysis (MCA) is a methodology widely used to support the decision-making processes. The tool allows clearing up complicated dilemma with multi-faceted characteristics. This is made by assessing the different elements of the problem and afterwards classifying them according to their relevance. Therefore, the MCA provides to the decision makers a comparison and evaluation of the elements of the processes. MCA are not only able to compare quantitative and qualitative aspect but also to compensating possible conflicts of contradictory criteria (Singhirunnusorn, 2009).

4.2.1 Types of Multi Criteria Analysis

There are plenty of different MCA methodologies based on complex mathematical models. Almost all decision analysis methodologies share similar steps of organization in the construction of the decision matrix. Each MCA methodology synthesizes the matrix information and ranks the alternatives by different means (Yoe 2002). Different methods require diverse types of value information and follow various optimization algorithms. Some techniques rank options, some identify a single optimal alternative, some provide an incomplete ranking, and others differentiate between acceptable and unacceptable alternatives.

Among the MCA, the Multi attribute utility theory or multi attribute value theory (MAUT/MAVT) and the analytical hierarchy process (AHP) are widely used. They employ numerical scores to communicate the merit of one option in comparison to others on a single scale. Scores are developed from the performance of alternatives with respect to an individual criterion and aggregated into an overall score. Individual scores may be simply summed or averaged, or a weighting mechanism can be used to favor some criteria more heavily than others.

The goal of MAUT/MAVT is to find a simple expression for decision-maker preferences. Through the use of utility/value functions, the MAUT method transforms the diverse criteria such as cost, risks, and stakeholder acceptance into 1 common dimensionless scale (typically 0–1) of utility or value. Utility functions for each criteria convert the criteria units into the 0 to1 utility scale and are combined with weighting functions of the criteria within the overall decision to form a decision score for each alternative. MAUT also relies on the assumptions that the decision maker is rational (e.g. more utility is preferred to less utility), preferences do not change, and the decision maker has perfect knowledge and is consistent in his or her judgments. The goal of decision makers in this process is to maximize utility/value, which makes this a compensatory optimization approach.

Like MAUT, AHP is a compensatory optimization approach. However, AHP uses a quantitative comparison method that is based on pairwise comparisons of decision criteria rather than utility and weighting functions. All individual criteria must be paired against all others and the results compiled in matrix form. In AHP method, it would require the decision maker to answer questions with respect to the selection of alternative, which is more important, public acceptability or cost. The user uses a numerical scale to compare the choices, and the AHP method moves systematically through all pairwise comparisons of criteria and alternatives. The AHP technique thus relies on the supposition that humans are more capable of making relative judgments than absolute judgments. Consequently, the rationality assumption in AHP is more relaxed than in MAUT.

Unlike MAUT and AHP, outranking is based on the principle that one alternative may have a degree of dominance over another (Kangas et al. 2001) rather than the supposition that a single best alternative can be identified. Outranking models compare the performance of 2 (or more) alternatives at a time, initially in terms of each criterion, to identify the extent to which a preference for one over the other can be asserted without using a prescribed scale such as the AHP method. In aggregating preference information across all relevant criteria, the outranking model seeks to establish the strength of evidence favoring the selection of one alternative over another, for example, by favoring a treatment alternative that performs the best on the greatest number of criteria. Therefore, outranking models are partially compensatory and most appropriate when criteria metrics are not easily aggregated, measurement scales vary over wide ranges, and units are incommensurate or incomparable and units are incommensurate or incomparable. More details about types of Multi Criteria analysis are found in Annex 3.

For this study the outranking method also called Scoring Rating model was used. This model was chosen because of its simplicity. The analysis is based on a scoring comparison. In the Scoring Rating model, the criteria of the different solutions are assessed with a score. The criteria are previously weighted by the level of importance. Therefore, the result of the model is a matrix with the scored criteria of the different solutions, the weight of the criteria and the final score of the different options. The model allows using a large number of criteria in a simple and flexible way. However, as was argued by Singhirunnusorn (2009), the pitfall of this model is that the inter connection of the criteria is barely achieved. This can be surmounted by the proper selection and weighing of indicators to compensate possible conflicts of contradictory or interconnected criteria.

4.3 Factors of consideration during selection of appropriate technologies using Scoring Rating model

During the technology selection process, the criteria weight was based on the system usefulness in terms of technical performance, simplicity in operation and maintenance, availability of spare parts and maintenance services, system affordability (space, time and money) and system social embracement (Figure 48).

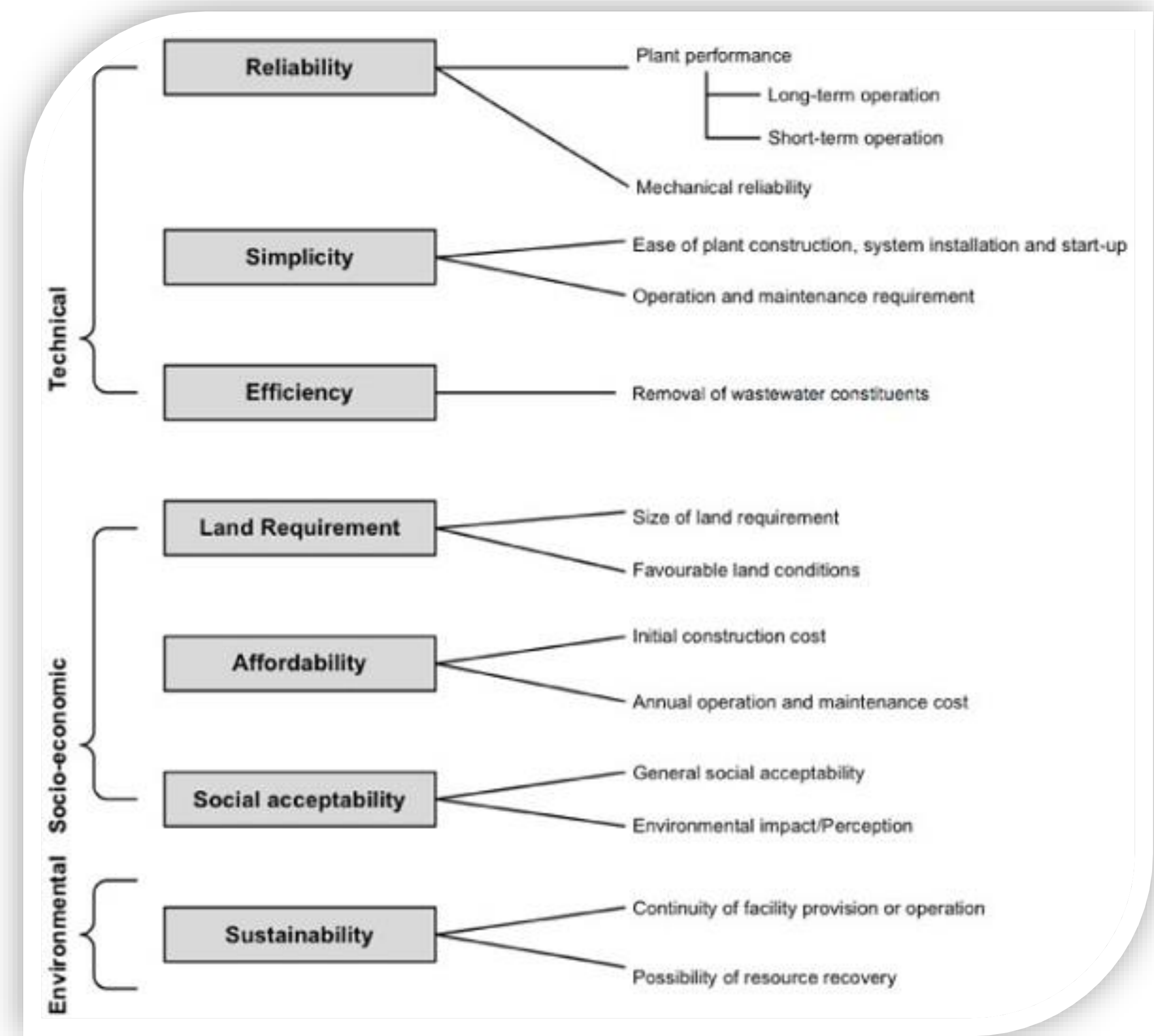


Figure 48: Factors determining the selection of appropriate wastewater treatment technologies

4.3.1 Land availability and energy requirement

It is evident that in urban environment land is expensive. To reduce capital costs, small and compact systems seem the most appropriate technology for urban sites, where there is no room available and the price of the land is high. However, energy requirements are inversely proportionate to the size of the plant (CENTA 2007a). Therefore, small plants could spend 5-6 times more energy than the big ones. Furthermore, wastewater systems that occupies large surfaces as wetlands and pond could result cheaper in terms of operational and maintenance. The dimension of the system and its relation to the cost would be critically assessed.

4.3.2 Centralized or decentralized systems

Centralized treatment plants require the transport of wastewater over larger distances. They involve high investments in infrastructure for wastewater transport from wastewater production to the site-of treatment. In rural areas a longer length of the infrastructure is required to connect dispersed households. According to Seto (2005), the collection system implies the 70% of the cost per capita meanwhile 30% is the cost of the treatment. Therefore, also due to the fact that they cannot benefit from the economy of scale, the inhabitants from small villages might pay 2 or 3 times as much as a resident of a big city (Hophmayer-Tokich, 2006). Decentralization involves local/onsite treatments that reduce the investment costs for implementation and maintenance of large sewage infrastructure. These onsite treatments let a better control of wastewater type and even with possibility of separation different effluents (black water, grey water, urban water, etc).

4.3.3 Design and construction cost

A proper design could simplify the performance of the system. The system should be able to de designed and operated with simplicity. Local technologies that has being already proved and successfully implemented in the area, would assure the long-term life of the project. Acknowledge and availability of the construction material or spare parts is required for the sustainable performance of the technology (Hellströma, 2000). In case of underground systems and earth basin designs, especially in rugged terrains, earth works can be rather extensive. Therefore, the topography might be also a factor to consider.

4.3.4 Simplicity of Operation and Maintenance

While the design and construction of the treatment last few months, operation and maintenance (O&M) remains during useful life of the Plant. At the local context, the O&M of the treatment plant would be done by a public institution, private or in case of agriculture reuse by water user association. Depending on that, the possibility of skilled labour employment varies. Looking at the technology, simplicity and minimized costs will guarantee the correct performance. In other terms, low levels of sophistication and high robustness and trustfulness are aimed. Complicated systems require the hire of skilled labour, the use of chemical additives, expensive and fragile devices (membranes, pumps or filters) and availability of spare parts therefore are costlier.

4.3.5 Energy requirements

The requirement of energy supply is an important criteria indicator. Energy supply is expensive so energy consumption should be minimized or non-existing. Furthermore, it may also be kept in mind the importance of energy supply reliability. Electricity is not always fully ensured in many places of Rwanda. Therefore, with random power breakdowns, plant operation should not depend on energy. One third of the O&M costs are related to the energy requirements. Electromechanical devices are very expensive, as an example aeration device consume up to 75% of the total energetic cost (CENTA, 2007a). Manual devices that do not depend on external energy supply to work may reduce this cost.

4.3.6 Robustness

Robustness is an important indicator of the technology in terms of adaptability of load and flow fluctuations. The quality and quantity of the stream that flow through the drains will change over the time in an unpredictable way and the capacity to adapt is essential.

4.3.7 Environmental nuisances

The implementation of the technology is associated to additional outcomes that might impact the local environment of users or workers. Therefore, nuisance like odour, landscape, mosquitoes or noise are by-products to contemplate. There is also necessary to keep in mind the possibility of overflowing of devices and tanks that could cause a threat for groundwater bodies' pollution.

4.4 Selection of Indicators

The selection of the appropriate indicators for this study was done based on local needs, availability of resource and constraints. These were obtained from the community survey, informal interview with users and providers of wastewater treatment systems, who informed on local factors, which determine the extent of long-term success of a community-scale wastewater treatment system. Those factors include technical, socio-economic, environmental and institutional aspects (Figure 48). The definitions of different indicators are discussed in Table 20.

Table 20: Meaning of indicators for wastewater treatment and sludge treatment performance

Indicators	Definition of Indicators and ranking criteria
Reliability (Service life)	Reliability refers to the mechanical performance, consistency or probability of mechanical failure. In this assignment, Service life (number of year) a system can satisfactorily run was considered the best indicator that captures the system reliability. Systems are ranked according the number of years of service life. A system with many years of service has higher score, while a system with few years of service has lower score
Simplicity	Evaluate the ease of plant construction, installation and commissioning. Determine the ease with which construction material can be sourced, compatibility with existing processes and level of automation. It also determines the operation and maintenance requirement (robustness of equipment, operational familiarity with the process, spares lead time.
Simplicity and affordability	Affordability determines the initial construction costs as well as operational and maintenance expenses over the technology life cycle. In this study we assume the system simplicity implies its affordability. A system with lower cost scored high, while an expensive system has score low.
Efficiency	The efficiency determines the extent of removal of impurities (TSS, bad odours, BOD, COD, Nitrogen, Phosphorus, Pathogens and chloride) from wastewater. Systems are ranked according the number of pollution variables a system can remove or possibility of resource recovery. A system that can remove all impurities is ranked the first. Systems that remove little types of pollutants are ranked the last.
Land requirement	Determine size of land requirement (physical footprint of technology) an the favourable land conditions in terms of the extent of site preparation required. Land requirement for a system determines the size of land requirement in terms of physical footprint of that system. A system requiring lower surface area footprint is ranked first, while a higher surface area requirement is ranked the last.
Social acceptability	Determine the social acceptability and perception of environmental impact in terms of the extent to which technology is accepted by the impacted community. In our study social acceptability is captured by the number of

	installed systems. More common systems were given higher score as they are more embraced, while fewer common systems were given lower score as they are socially less embraced. Figures used were obtained from field survey and review of REMA (2015) and WASAC (2018).
Sustainability	Determine the continuity or system provision or operation in terms of the ease with which a system can be expanded in time and space. It is important that a technology should have a life cycle of at least 25 years. Sustainability also determines which by-products or wastes are generated that require additional treatment

4.5 Scoring of different technologies

The scoring of different technologies versus different indicators was done based on 5 levels score (Table 17, 18). Lower scores were given to the system with low performance or low favourable conditions.

Table 21: Levels of importance for indicator rating

Level of importance	Weight
Very bad	1
Bad	2
Fair	3
Good	4
Very Good	5

Table 22: Scoring of different systems for different indicators of wastewater treatment technologies

Indicators	Sub-indicators	Assigned Score				
		1	2	3	4	5
Reliability	Plant operational reliability (performance consistency)					
	Mechanical reliability (probability of mechanical failure)					
Simplicity	Ease of system construction, installation and start up					
	Ease of operation and maintenance					
Efficiency	Working and surrounding environment free from bad odours, flies, objectionable discharge, sludge and other nuisance					
	Effluent free from TSS, BOD, COD, N, P, Pathogens					
Land requirement	Size of land requirement					
	Conflict with the surrounding communities					
	Conflict with the surrounding biophysical environment (water, land and air)					
Affordability	Reduced initial construction cost					
	Reduced annual operation and maintenance cost					
Social embracement	Number of installed systems					
	Perception of stakeholders					
Sustainability	Continuity of facility provision (operation)					
	Possibility of resource recovery					

4.6 Indicators weighting

The weight of indicators varies depending on prevailing local conditions which are critical to the proper operation of a system. von Sperling (1996) assessed the indicators for determining the selection of appropriate wastewater treatment system in both developing and developed countries. A critical comparison showed that criteria for selecting an appropriate system for developing and developed countries were quite different (Figure 49).

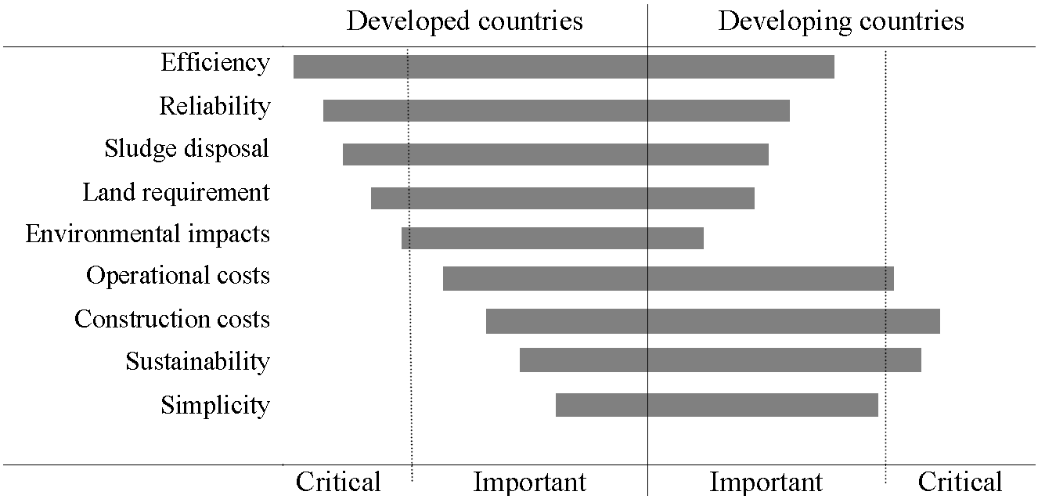


Figure 49: **Important Aspects in the Selection of Wastewater Treatment Systems (von Sperling, 1996)**

Since the limitation of local resources is the prime issue in most developing countries, costs and simplicity were among the foremost factors. In contrast, the developed countries' most critical items are system efficiency, reliability, and land requirement, while costs, sustainability and simplicity are less important compared to the developing countries' perspective.

Based on country's land scarcity, the current national income (low), and the national political will to transform Rwanda into a middle income country by 2035 and high income by 2050 with clean and improved sanitation countrywide, the "efficiency", "reliability", "affordability" and "land requirement" were given higher weight over other indicators. By extrapolation indicator's weights as shown in Figure 49, the efficiency was given the highest weight (weight coefficient of c = 1.0), followed by reliability (c = 0.88), affordability (c = 0.85), Sustainability (c = 0.76), land requirement (c = 0.72) and simplicity (c = 0.60).

4.7 Results

4.7.1 Appropriate technology for sewage treatment

The results from the multicriteria analysis for the selection of appropriate technology for sewage treatment are shown in Table 19 and 20. The analysis considered the cost of system installation, operation & maintenance, land requirements, pollutant removal efficiency, simplicity, system sustainability and social embracement or acceptability. While Table 19 shows performance of different systems versus different indicators, Table 20 translates the performance indicators in scores.

Overall, by order of applicability to Rwandan context, the most suitable systems are waste stabilization ponds (19.1), (2) Oxidation ditch (17.5), Activated sludge process (17.0) and Sequencing batch reactor (17.0). While waste stabilization ponds (WSP) and oxidation ditch scored high because of their flexibility, financial, economic, technology and operation simplicity, the activated sludge and sequencing batch reactor scored high due to their efficiency and low land requirement. Although waste stabilization ponds scored high, their implementation in Rwanda, especially in urban area face a serious problem related to land scarcity.

This is also reflected in Kigali Sanitation master plan of 2006 that rejected the waste stabilization ponds due to lack of space. On the other hand, the activated sludge process and its modification like sequencing batch reactor have the disadvantage of high cost and complexity that limit its sustainable use. While the activated sludge process and sequencing Batch Reactor, can be used for buildings without fund constraints (real estates, hotels, etc), waste stabilization ponds could be used in area without land constraints and where their end products (gas, sludge and effluent) can be safely evacuated, recycled or disposed (suburbs, rural areas, prisons, markets, schools and IDP models). In conditions where the required land size is available, waste stabilization ponds are the best as they offer more facilities in terms of affordability, simplicity and sustainability.

The alternative to waste stabilization pond, activated sludge process and sequencing batch reactor, is the oxidation ditch that has higher treatment efficiency, and less land requirements than waste stabilization ponds. The oxidation ditch is easier to control than the activated sludge but requires higher land than the activated sludge.

Although overall, septic tanks scored low, these systems scored high in terms of affordability, simplicity and social embracement. Most buildings use septic tanks and their full replacement should be progressive. Septic tanks can be used as temporal, transitional, or short to mid-term solution systems to the buildings that are not able to afford the cost and land requirements for the activated sludge process /sequencing Batch Reactor, and waste stabilization and biogas systems respectively. Septic tanks should be used as semi-centralized or decentralized individual household systems that could be connected to semi-centralized or centralized systems. Septic tanks are also the only suitable technologies in slums, due to lack of space, vehicular access and financial and operational capacities.

A similar study conducted in Ghana (Amoatey and Bani, 2011) to identify the appropriate sanitation systems concluded that Individual and community/residential based septic tanks and waste stabilization ponds were the most preferred. Waste stabilization ponds work well due to the convenient climatic conditions, without requiring energy for pumping. They are less energy dependent thus plant activities cannot be interrupted due to power cuts. Their disadvantages however include odour problems and require a large area of land to function properly. A study conducted in India (Kvernberg, 2012) arrived at the same conclusion that septic tank had the overall best score, despites its inconvenient health and hygiene conditions.

Table 23: Criteria used in assigning scores for different indicators of different sewage treatment technologies

Indicators / Systems	Efficiency	Reliability	Affordability		Social acceptability	Sustainability	Land requirement per PE	Simplicity
			Installation Cost	O&M cost				
Activated sludge process	Very good (only pathogens remain in effluents)	Fair	Very bad (very expensive)	Very bad (very expensive)	Good (common)	Fair (less environmental problems but high energy wastage)	Very good (very small land is required)	Very bad (Very complex)
Aerated lagoon	Good (Few P, N and pathogens remain in effluents)	Good	Fair (moderate cost)	Fair (moderate cost)	Bad (less common)	Fair (less environmental problems but high energy wastage)	Bad (big land is required)	*Fair (moderately complex)*
Biogas and composting system	Bad (BOD, N, P, odours and pathogens remain in effluents)	Fair	Good (low cost)	Very good (very low cost)	Fair (common)	Very good (rely on natural energy, possibility of nutrient & energy biomass recovery)	Fair (moderate size of land is required)	Fair (moderately complex)
Constructed wetland	Bad (BOD, N, P and pathogens remain in effluents)	Fair	Very good (very low cost)	Very good (very low cost)	Bad (less common)	Very good (rely on natural energy, possibility of biomass recovery)	Very bad (very big land is required)	Very good (very simple)
Enpure wastewater treatment system	Very good (only pathogens remain in effluents)	Fair	Very bad (very expensive)	Very bad (very expensive)	Bad (less common)	Fair (less environmental problems but high energy wastage)	Very good (very small land is required)	Very bad (Very complex)
Jet loop Aerobic treatment	Very good (only pathogens remain in effluents)	Fair	Very bad (very expensive)	Very bad (very expensive))	Bad (less common)	Fair (less environmental problems but high energy wastage)	Very good (very small land is required)	Very bad (Very complex)
Oxidation Ditch	Very good (only pathogens remain in effluents)	Good	Fair (moderate cost)	Fair (moderate cost)	Bad (less common)	Fair (less environmental problems but high energy wastage)	Fair (Moderate size of land is required)	Fair (complex)

Indicators / Systems	Efficiency	Reliability	Affordability		Social acceptability	Sustainability	Land requirement per PE	Simplicity
			Installation Cost	O&M cost				
Rotating biological contactor	Very good (only pathogens remain in effluents)	Fair	Very bad (very expensive)	Very bad (very expensive)	Bad (less common)	Fair (less environmental problems but high energy wastage)	Very good (very small land is required)	Very bad (Very complex)
Septic Tank & soak away pit	Very bad (BOD, N, P, odours and pathogens remain in effluents)	Bad	Very good (very low cost)	Good (low cost)	Very good (very common)	Very bad (high pollution potential, regular desludging & transportation and disposal of sludge)	Good (small land is required)	Very good (very simple)
Sequencing Batch Reactor/SBR	Very good (only pathogens remain in effluents)	Fair	Very bad (very expensive)	Very bad (very expensive)	Good (common)	Fair (less environmental problems but high energy wastage)	Very good (very small land is required)	Very bad (Very complex)
Trickling filter and Biofilter	Fair (N, P and pathogens remain in effluents)	Fair	Fair (moderate cost)	Fair (moderate cost)	Bad (less common)	Bad (problem of regular maintenance & disposal of sludge))	Good (small land is required)	*Bad (Complex)*
Vacuum evaporation	Fair (Zero discharge, problem of faecal cake disposal)	Good	Bad (expensive)	Fair (Moderate cost)	Very bad (Not common)	Fair (Waste of energy, need for regular & safe disposal of faecal cake)	Bad (big land is required)	*Good (Simple)*
Waste stabilization pond	Fair (N, P and pathogens remain in effluents)	Very Good	Fair (low cost)	Very good (very low cost)	Bad (less common)	Very good (rely on natural energy, possibility of biomass recovery)	Very bad (very big land is required)	Very good (very simple)

Table 24: Results from scoring different wastewater treatment system considering the weight of each indicator

Indicators / Weight / Systems	*Technical*						*Social Economic*						*Environmental*		Overall score /27.5
	Efficiency (weight =1.0)		*Reliability* (weight = 0.88)		*Simplicity* (weight = 0.60)		*Affordability* (weight = 0.85)		*Land requirement* (weight = 0.72)		*Social Acceptability* (*weight = 0.50*)		*Sustainability* (weight = 0.76)		
	Score	*Total score*	*Score*	*Total score*	*Score*	*Total score*	*Score*	*Total score*	*Score*	*Total score*	*Score*	*Total score*	*Score*	*Total score*	
Waste stabilization pond	*3*	*3*	*5*	*4.4*	*5*	*3*	*4*	*3.2*	*1*	*0.72*	*2*	*1*	*5*	*3.8*	**19.12**
Oxidation Ditch	*5*	*5*	*4*	*3.52*	*3*	*1.8*	*3*	*1.7*	*3*	*2.16*	*2*	*1*	*3*	*2.28*	**17.46**
Activated sludge and its modifications	*5*	*5*	*3*	*2.64*	*1*	*0.6*	*1*	*0.85*	*5*	*3.6*	*4*	*2*	*3*	*2.28*	**16.97**
Sequencing Batch Reactor/SBR	*5*	*5*	*3*	*2.64*	*1*	*0.6*	1	*0.85*	*5*	*3.6*	*4*	*2*	*3*	*2.28*	**16.97**
Constructed wetland	*2*	*2*	*3*	*2.64*	*4*	*2.4*	*5*	*4.25*	*1*	*0.72*	*2*	*1*	*5*	*3.8*	**16.81**
Biogas system	*1*	*1*	*3*	*2.64*	*3*	*1.8*	*4.5*	*3.83*	*3*	*2.16*	*3*	*1.5*	*5*	*3.8*	**16.73**
Aerated lagoon	4	4	*4*	*3.52*	*3*	*1.8*	*3*	*2.55*	*2*	*1.44*	*2*	*1*	*3*	*2.28*	**16.59**
Septic Tank & soak away pit	*1*	*1*	*2*	*1.76*	*5*	*3*	*5*	*4.25*	*4*	*2.88*	*5*	*2.5*	*1*	*0.76*	**16.15**
Enpure wastewater treatment system	*5*	*5*	*3*	*2.64*	*1*	*0.6*	*1*	*0.85*	*5*	*3.6*	*2*	*1*	*3*	*2.28*	**15.97**

Indicators / Weight / Systems	*Technical*						*Social Economic*						*Environmental*		*Overall score /27.5*
	Efficiency (weight =1.0)		*Reliability* (weight = 0.88)		*Simplicity* (weight = 0.60)		*Affordability* (weight = 0.85)		*Land requirement* (weight = 0.72)		*Social Acceptability* *(weight = 0.50)*		*Sustainability* (weight = 0.76)		
	Score	*Total score*	*Score*	*Total score*	*Score*	*Total score*	*Score*	*Total score*	*Score*	*Total score*	*Score*	*Total score*	*Score*	*Total score*	
Jet loop Aerobic treatment	*5*	*5*	*3*	*2.64*	*1*	*0.6*	*1*	*0.85*	*5*	*3.6*	*2*	*1*	*3*	*2.28*	**15.97**
Rotating biological contactor	*5*	*5*	*3*	*2.64*	*1*	*0.6*	*1*	*0.85*	*5*	*3.6*	*2*	1	*3*	*2.28*	**15.97**
Vacuum evaporation	*3*	*3*	*4*	*3.52*	*4*	*2.4*	*2*	*1.7*	*2*	*1.44*	*1*	0.5	*3*	*2.28*	**14.84**
Trickling filter and Biofilter	*3*	*3*	*2*	*1.76*	*2*	*1.2*	*3*	*2.55*	*4*	*2.88*	*2*	*1*	*2*	*1.52*	**13.91**

4.7.2 Appropriate technology and practices for fecal sludge management

The results from the multicriteria analysis for the selection of appropriate technology for faecal sludge management are shown in Table 21 and 22. As for the wastewater treatment system, the analysis took into account the cost of system installation, operation & maintenance, land requirements, pollutant removal efficiency, simplicity, system sustainability and social embracement or acceptability. While Table 21 shows performance of different systems versus different indicators, Table 22 translates the performance indicators in scores.

Overall, by order of applicability or suitability in Rwandan context, from the best to the worst, the analysis showed the following order

- Co-composting of faecal sludge with biodegradable wastes (20.29);
- Biogas system (18.50)
- A multistage landfill (like the one constructed in Nyagatare) with screening, grit removal, thickening, drying, composting & effluent treatment and disposal (18.23);
- Char Briquette manufacturing (16.40) and Incineration with energy recovery (16.40).

Co-composting of faecal sludge with biodegradable wastes scored higher because of its simplicity, affordability and sustainability. It was followed by a conventional multistage faecal sludge treatment system/ landfill with screening, grit removal, thickening, drying, composting & effluent treatment and disposal. This system is good because of its efficiency and possibility to recover nutrients through compost. Char Briquette manufacturing and Incineration with energy recovery scored low because of their high energy requirements and greenhouse emissions.

Therefore, this study highly recommends three technologies (Co-composting, multistage landfill system and biogas system) that can interchangeably being used depending on the availability of funds (multistage landfill system), availability of land and market for compost (co-composting system) or possibility to reuse the system by-products (biogas system).

Table 25: Criteria used in assigning scores for different indicators of faecal sludge treatment systems

Indicators / Systems	Efficiency	Reliability	Affordability		Social acceptability	Sustainability	Land requirement per PE	Simplicity
			Installation Cost	O&M cost				
Char Briquette system	Very high (all contaminants are controlled)	Moderate	High	High	Moderate	Moderate (some greenhouse gas emission)	Low	Complex
Co-composting with organic wastes	Moderate (pathogens may remain)	Very high	Very low	Very low	Low	Very high (recovery of nutrients)	High	Simple
Drying and incineration with energy recovery	Very high (all contaminants are controlled)	Moderate	High	High	Moderate	Very low (high emission of greenhouse gases)	Very low	Complex
Biogas Reactor	Very low (BOD, N, P, odours and pathogens remain in sludge and effluents)	High	Low	Low	Moderate	Very high (energy recovery)	Low	*Simple*
Landfill system (screening, grit removal, thickening, drying, composting & effluent treatment and disposal)	Very high (all contaminants are controlled)	Moderate	Very high	Very high	Very high	Moderate (nutrients recovery, but energy wasting)	Low	*Very complex*

Table 26: *Results from scoring different faecal sludge treatment systems considering the weight of each indicator*

Indicators / Weight / Systems	Technical						Social Economic						Environmental		Overall score /27.5
	Efficiency (weight =1.0)		Reliability (weight = 0.88)		Simplicity (weight = 0.60)		Affordability (weight = 0.85)		Land requirement (weight = 0.72)		Social Acceptability (weight = 0.50)		Sustainability (weight = 0.76)		
	Score	Total score	Score	Total score	Score	Total score	Score	Total score	Score	Total score	Score	Total score	Score	Total score	
Co-composting with organic wastes	3	3	5	4.40	4	2.40	5	4.25	2	1.44	2	1.0	5	3.80	**20.29**
Biogas Reactor	1	1	4	3.52	4	2.40	4	3.40	4	2.88	3	1.50	5	3.80	**18.50**
Landfill (screening, grit removal, thickening, drying, composting & effluent treatment and disposal)	5	5	3	2.64	1	0.60	1	0.85	5	3.60	5	2.50	4	3.04	**18.23**
Char Briquette system	5	5	3	2.64	2	1.20	2	1.70	4	2.88	3	1.50	3	2.28	**16.4**
Drying and incineration with energy recovery	5	5	3	2.64	2	1.20	2	1.70	5	3.60	3	1.50	1	0.76	**16.4**

4.7.3 Guidelines for fecal sludge management

4.7.3.1 Manual Emptying

When manual emptying, it is mandatory to use personal safety equipment. An employer shall not engage any workers in work without providing and ensuring use of personal safety equipment, and in doing so, a record book shall be maintained as designated by the owner. In spite of supply of personal safety equipment if those are not used by workers concerned, they are to be held liable thereof. To ensure occupational health and safety for workers in the workplace, each worker shall be made aware of the risks of the work through trainings. When emptying is manually done, the following safety guidelines should be taken into consideration:

- Wear and use appropriately the Personal Protection Equipment such as overalls, safety helmets, safety boots, safety goggles and protective gloves, among others;
- Examine suitability of equipment to be used for emptying and transportation;
- Check the leaking points of pipe or container being used;
- Ensure sufficient lighting, first aid, water bottles;
- Locate the on-site sanitation system the sludge is to be removed from and determine the accessibility of the system;
- Be careful when opening tank covers or manhole using hands;
- Entering the tank should be avoided but if necessary give certain time for the gases to flow out and ladders should be used when needed;
- Proceed by removing the fecal sludge;
- Close and secure the system once sludge removal is completed;
- Clean up appropriately on completion to ensure personal hygiene; bathe using soap.

4.7.3.2 Vacuum Truck Emptying, Transportation and disposal

Pumping systems that utilize a vacuum should be given priority over manual emptying. Vacuum trucks are available in a wide variety of sizes and models to accommodate different needs, with the most commonly used having capacities ranging from 200 litres to 16,000 litres. The operator should respect the hygienic emptying requirements that leave trashes in pits, minimize spills, offensive odors and associated inconveniences at the collection, transport and off-loading sites.

When using vacuum trucks the following should be taken into account:

- Park the truck as close to the system as possible.
- The maximum distance is determined by the length of hose and elevation rise from the bottom of the pit or septic tank to the vacuum truck tank inlet.
- This should typically be no more than 25 metres in linear distance and 4 metres in elevation. Further distances or elevation differences may require intermediate pumps.
- Clearing the area of people and inspect the site for possible hazards, such a high groundwater table that can cause a tank to 'float' if emptied
- Secure the truck using wheel chocks
- Lay out and connect the hoses from the truck to the tank or pit to be emptied.
- Open the tank or pit by removing the access ports or covers over the storage system
- Engage the vacuum equipment by using a power take-off from the truck's transmission
- Increase the vacuum to the proper level with the valve closed by watching the vacuum gauge, then lowering the end of the hose into the storage system and open the valve sufficiently such that the sludge is drawn out of the tank or pit.
- Closing the valve periodically re-builds the vacuum to enable the removal of further sludge
- Continue this process until the job is complete

- Break up sludge that has agglomerated into a solid mass, either by making use of a long-handle shovel and adding water when necessary to reduce the viscosity of the sludge, or by reversing the direction of the flow and forcing the contents of the vacuum truck tank back through the hose and into the sanitation system in order to use the high pressure stream to break up the sludge.

4.8 Factors for the Operationalization of semi-centralized wastewater treatment technologies in Rwanda

4.8.1 Limiting factors for Operationalization of semi-centralized wastewater treatment technologies in Rwanda

From the field observation and consultation with wastewater systems users and providers, technical factors, land requirement and affordability were the most important limiting factors for the operationalization of wastewater treatment systems in Rwanda.

4.8.1.1 Technical Factors

The quality of the personnel employed in wastewater treatment plants plays a key role in its proper operation. One of the major problems of effective wastewater treatment in Rwanda is the lack of operational skill and knowledge among plant operators. It is difficult to find local engineers with good experience and awareness of the technologies especially the more advanced processes like Activated Sludge process, Sequencing Batch Reactor, Rotating Bioreactor, Jet loop Aerobic treatment, etc).

For this reason, most of these systems rely on external technical skills and imported spare materials. Although these systems provide higher removal efficiencies for impurities and require small surface area, they are not good choice for communities with limited skills and funds. Instead, waste stabilization ponds and septic tanks offer more simplicity, flexibility and affordability, although require more land space and have low impurity removal efficiency.

4.8.1.2 Land Requirement

Land is big problem in Rwanda, especially in urban areas. The total area required for waste stabilization pond and septic tanks is not always available. For this reason, more expensive processes, with low land requirement (Activated Sludge process and Sequencing Batch Reactor) would be more suitable in most crowded area of urban area without availability of land.

4.8.1.3 Affordability

The estate occupants raised the issues of impossibility or low willingness to financially support the construction and operation of semi centralized wastewater treatment system. Many occupants in real estates in Kigali stressed that they should not pay higher than 5,000 RwF, while others estimated that the service should be free of charge.

Without strong motivation and awareness rising to users as well as incentives and penalties by institutions in charge of sanitation (WASAC and REMA), some users could by no means be able to achieve the operating requirements for the expensive semi-centralized systems like Activated Sludge process and Sequencing Batch Reactor. For this reason, waste stabilization ponds and septic tanks are better choice in rural and low communities not able or willing to pay the bill.
Alternatively, the Government should provide financial supports to the construction and operation of semi centralized wastewater treatment system.

4.8.2 Factors for the proper operation of existing semi-centralized wastewater treatment and faecal sludge management system

4.8.2.1 Operationalization of existing semi-centralized wastewater treatment plants

The results from field surveys involving interview with the system providers have shown that the cost of operation and maintenance varies between 2,000 and 60,000 FRw per household per month with average of 13,000 FRw. This cost is higher than 5,000 FRw many people are ready to pay for semi-centralized sewage systems. Higher costs were associated modern system (activated sludge, SBR, Jet loop Aerobic treatment, Enpure wastewater treatment system and Rotating biological system), with few users. Lower costs were associated with septic tank systems with big number system users. For the proper management of semi-centralized sewerage, the appropriate management practices should be implemented, following the design, characteristics and operation and maintenance problems of each system. In general, we noted the following problems as key for the sewage system failure:

- Lack of understanding and awareness on the need to have a properly operated and maintained sewage treatment system;
- Not budgeted the cost for the operation and maintenance of the sewage treatment system;
- Lack of technicians in charge of the system operation and maintenance
- No easy access or no access to some sewer compartments (e.g. the outlet)
- Lack of self-regular monitoring and records keeping of any activities carried out at the plant by the sewage system operator
- Lack of regular monitoring and punishment measures to uncompliant by regulating agencies (WASAC or REMA)

The remedial actions that should be taken into account for better management of the system include:

- Raise the awareness of the Estate occupants and sewage treatment system managers (through trainings organized by MININFRA, WASAC or REMA) on the need to have a properly operated and maintained sewage treatment system;

- Subsidies to some construction, operation & maintenance activities of sewage treatment systems for users non able to pay the bill and sensitisation of users (through trainings organized by MININFRA, WASAC and REMA) on the punishment measures to uncompliant sewage treatment effluent

- In collaboration with estate occupants, sewage treatment system managers and regulation/enforcement authority (WASAC or REMA), put in place a committee in charge of the day to day operation of the system and collection of money from occupants

- For the sewage treatment operator, ensure regular check-up of the system structural integrity, regular desludging, regular check-up of effluent quality and ensure effluent chlorination as tertiary treatment to reduce the concentration of faecal coliforms discharged in the environment.

- For the sewage treatment operator, records keeping of the system structural integrity and effluent quality and report to the competent authority (WASAC or REMA)

- Regular monitoring of the system structural integrity and effluent quality by the regulating agencies (WASAC or REMA) and enforcement of punishment measures to uncompliant systems and certification of the compliant systems.

More details about the operational problems and required remedial actions are presented in Table 27 below.

Table 27: Criteria for the improved operationalization of semi-centralized wastewater treatment technologies in the City of Kigali

Estates,type of sewage treatment plant and location (District, sector, cell)	Problems and causes	Criteria for the improved system operation & maintenance	Responsibility
Kabuga hillside housing estate (Jet loop Aerobic treatment), Gasabo, Rusororo, Nyagahinga	• The soak away pit is open and can cause accidents to people, animals, mosquito breeding • Technicians are not regularly paid as contracted • The effluent does not satisfy the national standards	• Installation of a soak away pit & drain field for the effluent, appropriately sealed to avoid breeding of flies and mosquito and fall accidents by animals and humans; • Respect the operating requirements of the system • Ensure contribution of 17,000 Rwf per household per month to cover the cost of operation, maintenance and monitoring, otherwise secure the budget from other source and regularly paying the technicians as per the contract • Records keeping of the system structural integrity and effluent quality and report to the competent authority (WASAC or REMA)	• operator
		• Ensure regular check up of the system structural integrity and the effluent quality	• Operator • WASAC/REMA
Gate Hills Estate I (Sekimondo) (Common Septic Tank) Kicukiro, Nyarugunga, Kanombe	• No access to the components of the septic tank, making impossible to monitor the performance of the system • Not possible to evaluate the performance of the system in terms of structural integrity or effluent quality	• Make accessible all the system components especially the outlets • Ensure regular (6-12 months) and professional desludging and transport of the septic sludge • Respect the operating requirements of the system • Records keeping of the system structural integrity and effluent quality and report to the competent authority (WASAC or REMA) • Ensure contribution of 6,000 Rwf per household per month to cover the cost of operation, maintenance and monitoring	• Operator
		• Ensure regular check up of the system structural integrity and the effluent quality	• Operator • WASAC/REMA
Kacyiru Estate (Activated sludge process) Gasabo Kacyiru	• Illegal storm water connection • Lack of operation, maintenance and monitoring responsibility	• Separate the dry and weather flows to avoid the illegal storm water connection • Respect the operating requirements of the system • Ensure contribution of 13,000 Rwf per household per month to cover the cost of operation, maintenance and monitoring • Records keeping of the system structural integrity and effluent quality and report to the competent authority (WASAC or REMA)	• Operator
		• Ensure regular check up of the system structural integrity and the effluent quality	• Operator • WASAC/REMA

Estates,type of sewage treatment plant and location (District, sector, cell)	Problems and causes	Criteria for the improved system operation & maintenance	Responsibility
	• The effluent does not satisfy the national standards		
VISION 2020 ESTATE (activated sludge) Gasabo, Kinyinya, Gacuriro	• Illegal storm water connection • Lack of operation, maintenance and monitoring responsibility • The effluent does not satisfy the national standards	• Separate the dry and weather flows to avoid the illegal storm water connection • Respect the operating requirements of the • Ensure contribution of 10,000 Rwf per household per month to cover the cost of operation, maintenance and monitoring • Records keeping of the system structural integrity and effluent quality and report to the competent authority (WASAC/REMA)	• Operator
		• Ensure regular check up of the system structural integrity and the effluent quality	• Operator • WASAC/REMA
Vision city estate (SBR) Gasabo, Kinyinya, Gacuriro	• The system is working well • The effluent satisfies the national standards	• Although the system is still new, it is very important for the Estate manager to put in place a system with the required budget and technical staff for the proper operation and maintenance of the system. • Respect the operating requirements of the	• operator
		• Ensure regular check up of the system structural integrity and the effluent quality	• Operator • WASAC/REMA
Kagugu villas housing (Sequencing Batch Reactor/SBR)	• Illegal storm water connection • Illegal discharge of the untreated sewage to the environment	• Separate the dry and weather flows to avoid the illegal storm water connection • Replace the pumping system and respect the desludging frequency, • comply to the proper operation and maintenance requirements of the system and protect the sewer system from storm water intrusion and illegal sewage discharge • Ensure contribution of 11,000 Rwf per household per month to cover the cost of operation, maintenance and monitoring	• Operator

Estates,type of sewage treatment plant and location (District, sector, cell)	Problems and causes	Criteria for the improved system operation & maintenance	Responsibility
Gasabo, Kinyinya, Gacuriro	• Collapse of pump • sedimentation tank full of sludge • The effluent does not satisfy the national standards	• Ensure regular check up of the system structural integrity and the effluent quality	• Operator • WASAC/REMA
Kami Executive Apartment (Activated sludge process) Gasabo, Kinyinya, Kagugu	• Fault in installation • The electric cabin is off service • Inadequate maintenance and operation services. • aeration tank off service • The effluent does not satisfy the national standards	• Need to to fix all problems in different components of the system • put in place a system for operation, maintenance and monitoring of the system, by securing of the budget and qualified staff in charge. • Mobilization of 56,600 Rwf per household per month for the system reoperation	• Operator
		• Ensure regular check up of the system structural integrity and the effluent quality	• Operator • WASAC/REMA
Highland Apartment & Suites (Activated sludge process) Gasabo, Remera, Nyarutarama	• The system is not yet operational as houses are not yet occupied	• Although the system is still new, it is very important for the Estate manager to mobilize the required budget for the proper operation and maintenance of the system.	• Operator
		• Ensure regular monitoring of the system structural integrity and the effluent quality	• Operator • WASAC/REMA
Highland Hotel 1	• The system is not yet operational as houses are not yet occupied	• Although the system is still new, it is very important for the Estate manager to mobilize the required budget and technical staff for the proper operation and maintenance of the system.	• operator

Estates,type of sewage treatment plant and location (District, sector, cell)	Problems and causes	Criteria for the improved system operation & maintenance	Responsibility
Gasabo, Remera, Nyarutarama		• Ensure regular check up of the system structural integrity and the effluent quality	• Operator • WASAC/REMA
Gate Hills Estate II (Sekimondo) Common septic Kicukiro, Nyarugunga, Kanombe	• The system looks nice, without bad odors or objectionable discharge • The effluent does not satisfy the national standards	• Ensure contribution of 5,000 Rwf per household per month to cover the cost of operation, maintenance and monitoring • Records keeping of the system structural integrity and effluent quality and report to the competent authority (WASAC or REMA)	operator
		• Ensure regular check up of the system structural integrity and the effluent quality	• Operator • WASAC/REMA
Landmark Apartment (Activated sludge process Gasabo, Kinyinya, Kagugu	• The system looked nice at the time of the first survey (October 2018), without bad odors or objectionable discharge • Three months later (January 2019), the system was out of service	• Need to to fix all problems in different components of the system • Need to put in place a system for operation, maintenance and monitoring of the system, by securing of the budget and qualified staff in charge. • A sum of 31,600 Rwf per apartment per month could cover the cost related to operation, maintenance and monitoring	• Operator
		• Ensure regular check up of the system structural integrity and the effluent quality	• Operator • WASAC/REMA
Mountain Ridge Estate (Activated Sludge Treatment) Gasabo, Rusororo, Kabuga	• The system is not yet operational as houses are not yet occupied	• Although the system is still new, it is very important for the Estate manager to mobilize the required budget and technical staff for the proper operation and maintenance of the system.	• Operator
		• Ensure regular check up of the system structural integrity and the effluent quality	• Operator • WASAC/REMA

Estates,type of sewage treatment plant and location (District, sector, cell)	Problems and causes	Criteria for the improved system operation & maintenance	Responsibility
Masaka Hill view estate (Jet loop Aerobic treatment) Kicukiro, Masaka	• The system is out of service. Occupants, unwilling to pay the cost related to the system operation and maintenance, now rely on individual septic tanks and soak away pits	• To sensitize the occupants on the need for rehabilitation of the system • Ensure regular check up of the system structural integrity and the effluent quality	WASAC/REMA
	•	• To rehabilitate the sewer system and securing the required budget for the proper operation and maintenance of the system and hiring a technician in charge ot the day to day operations. The monthly cost of operation and maintenance services was estimated at 17,000 Rwf Rwf per household. • Ensure regular check up of the system structural integrity and the effluent quality	• Operator
Sunset estate (Common open pit) Gasabo, Kimironko, Kibagabaga	• Sewer pipeline is damaged and fresh sewage is flowing to the environment	• To rehabilitate the entire sewer pipeline and sewage treatment system. • To mobilize the required budget (35,600 Rwf per household per month) and tecnical staff for the proper operation and maintenance of the system.	• Operator
		• Ensure regular check up of the system structural integrity and the effluent quality	• Operator • WASAC/REMA
Umucyo Estate (Activated sludge process Gasabo, Kinyinya, Gacuriro	• The system is not functional • Illegal connection of storm runoff	• To rehabilitate the entire sewer pipeline and sewage treatment system. • To mobilize the required budget (3,500 FRw per household per month) and tecnical staff for the proper operation, maintenance and monitoring of the system	• Operator
		• Ensure regular check up of the system structural integrity and the effluent quality	• Operator • WASAC/REMA

Estates,type of sewage treatment plant and location (District, sector, cell)	Problems and causes	Criteria for the improved system operation & maintenance	Responsibility
Juru Estate (Waste stabilization pond) Gasabo, Remera Nyarutarama	• Sewer pipeline and manholes are damaged and fresh sewage is flowing to the environment • Intrusion of storm runoff to the system	• The requirements for the proper operation of WSP range from repairs of the sewer system (pipeline and manholes) to the complete rehabilitation of the whole system and securing the budget for the proper operation and maintenance of the WSP. The budget for the proper operation, maintenance and monitoring of the WSP was estimated at 9,500 FRw per household per month.	• Operator
		• Ensure regular check up of the system structural integrity and the effluent quality	• Operator • WASAC/REMA
Home comfort Estate (Septic tank) Kicukiro, Rebero	• The system is not yet operational as houses are not yet occupied	• Although the system is still under construction, it is very important for the Estate manager to put in place a system (budget and technical staff) for proper operation, maintenance and monitoring of the system. • Need for properly designed, operated and maintained, with regular and professional desludging and transport to faecal sludge treatment plants.	• Operator
		• Ensure regular check up of the system structural integrity and the effluent quality	• Operator • WASAC/REMA
Cooperative COHAKI (Common septic tank) Gasabo, Kinyinya, Gasharu	• The system is not yet operational as houses are not yet occupied	• Although the system is still under construction, it is very important for the Estate manager to put in place a system (budget and technical staff) for proper operation, maintenance and monitoring of the system. • Need for properly designed, operated and maintained, with regular and professional desludging and transport to faecal sludge treatment plants.	• Operator
		• Ensure regular check up of the system structural integrity and the effluent quality	• Operator • WASAC/REMA

Estates,type of sewage treatment plant and location (District, sector, cell)	Problems and causes	Criteria for the improved system operation & maintenance	Responsibility
Urukumbuzi Estate (Septic tanks) Gasabo, Kinyinya, Gasharu	• The system is not yet constructed (now using individual soak way pits) • Grey water is discharge untreated to environment	• Construct the sewage treatment system as planned • Meanwhile, for the proper operation of the system it is worth to consider connecting the grey water to sewage system and compliance to the proper operation and maintenance (regular and sanitary desludging of septic sludge). The budget for the proper operation and maintenance of the WSP is estimated at 4,000 FRw	• Operator
		• Ensure regular check up of the system structural integrity and the effluent quality	• Operator • WASAC/REMA
Izuba City Estate (Enpure wastewater treatment system) Gasabo, Kinyinya, Batsinda	• The system is not yet constructed (now using individual soak way pits)	• Although the system is still under construction, it is very important for the Estate manager to put in place a system with enough budget and committed technical staff for the proper operation and maintenance of the system • Monitoring of the treatment performance (effluent quality, structure integrity, smells in the surroundings, etc) should integral part of the system operation	• Operator • WASAC/REMA
		• Ensure regular check up of the system structural integrity and the effluent quality	• Operator • WASAC/REMA
Gate hills Estate III (Individual Septic tanks) Gasabo, Ndera, Masaro	• The system is not yet constructed (now using individual soak way pits)	• Although the system is still under construction, it is very important for the Estate manager to put in place a system with enough budget and committed technical staff for the proper operation and maintenance of the system • Monitoring of the treatment performance (effluent quality, structure integrity, smells in the surroundings, etc) should integral part of the system operation	• Operator • WASAC/REMA
		• Ensure regular check up of the system structural integrity and the effluent quality	• Operator • WASAC/REMA

Estates,type of sewage treatment plant and location (District, sector, cell)	Problems and causes	Criteria for the improved system operation & maintenance	Responsibility
Garden estate (Individual Septic tanks) Gasabo, Kinyinya	• The system is not yet constructed (now using individual soak way pits)	• Although the system is still under construction, it is very important for the Estate manager to put in place a system with enough budget and committed technical staff for the proper operation and maintenance of the system • Monitoring of the treatment performance (effluent quality, structure integrity, smells in the surroundings, etc) should integral part of the system operation	• Operator • WASAC/REMA
		• Ensure regular check up of the system structural integrity and the effluent quality	• Operator WASAC/REMA
BNR Estate (Individual septic tank Kicukiro, Kimisange, Rebero	• The systems look nice without offensive odors	• Need to comply with the proper operation and maintenance requirements (regular desludging) • Need for constructing, operation, maintenance and monitoring of semi a centralized sewage treatment system for the whole estate • The budget for the proper operation and maintenance of the WSP is estimated at 5,300 FRw per household per month	• Operator
Rujugiro Estates (Individual septic tank) Kicukiro, Gikondo	• The systems look nice without offensive odors	• Need to comply with the proper operation and maintenance requirements (regular desludging) • Need for constructing, operation, maintenance and monitoring of semi a centralized sewage treatment system for the whole estate • The budget for the proper operation and maintenance of the WSP is estimated at 11,500 FRw per household per month	• Operator

Estates,type of sewage treatment plant and location (District, sector, cell)	Problems and causes	Criteria for the improved system operation & maintenance	Responsibility
Niboye Estate Activated sludge process) Kicukiro, Niboye	• The system is not yet operation (under construction)	• Although the system is still new and not yet operational, it is very important for the Estate manager to ensure the availability of budget and technical staff for the proper operation, maintenance and monitoring of the system. • Monitoring of the treatment performance (effluent quality, structure integrity, smells in the surroundings, etc) should integral part of the system operation	• Operator
Goboka Estate (Individual septic tank), Gasabo, Kibagabaga, Kimironko	The system is not yet operation (under construction)	• Although the system is still new and not yet operational, it is very important for the Estate manager to ensure the availability of budget (5,300 FRw per household per month) and technical staff for the proper operation, maintenance and monitoring of the system. • Monitoring of the treatment performance (effluent quality, structure integrity, smells in the surroundings, etc) should integral part of the system operation.	• Operator

4.8.2.2 Operationalization of Nduba faecal sludge dumping site

Nduba dumping site is the only site receiving faecal sludge from Kigali city and its surrounding. Pumped sewage with enormous quantity of trashes from septic tank, toilet, soak away pits is discharge in open ponds. There is any treatment-taking place there save water evaporation and ground infiltration. One of the challenges for the proper operation of the Nduba sewage system is higher trash load.

Leaving the trash behind in the pit or provide a system for screening the trash at the reception could avoid messy trash at the Nduba sewage offloading site. It is possible to put in place a vacuum system to dewater faecal sludge to some extent to prepare sludge to be dealt with more efficiently in subsequent treatment stages like co-composting with other biodegradable organic wastes and Char Briquette making, biogas production or sludge incineration with energy recovery. Alternatively, a complete faecal sludge treatment plant like those constructed in Nyagatare, Kayonza, Nyanza should be implemented at Nduba dumping site. The key components of the plant include:

- **Pre-treatment** (Screening and Grit removal);
- **Thickening (**Screw press or Disc thickener);
- **Liquid phase treatment** (Lamella compact system or equivalent);
- **Solar Drying beds** (green house in polycarbonate);
- **Evacuation** (composting area for treated sludge and infiltration pit for wastewater) and leachate treated phase.

More details about best practices in faecal sludge management are discussed in Chapter 2 (section 2.2, and 2.3).

4.9 Link the study with recent completed master plan of Kigali City and Kigali centralized sewerage system to be located at Giticyinyoni

Centralized Wastewater Treatment Plant (CWTP) will be constructed at Giticyinyoni near the road crossings Kigali-Musanze and Kigali-Muhanga. Considering the topography of the Kigali city, the centralized sewage system will not be able to connect all areas of Kigali City (Figure 1). Semi-centralized and individual sewage systems located inside the area of coverage of the centralized sewer system should connect to it. The institution in charge of sanitation (e.g WASAC) should issue permits to support the compliance to the sewage effluent discharge. The sewage treatment operator should apply for a permit for connection to the centralized sewer system and pay a bill according to the discharge pollutant load in terms of BOD, COD, TSS, TDS, nitrogen, phosphorus, pathogens, acidity/basicity, etc. A compliant system may be exempted for effluent discharge fees, while the non-compliant system may be penalized. Special attention should be paid to the effluent with high content of trash, grit material and suspended material, whose discharge to the sewer system may interfere with the proper functioning of the system. The sewer operator should ensure these materials are avoided or kept at the lowest quantity. This calls for regular monitoring of the characteristics of the effluent being discharged to the centralized sewer line. Buildings outside the coverage of the central sewer line should be encouraged to have their own sewage treatment systems and the government should help to establishing semi-centralized sewage systems.

4.10 Monitoring and Evaluation framework of the implementation of appropriate semi-centralized wastewater treatment technologies and fecal sludge management

Table 25 and Table 26 present the proposed Monitoring and evaluation framework of the implementation of appropriate semi-centralized wastewater treatment technologies and faecal sludge management. The frameworks identify the most important indicators for discharge wastewater effluent, where those indicators will be measured, how they will be measured, what are the guidelines, what is the measurement cost, the frequency of measurements, measurement and reporting responsibilities. Table 28 present the Monitoring and evaluation framework of the implementation of appropriate faecal sludge management.

The discharger should have a log book for keeping records on effluent characteristics and monthly report to the competent authority (WASAC). Every discharger must make the appropriate arrangements to make accessible the effluent to any person at any occasion. Failing to keep records on effluent characteristics or reporting in due time to the competent authority or to make accessible the effluent, should be considered as incompliance to regulation of discharge of wastewater.

Like wastewater treatment monitoring framework, the faecal sludge treatment system operator should have a log book for keeping records on the air quality, effluent, end products characteristics of the system and monthly report to the competent authority (WASAC. Arrangements should be done to make accessible the points of discharge (air emission, effluent, end products and residues to any person at any occasion. Failing to keep records on effluent characteristics or reporting in due time to the competent authority or to make accessible the effluent, should be considered as incompliance to regulation of discharge of wastewater.

Table 28: Monitoring and evaluation framework of the implementation of appropriate semi-centralized wastewater treatment technologies

Indicators	Where will it be measured	How is it measured (RSB, 2017)	What is the target value (RSB, 2017)	What is the cost	How often will it be measured	Who will measure it	Where will it be reported
PH	Effluent	RS ISO 10523	5-9	7,606	Monthly	Discharger or Consultant which is contracted by the discharger and authorised by the authority (WASAC)	Authority in charge of Sanitation (WASAC)
Electrical conductivity (uS/cm)	Effluent	Using well calibrated EC meter or Multimeter	<1,000	7,606			
Total Suspended Solids (mg/L)	Effluent	RS ISO 11923	< 50	7,606			
Oil & grease (mg/L)	Effluent	ISO 9377	<10	32,424			
Biological Oxygen Demand (mg/L)	Effluent	RS ISO 5815	<50	32,424			
Chemical Oxygen Demand (mg/L)	Effluent	RS ISO 6060	<250	32,424			
Total Phosphorus (mg/L)	Effluent	RS ISO 6878	<5	15,820			
Total Nitrogen (mg/L)	Effluent	RS ISO 11905	<30	15,820			
Chloride (mg/L)	Effluent	ISO 9297:1989	<250	15,820			
E-coli (fcu /100ml)	Effluent	RS ISO 4831	<400	32,424			

Table 29: Monitoring and evaluation framework of the implementation of appropriate faecal sludge management

Indicators	Where will it be measured	How is it measured	What is the target	How often will it be measured	Cost	Who will measure it	Where will it be reported
Procedures for receiving and off-loading of faecal sludge(FS) and faecal sludge Treatment	**Feacal sludge treatment site**	Photos, complaints records, presence of trash, scavengers Offensive odours and flies	Sanitary, no complaints, no trash, no scavengers offensive odours, flies	Monthly	50,000	Consultant which is contracted by the discharger and authorised by the authority (WASAC)	Authority in charge of Sanitation (WASAC)
Emptying and disposal	**Feacal sludge treatment site**	Taking photos, complaints records, observation of trash, scavengers and flies, feeling of offensive odours	Sanitary, no complaints, no trash, no scavengers offensive odours, flies	Monthly	50,000		
Quantity and quality of final effluent	**Feacal sludge treatment (FST) site**	FST Effluent should be assessed in terms of pH, EC, TSS, BOD_5,COD, TP, TN, Chloride and E-coli	FST Effluent should comply to the RSB standards for discharged wastewater as shown in Table 22	Quarterly	200,000		
Amount of greenhouse gases and other air pollutants	**Feacal sludge treatment (FST) site**	Air quality should be monitored for CH_4, CO_2, N_2O, H_2S, SO_2 according RSB standards	Air quality at the FST should comply with RSB Air quality Standards (EAS 752: 2010)	Quarterly	100,000		
Quality of end products and faecal solid residues	**Feacal sludge treatment (FST) site**	Observation of the consistency and stabilization of end products and residues	Stabilized end product and residue, without offensive odours	Quarterly	50,000		

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study assessed the appropriate semi-centralized wastewater treatment technologies and faecal sludge Management in Rwanda. Field surveys showed that only one treatment plant (Vision City) out of 28 surveyed in the City of Kigali complied with the National Standards Requirement for tolerance limits for discharged domestic wastewater for all measured parameters (pH, Electrical conductivity (EC), Total Suspended Solids (TSS), Biological Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), Total Phosphorus (TP), Total Nitrogen (TN), Chloride and E-coli). Sewage treatment systems in other provinces of Rwanda did not satisfy the sanitary operating indicators discussed in this assignment. Failure of sewage treatment systems was in most cases attributed to the lack of required technical skills and budget for the running and maintaining the systems.

Our study corroborates the study findings by WASAC in 2017. Most of wastewater treatment systems do not comply with the National Standards Requirement for tolerance limits for discharged domestic wastewater. The Vision City was the only Estate with compliant wastewater treatment system in the time of our sampling (2019). Kagugu and Kabuga Villa Estates that were uncompliant for only the two parameters in 2017 became uncompliant for much more parameters two years later (2019). This explains well the need for regular monitoring to ensure the continuous of performance of wastewater treatment systems. It is shocking that systems like Juru Estate and Sunset estate that were discharging untreated faecal material in open environment in 2017 during WASAC study were still discharging them two years later in 2019. This means much more effort is needed to enforce the sanitation strategies and environmental laws, through regular monitoring of wastewater treatment structural integrity and effluent discharge.

The study has identified waste stabilization ponds, oxidation ditch, activated sludge process and sequencing batch reactor as the most suitable systems for treating wastewater in Rwandan context (affordability, efficiency, land scarcity, land requirement, simplicity, social acceptability and sustainability). While the activated sludge process and sequencing Batch Reactor could be used for buildings without funds constraints (real estates, hotels, etc), waste stabilization ponds could be used in buildings without land constraints and where their end products (gas, sludge and effluent) can be sustainably reused (suburbs, rural areas, prisons, markets, schools and IDP models). The alternative to waste stabilization pond, activated sludge process and sequencing batch reactor, is the oxidation ditch that has higher treatment efficiency, and less land requirements than waste stabilization ponds. The oxidation ditch is easier to control than the activated sludge but requires higher land than the activated sludge.

Although overall, septic tanks scored low, these systems scored high in terms of affordability, simplicity and social embracement. Most buildings use septic tanks and their full replacement should be progressive. Septic tanks can be used as temporal or transitional or short to mid-term solution (2-5 years) systems to the buildings that are not able to afford the cost and land requirements for the activated sludge process and sequencing Batch Reactor, and oxidation and waste stabilization pond. As temporal sewage treatment systems, septic tank could be designed in such a way to allow further connection to the semi-centralized or centralized systems. Septic tanks could also be considered the only affordable systems in slums and low income without financial and operational capacities.

The analysis for alternatives for the appropriate technology for faecal sludge management concluded that co-composting of faecal sludge, biogas system and a multistage faecal treatment can successfully work in Rwanda. Those systems that can interchangeably being used depending on the availability of funds (multistage landfill system), availability of land and market for compost (co-composting system) or possibility to reuse the system by-products (biogas system.

5.2 Recommendations

For the proper operationalization of the semi centralized sewage treatment, the remedial actions should be considered:

- The activated sludge and its modification process could be used for buildings without funds constraints (real estates, hotels, etc), while waste stabilization ponds could be used in areas without land constraints and where their end products (gas, sludge and effluent) can be sustainably reused (suburbs, rural areas, prisons, markets, schools and IDP models).

- Septic tanks can be used as transitional or short to mid-term solution (2-5 years) systems to the buildings that are not able to afford the cost and land requirements for the activated sludge process and sequencing Batch Reactor, and waste stabilization and biogas systems respectively. As short to mid-term solution, septic tanks should be designed/sited in such a way to allow further connectivity to semi-centralized or centralized system. The use of septic tank could be licensed for up to 5 years renewable.

- It is important to raise the awareness of the Estate occupants and sewage treatment system managers (through trainings organized by MININFRA, WASAC and REMA) on the need to have a properly operated and maintained sewage treatment system and punishment measures to uncompliant systems;
- In collaboration with estate occupants, sewage treatment system managers and regulation/enforcement authority (WASAC or REMA), it is important to put in place a committee in charge of the day to day operation of semi-centralized system, including mobilization of the budget the proper operation, maintenance and monitoring;
- It is important for the sewage treatment operator, to ensure regular check-up of the system structural integrity, regular desludging, and regular check-up of effluent quality and ensure effluent chlorination as tertiary treatment to reduce the concentration of faecal coliforms discharged in the environment. It is also important for records keeping of the system structural integrity and effluent quality and report to the competent authority (WASAC or REMA);
- It is important to regularly monitoring the system structural integrity and effluent quality by the regulating agencies (WASAC or REMA) and enforcement of punishment measures to incompliant systems and certification to the compliant systems.

5.2.1 Lack of operation and Maintenance

Sanitation sub-sector is one of the areas where capacity is limited. The gap is mostly identified in the management of wastewater from domestic (residential), non-residential (hotels) as well as in industry. To ensure sustainable management of the sanitation services in near future, the Government of Rwanda needs to include sanitation related subject in the curriculum of universities or Technical Vocational Training Schools to have more people in the sector.

Another thing, which was identified in real estates, is that the developer who have sold houses did not include the cost for operating the sanitation systems to handle wastewater generated in houses. This has implications on the systems, which function for a certain period, and because of no maintenance, they end up failing to deliver start polluting the environment.

The developer as well as owners of the systems, for improved performance, they need to include the budget for the operation and maintenance of the sewage treatment system, in the business plan of the construction project.

5.2.2 Effluent from systems non-compliant with environmental discharge

The results have shown that only one treatment plant (Vision City) out of 28 surveyed in the City of Kigali complied with the National Standards. Requirement for tolerance limits for discharged domestic wastewater for all measured parameters (pH, Electrical conductivity (EC), Total Suspended Solids (TSS), Biological Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), Total Phosphorus (TP), Total Nitrogen (TN), Chloride and E-coli) for other estates did not comply with the environment. This means that, the polluting is high for the fresh water downstream.

High amount of Nitrogen and Phosphorus in the environment cause the eutrophication of lakes and other water bodies, resulting in the depletion of dissolved oxygen. High E-coli, means simply bacteria which are detrimental to human health who might consume water by causing diarrhoea and other sickness.

5.2.3 Lack of clear roles and responsibilities for the management of the systems

For those who have bought houses without systems, are the ones whose wastewater discharge in the environment are highly polluting. There is no clear roles and responsibilities on how the systems should be managed. It has to be clear well before, that the systems should be in hands preferably of the buyers, of the estates or apartments, or Developer to avoid miss management of the systems. In housing cost, should include building capacity of buyers on how to do it in case the pricing of the estates includes the system. Unless it is, the developer will be responsible of the management of the systems.

The government need to enforce the organic law for the protection and conservation of the environment, which states that the polluter needs to pay the pollution caused to the environment. Sanctions and charges need to be applied accordingly for those who do not comply with Rwanda Standard Board (RSB) discharge.

5.2.4 Fecal sludge management in the country

The urbanization rate is increasing in the country as a results population in cities and towns are increasing. Hence, the amounts of wastes (solid and liquid wastes) are also increasing while off-site technologies or collective sanitation facilities, semi-centralized, are increasing. However, there is a need to carry out the Shit Flow Diagram (SFD), which is a tool used to readily understand and communicate how excreta physically flows through a city or town. This help to know how the excreta is managed, it will identify where the gaps lies in terms of managing faecal matter. It will help in decision makers to decide on what need to be done.

The business of Faecal Sludge management is almost non-existence given the number of people involved in the sanitation sub-sector. Sometimes, this makes the business expensive to access it. Hence, it ended up having people practicing it in abnormal way for example manual emptying which is risk to human health as well as the environment. There is a need for the government to incentivize the business to allow more people in the business.

5.2.5 Nduba dumping site

Like for solid wastes generated in the city of Kigali that are collected and dumped at Nduba, the emptied wastewater, mixed with kitchen water and flushed faecal matter from toilets, from non-residential and ones from the individual houses are dumped in to pit dug at vicinity of Nduba Dumping site. Given the fact there is no technology to handle or treat wastewater at Nduba, Government need to install a wastewater treatment plant that might treat faecal matter transported to Nduba.

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ANNEXES

Annex 1: Template for assessment of the status of wastewater treatment systems using field observation

- Type of system ◉ Individual ○ Centralized
- Treatment technology (specify)
  ○
- Status of the structure of the system
  ○ Fit ○ Fair
  ○ Inadequate (specify)
- System sizing
  ○ Adequate ○ Small
  ○ Other (specify)
- Drainage system
  ○ Adequate ○ Fair ○ Inadequate
  ○ Other (specify)
- Nuisance to the surrounding
  ○ Offensive odors ○ Objectionable discharge
  ○ Flies & scavengers ○ Objectionable discharge
  ○ No nuisance to the surrounding
- Sludge treatment & disposal
  ○ existing ○ Non existing ○ Other (specify)

Other comments

Annex 2: Surveying Questionnaire

Consultancy services for the study on appropriate semi-centralized wastewater treatment technologies and faecal sludge management

0. Introduction to Informants

Good morning/ Afternoon,

My name is………………………………………………………………………………one of team members from HICE CONSULT Ltd, a company contracted the Consultancy Services for the Study on Appropriate Semi-Centralized Wastewater Treatment Technologies and Faecal Sludge Management by the Ministry of Infrastructure (MININFRA).

We are collecting data on the status of existing semi-centralized waste water treatment technologies in all Estates in Kigali City and *the status of the faecal sludge management countrywide*.

The information from our observations and your answers will be used for the purposes of the proposed study and will not be communicated to anyone else.

Your cooperation is highly appreciated and we thank you in advance for support.

Questionnaire I (about wastewater treatment system)

Q1. In which of the following Province and District is your estate/building located?

Kigali City: Gasabo Kicukiro Nyarugenge Gasabo

Eastern Province : Bugesera Nyagatare Kayonza Rwamagana Other district (specify) ....

Southern Province : Huye Muhanga Nyanza Other district (specify) ....

Western Province : Rubavu Rusizi Other district (specify) ....

Northern Province : Gicumbi Musanze Other district (specify) ....

Q2: What kind of strata is concerned?

Real Estate Specify its name ....

IDP Models Specify its name ....

Slum Specify its name ....

Settlement Specify its name ....

Prison Specify its name ....

Public place Specify its name ....

Other Specify its name ....

Q3: When were these buildings established?

- Before 1994
- Between 1994 and 2005
- 2005 or later
- Don't know/not sure

Q4: What kind of toilet facility do members of the buildings usually use?

- Flush toilet
- Pour flush toilet
- Traditional Pit latrine
- Ventilated Improved Pit Latrine
- ECOSAN
- Other (specify)

Q5: Where are fecal materials from the toilet flushed/ended to?

- Open pit
- Drying bed
- Open Land
- Pit with slab
- Portable latrine
- Composting toilet
- Biogas system
- No facility, bush or field
- Elsewhere
- Unknown place
- Other (specify

Q6: Are the buildings having a sewage treatment system?

- Yes
- No (Describe what happens to the sewage)

Q7: If yes what type of sewage treatment system is serving the building?

- Constructed wetlands
- Waste Stabilization ponds
- Biogas system
- Activate sludge process
- Sequencing Batch Reactor
- Aerobic treatment through trickling filter
- Rotating Bioreactor Contact
- Septic tank
- Other (specify)

Q8: Is the sewage treatment facility in this estate failing?

- Yes, very often
- Yes, but less often
- Never

Q9: What is the cause for the system failure?

- Energy/power problems
- Structural fault
- Process design fault
- Fault in installation
- Lack of spare parts
- Lack of maintenance technical skills

- High operation and maintenance cost
- Hazard (specify)
- Unkown
- Other (specify)

Q10: How available are the maintenance services

- Hardy available
- Fairly available
- Readily available
- Other (specify)

Q11: From where you get the maintenance services

- From the system provider
- Elsewhere
- Other (specify)

Q12: Is there a person in charge of the system operation & maintenance services

- Yes
- No
- Not applicable (specify why)

Q13: How satisfied about the skills and services of the person in charge

- Satisfied
- Not satisfied
- Not applicable (specify why)

Q14: Where the treated effluent from your estate/building's sewage treatment system is discharged?

- Pit/Cesspool
- Nearby river/wetlands
- Open space
- Reuse for other purposes (specify)
- Recycled for other uses (specify)
- Other (specify)
- Not applicable (specify why)

Q15: What is the fate of fecal sludge from your estate/buildings?

- Pumped out
- Pit/Cesspool
- Biogas system

- Compost
- Land application
- Compost
- Open spaces
- Unknown place
- Other (specify)
- Not applicable (specify why)

Q16: When was your septic tank/cesspool or fecal sludge last pumped out?

- Within last 3 years
- Last 3-5 years
- Last 6-10 years
- More than 10 years
- Has not been pumped out
- Do not know / not sure
- Not applicable (specify why)

Q17: How often do you need to have your cesspool or septic tank pumped out?

- Less than 3 years
- 3-5 years
- 5-10 year
- Greater than 10 years
- Do not know / not sure
- Not applicable (specify why)
- Other (specify)

Q18: What is the fate of the pumped out fecal materials?

- Municipal land fill
- unkown
- Other (specify)

Q19: Views of the surrounding communities about the sewage management

- Positive view (specify why)
- Negative view (specify why)
- Other (specify)
- Not applicable (specify why)

Q20: If negative are views of the surrounding communities about the sewage management, what the communities are complaining against

- Offensive odors
- Unaesthetic reasons
- Source of diseases (specify)
- Other (specify)

Q21: Looking ahead, if you needed to select the most convenient wastewater treatment system, which of the following would you select? (You may pick more than one, but not more than three)

- Constructed wetlands
- Waste Stabilization ponds
- Biogas system
- Activate sludge process
- Sequencing Batch Reactor
- Aerobic treatment through trickling filter
- Rotating Bioreactor Contact
- Septic tank with soak away pits
- Community sewer (decentralized with semi-centralized waste water treatment plants)
- Central municipal sewer with centralized waste water treatment plant
- Do not know / not sure
- Other (specify)
- Not applicable (specify why)

Q22: How interested would you be in learning more about the best practices of operation and maintenance of sanitation or wastewater treatment and disposal for individual homes or estates?

- Extremely interested
- Very interested
- Possibly interested
- Not very interested
- Not at all interested

Q23: For the proper operation of wastewater treatment and disposal systems, how do you think a system should be operated/funded? You may check more than one choice.

- [ ] Solely by individual property owners participating
- [ ] Subsidized by the larger community that will benefit from the improved sanitation
- [ ] Subsidized by County
- [ ] Other (specify)

Question II (about fecal material and sludge management practices)

Q1: Is there any system to handle and treat fecal materials or sludge from these buildings?

- Yes
- No
- Other (specify)

Q2: If yes (Q1) which kind of system deals with fecal materials/sludge from your buildings?

- Energy recovery through biogas system
- Energy recovery through drying and biomass fuel combustion
- Nutrient recovery through compost and agricultural production
- Abandoned in drying bed
- Disposed in pits
- Transfer to municipal land fills
- Do not know
- Other (specify)

Q3: If yes (Q1) what is the status of the fecal sludge management system?

- Adequate
- Not adequate
- Other
    - ……
    - ……
    - ……

Q4: If no (Q1) what is the fate of the fecal materials/sludge?

- Open space
- unkown
- Other (specify)

Q5: What are concerns of the surrounding communities on the fecal material/sludge from these buildings?

- Concerns over offensive odors
- Concerns over flies and scavengers feeding on fecal material
- Concerns over land pollution
- Concerns unaesthetic and less attractive/comfortable environment
- Others (specify)

Q6: What do you think is the most suitable management technology for the sudge from these buildings?

- Biogas system
- Compost for agricultural production
- Drying for biomass fuel
- Contained in pit
- Emptying to municipal land fill
- Emptying to centralized sewage treatment system
- unkown
- Other (specify)

Annex 3: Applications of decision support tools in environmental management (Kiker 2005)

Application area	Method	Decision context	Funding agency	Citation
Prioritization of sites/ areas for industrial/ military activity	AHP + GIS	Land condition assessment for allocation of military training areas	U.S. Army Engineering Research and Development Center	Mendoza et al. (2002)
	AHP + GIS	Selection of boundaries for national park	International Institute for Geoinformation Science and Earth Observation, The Netherlands	Sharifi et al. (2002)
	PROMETHEE	Waste management activities in Canada	Natural Sciences and Engineering Research Council of Canada	Vaillancourt and Waaub (2002)
	ELECTRE + GIS	Land management: develop a land suitability map for housing in Switzerland	Swiss National Foundation for Research (FNRS)	Joerin and Musy (2000)
	AHP + GIS	Landfill sitting		Siddiqui et al. (1996)
	MAUT + GIS	Selection of park boundaries	USDOE	Keisler and Sundell (1997)
Environmental/remedial technology selection	SMART	Choosing a remedial action alternative at Superfund site	U.S. Army Corps of Engineers	Wakeman (2003)
	MAUT	Selection of management alternative Missouri River	University of Missouri—Columbia, USA	Prato (2003)
	MAUT + AHP	Regulation of water flow in a lake–river system	Academy of Finland	Hamalainen et al. (2001)
	MAUT	Offsite emergency management following a nuclear accident (such as the Chernobyl accident)	European Commission, Ukraine	Ehrhardt and Shershakov (1996); Hamalainen et al. (2000)
Environmental impact assessment	Review	Review of MCDA use for EIAs in Netherlands	Vrije University, The Netherlands	Janssen (2001)
	AHP	Socioeconomic impact assessment for a construction project in India	Indira Gandhi Institute of Development Research, India	Ramanathan (2001)
	ELECTRE	Highway environmental appraisal in Ireland	Dublin Institute of Technology; University College Dublin, Ireland	Rogers and Bruen (1998)
	AHP and MAUT/SMART	Environmental impact assessment of 2 water development projects on a Finnish river	Finnish Environmental Agency; Helsinki University of Technology	Marttunen and Hamalainen (1995)
	PROMETHEE	Prioritization of EIAs in Jordan	Staffordshire University, United Kingdom	Al-Rashdan et al. (1999)
Natural resource management	AHP	Natural park management	USDA Forest Services	Schmoldt et al. (1994); Peterson et al. (1994); Schmoldt and Peterson (2001b)
	AHP	Management of small forest in North Carolina,	USDA Forest Services	Rauscher et al. (2000)

Annex 3 continued: Applications of decision support tools in environmental management (Kiker 2005)

Application area	Method	Decision context	Funding agency	Citation
	MAUT	Management of spruce budworm in Canadian forests	National Science and Engineering Research Council of Canada	Levy et al. (2000)
	AHP, MAUT, and outranking	Forestry planning in Finland	Finnish Academy of Sciences; Finnish Forest Research Institute	Kangas et al. (2001)
	MAUT	Improvement of habitat suitability measurements	Finnish Forest Research Institute	Store and Kangas (2001)
	AHP	Environmental vulnerability assessment for mid-Atlantic region	USEPA/USDOE	Tran et al. (2002)
	Weighting	Management of marine protected areas in Tobago	U.K. Department of International Development	Brown et al. (2001)
	MAUT	Fisheries management: select among alternative commercial fishery opening days	Fisheries and Ocean, Canada	McDaniels (1995)
	AHP, MAUT, and outranking	Fisheries management		Mardle and Pascoe (1999)

[a] PROMETHEE = Preference Ranking Organization METHod for Enrichment Evaluations; ELECTRE = Elimination Et Choix Traduisant la Realite; AHP = analytical hierarchy process; GIS = geographic information system; MAUT = multiattribute utility theory; MCDA = multicriteria decision analysis; EIA = environmental impact assessment; USDA = U.S. Department of Agriculture; USDOE = U.S. Department of Energy; SMART = simple multiattribute rating technique.

Annex 4: Laboratory results for Effluent quality for Wastewater Treatment Plants in Real Estates in Kigali City

WASAC	**WASAC Central Laboratory**	Edition N° 1, Issue N° 1 Issue date, May 2018

ORGINAL
Sheet 1 of 2

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

WASAC CENTRAL LABORATORY (WCL)

TEST REPORT: No....01-19-018

1. DETAILS OF THE SAMPLE

Name of the Requester	HICE CONSULT LTD
Address of the Requester	Gasabo District
WCL Sample Code	20190109-004
Name of the Sample	Effluent Vision City Estate
Sampling site/ Location	Vision City Estate
Sampling person	WASAC Central Laboratory Staff
Date of delivery of sample	09/01/2019

2. ANALYSIS OF THE SAMPLE

Condition of the Sample	Good
Date analysis Started	10/01/2019
Date analysis Completed	16/01/2019
Name of Laboratory	WASAC Central Laboratory
Environmental Conditions	Suitable
Parameters	Bacteriological and physic-chemical parameters

3. STANDARD(S) USED

The quality of this influent was evaluated based on Rwanda National Standards for Tolerance limits of Dischargeable Domestic Wastewater **RS 110:2019, First Edition**

4. SAMPLING METHOD

The sample was collected following the procedure detailed in WASAC Central Laboratory Sampling's Procedure **(WCL/S/PM-022)**

This Certificate shall not be reproduced in full or in part without the written approval of WCL and information contained herein is based on laboratory tests and observations.

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5. LABORATORY RESULTS

Parameters	Unit	Effluent	Standards Requirements	Method used
E. coli	MPN/100 ml	1	-	EPA SM 9223
COD	mg/l	64	**250**	EPA 410.3
BOD5	mg/l	4.77	**50**	EPASM 5210I
pH		8	**5.0-9.0**	EPA 150.1
TSS	mg/l	4.0	**50**	HACH 8006
Electrical conductivity	µS/cm	0.19	-	HACH 8160
Total Nitrogen(TN)	mg/l	12	**30**	HACH 10072
Total Phosphorus (TP)	mg/l	4.6	**5**	HACH 8190
Chlorides	mg/l	34	-	HACH 8507

6. INTERPRETATION OF RESULTS

The Effluent from Vision City Domestic wastewater complies with National Standard Requirements for tolerance limits for discharged domestic wastewater for the measured parameters.

7. CONCLUSION AND RECOMMENDATIONS

The efficiency removal for nutrients is required as the total phosphorus (TP) found to be high (close to the requirement)

Date: 17/01/2019
At WASAC Central Laboratory

Analyst:

KARORA Evariste
Laboratory Technician Helper

Approved by:

WATER AND SANITATION CORPORATION * WASAC * COMMERCIAL SERVICES

Yvette Carine KASINE
Head of Water Central Laboratory

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

WASAC CENTRAL LABORATORY (WCL)

TEST REPORT: No....01-19-019

1. DETAILS OF THE SAMPLE

Name of the Requester	HICE CONSULT LTD
Address of the Requester	Gasabo District
WCL Sample Code	20190109-005
Name of the Sample	Effluent Vision 2020 Estate
Sampling site/ Location	Vision 2020 Estate
Sampling person	WASAC Central Laboratory Staff
Date of delivery of sample	09/01/2019

2. ANALYSIS OF THE SAMPLE

Condition of the Sample	Good
Date analysis Started	10/01/2019
Date analysis Completed	16/01/2019
Name of Laboratory	WASAC Central Laboratory
Environmental Conditions	Suitable
Parameters	Bacteriological and physic-chemical parameters

3. STANDARD(S) USED

The quality of this effluent was evaluated based on Rwanda National Standards for Tolerance limits of Dischargeable Domestic Wastewater **RS 110:2019, First Edition**

4. SAMPLING METHOD

The sample was collected following the procedure detailed in WASAC Central Laboratory Sampling's Procedure **(WCL/S/PM-022)**

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5. LABORATORY RESULTS

Parameters	Unit	Effluent	Standards Requirements	Method used
E. coli	MPN/100 ml	**≥ 2419.6**	-	EPA SM 9223
COD	mg/l	**256**	**250**	EPA 410.3
BOD5	mg/l	**104**	**50**	EPASM 5210B
PH		7	**5.0-9.0**	EPA 150.1
TSS	mg/l	**91**	**50**	HACH 8006
Electrical conductivity	µS/cm	0.19	-	HACH 8160
Total Nitrogen(TN)	mg/l	**37**	**30**	HACH 10072
Total Phosphorus (TP)	mg/l	**11**	**5**	HACH 8190
Chloride	mg/l	45	-	HACH 8507

6. INTERPRETATION OF RESULTS

The Effluent from Vision 2020 Domestic wastewater does not comply with National Standard Requirements Standards for Tolerance limits of Dischargeable Domestic Wastewater **(RS 110:2019, First Edition)** for some measured parameters.

7. CONCLUSION AND RECOMMENDATIONS

It is recommended to optimize the full treatment of influent from Vision 2020 Estate domestic wastewater treatment.

Date: 17/01/2019
At WASAC Central Laboratory

Analyst:

KARORA Evariste
Laboratory Technician Helper

Approved by:

Yvette Carine KASINE
Head of Water Central Laboratory

WATER AND SANITATION CORPORATION WASAC COMMERCIAL SERVICES

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

WASAC CENTRAL LABORATORY (WCL)

TEST REPORT: No...01-19-020

1. DETAILS OF THE SAMPLE

Name of the Requester	HICE CONSULT LTD
Address of the Requester	Gasabo District
WCL Sample Code	20190109-006
Name of the Sample	Effluent Kagugu villa estate
Sampling site/ Location	Kagugu Villa Estate
Sampling person	WASAC Central Laboratory Staff
Date of delivery of sample	09/01/2019

2. ANALYSIS OF THE SAMPLE

Condition of the Sample	Good
Date analysis Started	10/01/2019
Date analysis Completed	16/01/2019
Name of Laboratory	WASAC Central Laboratory
Environmental Conditions	Suitable
Parameters	Bacteriological and physic-chemical parameters

3. STANDARD(S) USED

The quality of this influent was evaluated based on Rwanda National Standards for Tolerance limits of Dischargeable Domestic Wastewater **RS 110:2019, First Edition**

4. SAMPLING METHOD

The sample was collected following the procedure detailed in WASAC Central Laboratory Sampling Procedure **(WCL/S/PM-022)**

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5. LABORATORY RESULTS

Parameters	Unit	Effluent	Standards Requirements	Method used
E. coli	MPN/100 ml	>2419.6	-	EPA SM 9223
COD	mg/l	256	250	EPA 410.3
BOD5	mg/l	31.2	50	EPASM 5210B
PH		7	5.0-9.0	EPA 150.1
TSS	mg/l	145	50	HACH 8006
Electrical conductivity	µs/cm	574	-	HACH 8160
Total Nitrogen(TN)	mg/l	43	30	HACH 10072
Total Phosphorus (TP)	mg/l	6.6	5	HACH 8190
Chlorides	mg/l	29	-	HACH 8507

6. INTERPRETATION OF RESULTS

The Effluent from Kagugu Villa Domestic wastewater does not comply with National Standard Requirements for Tolerance limits of Dischargeable Domestic Wastewater (**RS 110:2019, First Edition)** for some measured parameters.

7. CONCLUSION AND RECOMMENDATIONS

It is recommended to optimize the full treatment of influent from Kagugu Villa Estate domestic wastewater treatment.

Date: 17/01/2019
At WASAC Central Laboratory

Analyst:

KARORA Evariste
Laboratory Technician Helper

Approved by:

Yvette Carine KASINE
Head of Water Central Laboratory

WATER AND SANITATION CORPORATION WASAC COMMERCIAL SERVICES

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

WASAC CENTRAL LABORATORY (WCL)

TEST REPORT: No....01-19-021

1. DETAILS OF THE SAMPLE

Name of the Requester	HICE CONSULT LTD
Address of the Requester	Gasabo District
WCL Sample Code	20190109-007
Name of the Sample	Effluent KAMI Executive apartment
Sampling site/ Location	KAMI Executive apartment
Sampling person	WASAC Central Laboratory staff
Date of delivery of sample	09/01/2019

2. ANALYSIS OF THE SAMPLE

Condition of the Sample	Good
Date analysis Started	10/01/2019
Date analysis Completed	16/01/2019
Name of Laboratory	WASAC Central Laboratory
Environmental Conditions	Suitable
Parameters	Bacteriological and physic-chemical parameters

3. STANDARD(S) USED

The quality of this influent was evaluated based on Rwanda National Standards for Tolerance limits of Dischargeable Domestic Wastewater **RS 110:2019, First Edition**

4. SAMPLING METHOD

The sample was collected following the procedure detailed in WASAC Central Laboratory Sampling's Procedure **(WCL/S/PM-022)**

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5. LABORATORY RESULTS

Parameters	Unit	Effluent	Standards Requirements	Method used
E. coli	MPN/100 ml	>2419.6	-	EPA SM 9223
COD	mg/l	384	**250**	EPA 410.3
BOD5	mg/l	3.12	**50**	EPASM 5210B
PH		7	**5.0-9.0**	EPA 150.1
TSS	mg/l	10	**50**	HACH 8006
Electrical conductivity	µS/cm	0.13	-	HACH 8160
Total Nitrogen(TN)	mg/l	2.76	**30**	HACH 10072
Total Phosphorus (TP)	mg/l	3.34	**5**	HACH 8190
Chloride	mg/l	22	-	HACH 8507

6. INTERPRETATION OF RESULTS

The Effluent from KAMI Executive Apartment Domestic wastewater does not comply with National Standard Requirements for Tolerance limits of Dischargeable Domestic Wastewater (**RS 110:2019, First Edition)** for some measured parameters.

7. CONCLUSION AND RECOMMENDATIONS

It is recommended to optimize the full treatment of influent from KAMI Executive apartment domestic wastewater treatment

Date: 17/01/2019
At WASAC Central Laboratory

Analyst:

KARORA Evariste
Laboratory Technician Helper

Approved by:

Yvette Carine KASINE
Head of Water Central Laboratory

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

WASAC CENTRAL LABORATORY (WCL)

TEST REPORT: No..01-19-022

1. DETAILS OF THE SAMPLE

Name of the Requester	HICE CONSULT LTD
Address of the Requester	Gasabo District
WCL Sample Code	20190109-008
Name of the Sample	Effluent HIGHLAND Apartment
Sampling site/ Location	Domestic wastewater
Sampling person	WASAC Central Laboratory staff
Date of delivery of sample	09/01/2019

2. ANALYSIS OF THE SAMPLE

Condition of the Sample	Good
Date analysis Started	10/01/2019
Date analysis Completed	16/01/2019
Name of Laboratory	WASAC Central Laboratory
Environmental Conditions	suitable
Parameters	Bacteriological and physic-chemical parameters

3. STANDARD(S) USED

The quality of this influent was evaluated based on Rwanda National Standards for Tolerance limits of Dischargeable Domestic Wastewater **RS 110:2019, First Edition**

4. SAMPLING METHOD

The sample was collected following the procedure detailed in WASAC Central Laboratory Sampling Procedure **(WCL/S/PM-022)**

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5. LABORATORY RESULTS

Parameters	Unit	Effluent	Standards Requirements	Method used
E. coli	MPN/100 ml	<u>≥2419.6</u>	-	EPA SM 9223
COD	mg/l	96	**250**	EPA 410.3
BOD5	mg/l	10.4	**50**	EPASM 5210B
PH		7	**5.0 - 9.0**	EPA 150.1
TSS	mg/l	36	**50**	HACH 8006
Electrical conductivity	µS/cm	567	-	HACH 8160
Total Nitrogen(TN)	mg/l	8.21	**30**	HACH 10072
Total Phosphorus (TP)	mg/l	4.3	**5**	HACH 8190
Chloride	mg/l	20	-	HACH 8507

6. INTERPRETATION OF RESULTS

The Effluent from HIGHLAND Apartment Domestic wastewater does not comply with National Standard Requirements for Tolerance limits of Dischargeable Domestic Wastewater (**RS 110:2019, First Edition**) for some measured parameters.

7. CONCLUSION AND RECOMMENDATIONS

It is recommended to improve the disinfection process of effluent from HIGHLAND Apartment domestic wastewater treatment.

Date: 17/01/2019
At WASAC Central Laboratory

Analyst:

KARORA Evariste
Laboratory Technician Helper

Approved by:

Yvette Carine KASINE
Head of Water Central Laboratory

WATER AND SANITATION CORPORATION
WASAC
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Directorate of Urban Water and Sanitation Services (DWSS)
Quality Assurance Services (QAS)

WASAC CENTRAL LABORATORY (WCL)

TEST REPORT: No...01-19-023

1. DETAILS OF THE SAMPLE

Name of the Requester	HICE CONSULT LTD
Address of the Requester	Gasabo District
WCL Sample Code	20190109-009
Name of the Sample	Effluent Gate Hill Estate
Sampling site/ Location	Gate Hill Estate
Sampling person	WASAC Central Laboratory staff
Date of delivery of sample	09/01/2019

2. ANALYSIS OF THE SAMPLE

Condition of the Sample	Good
Date analysis Started	10/01/2019
Date analysis Completed	16/01/2019
Name of Laboratory	WASAC Central Laboratory
Environmental Conditions	suitable
Parameters	Bacteriological and physic-chemical parameters

3. STANDARD(S) USED

The quality of this influent was evaluated based on Rwanda National Standards for Tolerance limits of Dischargeable Domestic Wastewater **RS 110:2019, First Edition**

4. SAMPLING METHOD

The sample was collected following the procedure detailed in WASAC Central Laboratory Sampling Procedure **(WCL/S/PM-022)**

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5. LABORATORY RESULTS

Parameters	Unit	Effluent	Standards Requirements	Method used
E. coli	MPN/100 ml	≥2419.6	-	EPA SM 9223
COD	mg/l	96	**250**	EPA 410.3
BOD5	mg/l	13.5	**50**	EPASM 5210B
PH		7	**5.0-9.0**	EPA 150.1
TSS	mg/l	139	**50**	HACH 8006
Electrical conductivity	µs/cm	568	-	HACH 8160
Total Nitrogen(TN)	mg/l	60.2	**30**	HACH 10072
Total Phosphorus (TP)	mg/l	4.9	**5**	HACH 8190
Chloride	mg/l	35	-	HACH 8507

6. INTERPRETATION OF RESULTS

The Effluent from Gate Hill Estate Domestic wastewater does not comply with National Standard Requirements for Tolerance limits of Dischargeable Domestic Wastewater **(RS 110:2019, First Edition)** for some measured parameters.

7. CONCLUSION AND RECOMMENDATIONS

It is recommended to optimize the full treatment of influent from Gate Hill Estate domestic wastewater treatment

Date: 17/01/2019
At WASAC Central Laboratory

Analyst:

KARORA Evariste
Laboratory Technician Helper

Approved by:

Yvette Carine KASINE
Head of Water Central Laboratory

WATER AND SANITATION CORPORATION
COMMERCIAL SERVICES

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

WASAC CENTRAL LABORATORY (WCL)

TEST REPORT: No..01-19-024

1. DETAILS OF THE SAMPLE

Name of the Requester	HICE CONSULT LTD
Address of the Requester	Kicukiro District
WCL Sample Code	20190109-010
Name of the Sample	Effluent Kabuga Hillside Estate
Sampling site/ Location	Kabuga Hillside Estate
Sampling person	WASAC Central Laboratory staff
Date of delivery of sample	09/01/2019

2. ANALYSIS OF THE SAMPLE

Condition of the Sample	Good
Date analysis Started	10/01/2019
Date analysis Completed	16/01/2019
Name of Laboratory	WASAC Central Laboratory
Environmental Conditions	suitable
Parameters	Bacteriological and physic-chemical parameters

3. STANDARD(S) USED

The quality of this influent was evaluated based on Rwanda National Standards for Tolerance limits of Dischargeable Domestic Wastewater **RS 110:2019, First Edition**

4. SAMPLING METHOD

The sample was collected following the procedure detailed in WASAC Central Laboratory Sampling Procedure **(WCL/S/PM-022)**

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5. LABORATORY RESULTS

Parameters	Unit	Effluent	Standards Requirements	Method used
E. coli	MPN/100 ml	≥2419.6	-	EPA SM 9223
COD	mg/l	64	**250**	EPA 410.3
BOD5	mg/l	15.75	**50**	EPASM 5210B
PH		7.5	**5.0-9.0**	EPA 150.1
TSS	mg/l	131	**50**	HACH 8006
Electrical conductivity	µs/cm	140.1	-	HACH 8160
Total Nitrogen(TN)	mg/l	110.4	**30**	HACH 10072
Total Phosphorus (TP)	mg/l	5.41	**5**	HACH 8190
Chloride	mg/l	45	-	HACH 8507

6. INTERPRETATION OF RESULTS

The Effluent from Kabuga Hillside Estate Domestic wastewater does not comply with National Standard Requirements for Tolerance limits of Dischargeable Domestic Wastewater **(RS 110:2019, First Edition)** for some measured parameters

7. CONCLUSION AND RECOMMENDATIONS

It is recommended to optimize the full treatment of influent from Kabuga Hillside Estate domestic wastewater treatment

Date: 17/01/2019
At WASAC Central Laboratory

Analyst:

KARORA Evariste
Laboratory Technician Helper

Approved by:

Yvette Carine KASINE
Head of Water Central Laboratory

WATER AND SANITATION CORPORATION COMMERCIAL SERVICES

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

WASAC CENTRAL LABORATORY (WCL)

TEST REPORT: No....01/19/025

1. DETAILS OF THE SAMPLE

Name of the Requester	HICE CONSULT LTD
Address of the Requester	Gasabo District
WCL Sample Code	20190109-011
Name of the Sample	Effluent HIGHLAND Hotel 1
Sampling site/ Location	HIGHLAND Hotel 1
Sampling person	WASAC Central Laboratory staff
Date of delivery of sample	09/01/2019

2. ANALYSIS OF THE SAMPLE

Condition of the Sample	Good
Date analysis Started	10/01/2019
Date analysis completed	16/01/2019
Name of Laboratory	WASAC Central Laboratory
Environmental Conditions	Suitable
Parameters	Bacteriological and physic-chemical parameters

3. STANDARD(S) USED

The quality of this influent was evaluated based on Rwanda National Standards for Tolerance limits of Dischargeable Domestic Wastewater **RS 110:2019, First Edition**

4. SAMPLING METHOD

The sample was collected following the procedure detailed in WASAC Central Laboratory Sampling Procedure **(WCL/S/PM-022)**

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5. LABORATORY RESULTS

Parameters	Unit	Effluent	Standards Requirements	Method used
E. coli	MPN/100 ml	>2419.6	-	EPA SM 9223
COD	mg/l	192	250	EPA 410.3
BOD5	mg/l	15.9	50	EPASM 5210B
PH		7.5	5.0-9.0	EPA 150.1
TSS	mg/l	30	50	HACH 8006
Electrical conductivity	µs/cm	524	-	HACH 8160
Total Nitrogen(TN)	mg/l	32.9	30	HACH 10072
Total Phosphorus (TP)	mg/l	4.32	5	HACH 8190
Chloride	mg/l	25	-	HACH 8507

6. INTERPRETATION OF RESULTS

The Effluent from HIGHLAND Hotel 1 Domestic wastewater does not comply with National Standard Requirements for Tolerance limits of Dischargeable Domestic Wastewater **(RS 110:2019, First Edition)** for some measured parameters.

7. CONCLUSION AND RECOMMENDATIONS

It is recommended to optimize the full treatment of influent from HIGHLAND Hotel 1 domestic wastewater treatment.

Date: 17/01/2019
At WASAC Central Laboratory

Analyst:

KARORA Evariste
Laboratory Technician Helper

Approved by:

Yvette Carine KASINE
Head of Water Central Laboratory

WATER AND SANITATION CORPORATION * COMMERCIAL SERVICES

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

WASAC CENTRAL LABORATORY (WCL)

TEST REPORT: No. 021/19/026

1. **DETAILS OF THE SAMPLE**

Name of the Requester	HICE CONSULT LTD
Address of the Requester	Gasabo District
WCL Sample Code	20190109-012
Name of the Sample	Effluent Kacyiru Estate
Sampling site/ Location	Kacyiru Estate
Sampling person	WASAC Central Laboratory staff
Date of delivery of sample	09/01/2019

2. **ANALYSIS OF THE SAMPLE**

Condition of the Sample	Good
Date analysis Started	10/01/2019
Date analysis Completed	16/01/2019
Name of Laboratory	WASAC Central Laboratory
Environmental Conditions	Suitable
Parameters	Bacteriological and physic-chemical parameters

3. **STANDARD(S) USED**

The quality of this influent was evaluated based on Rwanda National Standards for Tolerance limits of Dischargeable Domestic Wastewater **RS 110:2019, First Edition**

4. **SAMPLING METHOD**

The sample was collected following the procedure detailed in WASAC Central Laboratory Sampling's Procedure **(WCL/S/PM-022)**

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5. LABORATORY RESULTS

Parameters	Unit	Effluent	Standards Requirements	Method used
E. coli	MPN/100 ml	>2419.6	-	EPA SM 9223
COD	mg/l	256	250	EPA 410.3
BOD5	mg/l	115.6	50	EPASM 5210B
PH		7	5.0-9.0	EPA 150.1
TSS	mg/l	304	50	HACH 8006
Electrical conductivity	µS/cm	637	-	HACH 8160
Total Nitrogen(TN)	mg/l	54	30	HACH 10072
Total Phosphorus (TP)	mg/l	12	5	HACH 8190
Chloride	mg/l	0.53	-	HACH 8507

6. INTERPRETATION OF RESULTS

The Effluent from Kacyiru Estate Domestic wastewater does not comply with National Standard Requirements for Tolerance limits of Dischargeable Domestic Wastewater **(RS 110:2019, First Edition)** for some measured parameters.

7. CONCLUSION AND RECOMMENDATIONS

It is recommended to optimize the full treatment of influent from Kacyiru Estate domestic wastewater treatment

Date: 17/01/2019
At WASAC Central Laboratory

Analyst: | **Approved by:**

KARORA Evariste
Laboratory Technician Helper

Yvette Carine KASINE
Head of Water Central Laboratory

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