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Review

Review on trends of wastewater pollution and treatment system challenges: A case study of Rwanda, East Africa

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***Abstract:** Sustainable access to clean water and basic sanitation is a crucial part of the Sustainable Development Goals (SDGs). Most sub-Saharan Africa countries are affected by wastewater pollution dilemma and poor effluent treatment systems. In Rwanda, the high population growth rate, urbanization, and industrialization has exacerbated wastewater generation beyond the bearing capacity of the available treatment systems. The wastewater discharge from diverse sectors during the last three decades become an important pollution source and is deteriorating the freshwater system (lakes, rivers, springs, groundwater, etc.), soil, fauna, and flora. Moreover, there is no centralized sewage system in Rwanda, only the existing decentralized wastewater treatment plants are inadequate to ensure basic sanitation. All these have placed the country on potential sewage catastrophe. Based on our knowledge, we know of no comparable study combining the wastewater pollution and the treatment systems failures in Sub-Saharan Africa. Consequently, this review highlights the wastewater pollution scenario and weaknesses of the treatment systems in Rwanda. Moreover, it proposes possible recommendations such as the improvement in operation and maintenance of treatment facilities, development of innovative and best affordable technology for Rwandan terrain, promoting public participation by improving joint efforts from different stakeholders to find their own way to protect water, and revolutionize wastewater quality standards by updating our own standard system for monitoring wastewater quality without compromising key health issues in Rwanda.*

Conclusively, this review will serve as all-inclusive model document on wastewater pollution and treatment systems statuses in developing countries, especially in Rwanda.

***Keywords**: Wastewater pollution, wastewater treatment systems, Rwanda, technical problems, trends*

List of Abbreviations

Abbreviations/Acronyms	**Meanings**
SDGs	Sustainable Development Goals
WHO	World Health Organization
UTEXRWA	Usine Textile du Rwanda
CIMERWA	Cimenterie du Rwanda
RSB	Rwanda Standard Bureau
USEPA	United States Environmental Protection Agency
EIA	Environmental Impact Assessment
RRA	Rwanda Revenue Authority
WWTP	Wastewater treatment plant
RBC	Rotating Bioreactor Contactor
SBR	Sequencing Batch Reactors
WSP	Waste Stabilization Ponds
CST	Combined Sewer Treatment
BRALIRWA	Braseries et Limonaderies du Rwanda
SOPYRWA	Société de Pyrèthre au Rwanda
AMEKI	Atelier de Meubles de Kigali
BMC	Brasserie des Mille Collines
WWTS	Wastewater Treatment System

1.0 Introduction

Equitable access to clean drinking water and adequate sanitation are central parts of Sustainable Development Goals (SDGs). Smart and sustainable wastewater management investment will produce several dividends in community, economy, and climate. Farmers benefit freshwater supply, soil quality, preventing surface and groundwater discharges and improving economic outputs from treated agricultural wastewater and reuse(Corcoran et al., 2010). Throughout California, for crop or landscape irrigation, 31 % of treated water is used. While in Mexico, the bulk of City's wastewater is used to irrigate Tula valley. On African continent, Ghana and Senegal safely reuse untreated wastewater for agricultural production and this was evaluated at different options in the fisheries, markets, and food vendors (Corcoran et al., 2010). Farmers in many countries tend to irrigate wastewater because of the economic advantages of saving fertilizers. Moreover, if wastewater treatment plant is harnessed, it can provide energy such as electricity and methane gas (CH_4).

However, 2 million tons of wastewater, manufacturing and agrarian wastes are dumped into the world's rivers (Corcoran et al., 2010). Sato et al.(2013) described a scarcity of data on wastewater production, treatment, and reuse. He revealed that in 181 countries; only 55 countries have data available. Among 48 Sub-Saharan African countries, only Senegal, Seychelles and South Africa had comprehensive information but most data were old (2000-2003). In general, wastewater is a mixture of one or more of: domestic effluent consisting of blackwater and greywater; water from commercial buildings and organizations, including hospitals; industrial sewage, storm water and other urban run-off; agricultural, horticultural and aquaculture effluent, either dissolved or as suspended matter(Burton et al., 2007; Raschid-Sally & Jayakody, 2009). It is composed of a broad-spectrum of components such as organic compounds, synthetic chemicals, nutrients, heavy metals, and pathogens. These components possess bio-cumulative, persistent and synergistic characteristics that affect environmental health and function, food production chain, human wellbeing, and endanger human safety. At the root of the wastewater crisis are insufficient facilities and management processes for rising wastewater volumes. The Africa's low levels of sanitation delivery and wastewater treatment and reuse is partially blamed on old or inappropriate regulations, and on the concentration of regulatory power at the national level while challenges are faced at the local level. Additionally, there is a lack of investment in building new systems or maintenance of those already existing, as well as loss of value when wastewater is neither treated, nor reused. Rwanda is the most densely populated country in East Africa, with 470.6 people per km^2. The population growth, urbanization, and industrialization are key contributors of increased domestic, industrial, and other types of wastewater generation and disposal, which contain a broad spectrum of toxic compounds. Limited capital, topography, old urban resettlements, and lack of qualitative and quantitative data on domestic or industrial wastewater aggravate wastewater complexities. In the past three decades, there have been numerous environmental studies as represented in Table 1, where authors reported wastewater pollution in soil and aquatic ecosystem such as lakes (Muhazi, South Cyohoha and Kivu), rivers (Nyabarongo, Nyabugogo, Mpazi, Rwanzekuma, Mukungwa, etc.), springs, groundwater, and wetlands. Additionally, heavy metals have been biomagnified in fauna (plants and fishes) (G. Wali, 2011; Muhirwa et al., 2006; Olapade, 2012; Patrick et al., 2017; Rutanga, 2014; Sekomo et al., 2011).

Recently, Rwanda experienced a catastrophic industrial wastewater pollution from SOPYRWA LTD and Kigali Leather factories, which killed a massive number of fishes and other aquatic species in rivers Mugara and Mukungwa. Therefore, this pushed the country to toughen their environmental laws. The preliminary laboratory report of a multidisciplinary team revealed a wastewater disposal containing toxic chemicals. Unfortunately, they did not reveal the type of pollutants (The New Times, 2018). The most cited point and non-point sources of wastewater contaminants comprise industries, urban wastes, household wastes, agricultural wastes, mining activities, land use practices, landfill leachates, and other manufacturing discharge products. Run-off from drains and leakages of other wastes from municipal areas add more loads to the main effluents (Bazimenyera et al., 2012). In addition, Rwanda has no centralized public sewage system, no system of sewers, whereas the existing few semi centralized wastewater treatment plants inappropriately function. This shortage of sewer facilities made the population of Kigali city depending on septic tanks and pit latrines, with 95% use in-situ sanitation, 4/5 of them are pit latrines (Akumuntu et al., 2017). However, there is ongoing construction of the first public wastewater treatment plant in Rwanda (The New Times, 2019). In their study, Kazora & Mourad (2018) reported technical, environmental, socioeconomic, legal, and institutional aspects of the nineteen (19) collective sewage treatment plants in Kigali City. This study concluded a poor technical aspect, socioeconomic status, institutional, and legal magnitudes.

Table 1: Main wastewater pollution events in Rwanda

Pollution site/source	**Year**	**Pollutant**	**Reference**
Nyabugogo River	2010,2020	Cd, Pb, Cr, Turbidity	(Nhapi, 2011; Omara et al., 2020)
Nyabarongo River	2020,2019	TN, Fe, Mn, Pb, PO_4^{3-}	(Gasana et al., 1997; Karamage et al., 2016; Nhapi, 2011; Omara et al., 2020)
Rubyiro River	2020	Fe, Mn, Cd, Pb, Turbidity, BOD_5, COD, TSS	(Harelimana et al., 2020; Hubert et al., 2018)
Mpazi River, Yanze River	2008	Chloride, COD, BOD_5, Ca^{2+}, TSS, Total Coliforms, Turbidity	(Nshimiyimana, 2008)
Rusine River	2011	PO_4^{3-}	(Nhapi, 2011)
Mukungwa River	2017	Toxic chemicals(unspecified)	(Nkurunziza, 2018; Ntirenganya, 2018)
Nyabugogo swamp	2011	Cd, Pb, Cr, EC, Mn	(Nkuranga, 2007; Sekomo et al., 2011)
Rweru-Mugesera wetland	2018	TSS	(Mukanyandwi et al., 2018)
Muhazi Lake	2011,2012	Cd, Fe, Pb, pH	(Usanzineza et al., 2011)
Kivu lake	2012, 2013	pH, Temperature, TSS, COD , BOD_5 , TN , TP , Mn, PO_4^{3-}, Coliforms	(Olapade, 2012; Rugwiro & Muhizi, 2013)
UTEXRWA	2020	COD,BOD	(Harelimana et al., 2020; Sano, 2007)
CIMERWA	2020	pH, Turbidity, Alkalinity, TDS	(Harelimana et al., 2020)
Gikondo Industrial Park	2014	Klebsiella, Enterobacter, *S. Aureus*, *E. coli*, BOD_5,COD	(Rutanga, 2014)

SOPYRWA, AMEKI COLOR, Masaka Dairy, Nyanza Dairy, Kitabi Tea Factory, Kinazi Cassava Plant, Eastern Africa Granite, BMC SKOL		2016 NO_3^-, PO_4^{3-},COD, BOD_5	(Mubera et al., 2016)
Muhima Hospital, Central Prison(1930)	2007	COD, TN, TP	(Sano, 2007)

2.0 Wastewater pollution scenario

The wastewater generated by different industries, households and other activities contains a broad spectrum of components, which alter the physicochemical parameters of water environment. Some important parameters used for evaluations include physical parameters (pH , temperature, EC, hardness , DO, alkalinity, TSS , TDS), carbon compounds (BOD , COD), nitrogenous compounds (NO_3^-, NO_2^-, NH_4^+), natural cations (Na^+, K^+, Ca^{2+} and Mg^{2+}), anions ($Cl^−$, $CO_3^{2−}$, $HCO_3^−$, $SO_4^{2−}$) and heavy metals such as (Cr, Cd, Cu, Pb , Ni, zinc, Co, Mg , Fe and As) (Perrin & Scharff, 2002). But the fluctuation of river water quality due to industrial wastewater may vary with corresponding industrial manufacturing processes (Rutanga, 2014). In a study on household wastewater production in Kigali City showed that 32 040 m^3 of domestic wastewater is the likely generated in town per day, which in turn generates 4151 kg / day of TN and 1384 kg / day of TP in terms of pollution load(Mbateye et al., 2010). Nonpoint source pollution of water bodies result from several activities that have been reported to cause a wide variations of critical parameters for assessing water quality across rivers in Rwanda.

2.1 Physico-chemical parameters

At Rwesero, the point after which Nyabugogo river flows out of Lake Muhazi, Nhapi et al.(2011) recorded a pH of 7.24±0.18. The pH of samples were slightly alkaline compared to 7.8 reported by (Usanzineza et al., 2011) in Lake Muhazi. Another research by Nhapi et al (2011) recorded a pH rise in Mpazi river water due to the Nyabugogo abattoir effluent that had a pH of 8.9 ± 0.2. The point source pollution causing the alkaline pH variability in Rwandan rivers was alkaline wastes of textile industry (UTEXRWA) and other factories in Kigali City. Harelimana et al. (2018) reported a high pH (5.0-9.0) in cement mills, storm water and a nearby School that surpassed the standard limit for drinkable water of Rwanda Standard Bureau (RSB). The pH value fluctuated from highly acidic (4.2- 5.2) to alkaline (7.6-8.6) in CIMERWA plant, and the turbidity value was high in every area of the industry. The cement mills showed the highest value of TDS (781mg/L), while raw water had lowest value (63.7mg/L). TDS variation was linked to the manufacturing activity of the industry(Harelimana et al., 2020). However, a study on the physicochemical quality of water and health risks linked to the consumption of *Protopterus annectens* from Nyabarongo and Nyabugogo rivers, Omara et al.(2020) reported a low EC and TDS compared to previously study reported from Nyabugogo, Rwanzekuma, Ruganwa rivers, and Nyabugogo marshland(Usanzineza et al., 2011).

Nkuranga (2007) recorded high values of EC in Nyabugogo swamp which were ascribed to the wastewater influxes particularly from the Rwanzekuma and Ruganwa Rivers. Nhapi et al. (2011) acknowledged a turbidity concentration of 707 ± 37 NTU and increased EC levels from 632 ± 33 to 726 ± 77 micro Siemens/cm on Mpazi River before and after its discharge. The high turbidity and EC levels were associated with a high concentration of TSS and effluent composition of wastewater released from the Abattoir, respectively. The composition of effluents was extremely polluted and can cause environmental hazards to that tributary. The study concluded that the high organic charge point source contamination was blood in wastewater from slaughterhouse(Nhapi, 2011). The high turbidity levels were reported at several sampled points on the Nyabugogo, Rwanzekuma and, Ruganwa rivers and Nyabugogo Marshland due to the Muhazi Lake discharges where high levels were documented in previous literature(Usanzineza et al., 2011). High TSS values of 67.91, 920.90 and 162.86 mg/L in Rweru-Mugesera wetland and Congo-Nile basins were measured, respectively. The different dissolved salts in Rwanzekuma and Ruganwa Rivers were informed, the author speculated various industries located in Kigali to be the point source of the pollution(Usanzineza et al., 2011). Mbateye et al. (2010) reported a ubiquitous straight release of wastewater specifically in areas in vicinity of swamps (Kajevuba, Kagugu, Gatenga, Mulindi, Rwampara) and the drains. The pH, conductivity, oxygen absorbed, total dissolved solids, demand for chemical oxygen, total nitrogen, and total phosphorous were predominantly very high.

High levels of NH_4-N have been reported in downstream areas towards Kigali city due to the release of domestic wastewater from Kigali urban areas (Nhapi, 2011). Giticyinyoni water had a total value of nitrogen (TN) greater than the appropriate maximum. Complete Kjeldahl concentrations of nitrogen, nitrite, nitrate, and ammonia were small. However, insignificant variations in nitrite levels have been observed in water from Nyabugogo river. At the other hand, nitrate levels were below those previously recorded for the Nyabugogo river(Nhapi, 2011). Recently, Omara et al. (2020) recorded a low concentration of sulphates (SO_4^{2-}) and phosphates (PO_4^{3-}), supporting previous study by Nhapi et al.(2011) who hypothesized that high level of sulphates in some Nyabugogo river sites may be caused by contamination from UTEXRWA factory waste.

Studies on the main brewing industries (Bralirwa Brewing LTD and Skol Brewing LTD) in Rwanda showed a wastewater pollution to the fresh water system (Kivu lake, Nyabarongo river) with high content of organic compounds such as BOD_5,COD, nitrate, and phosphate(Harelimana et al., 2020; Rugwiro & Muhizi, 2013). Harelimana et al.(2020) reported that BOD, COD, and TSS concentrations recorded in Rubyiro River were beyond WHO guidelines. This was attributable to a direct disposal of untreated wastewater into the River from Cimerwa factory. This amplified water hardness and worsens mineral ions loading from upper stream towards the river thereby intensifying the freshwater pollution incidents. The richness in limestone and clay quarries in the region influence much hardness of water, whereas it similarly aggravates mineral ions charging from upper stream to the river escalating the freshwater pollution occurrences. Physico-chemical analysis of effluent from Gikondo industrial park revealed a moderate turbidity and a high content of organic compounds (BOD, COD) compared to WHO standards. The effluent from Gikondo industrial park was characterized as highly polluted and need pretreatment before disposal in environment (Rutanga, 2014). Sano(2007) reported a high concentration of organic nutrient (COD, TN, TP) at most of the sampling sites of Muhima Hospital and Kigali Central Prison (1930).

2.2 Heavy metals

Gasana et al.(1997) conducted a research on the outflow of 16 industrial facilities on the Nyabarongo River tributaries comprising around 70% of all factories in Kigali City. The analysis of heavy metals did not exceed USEPA drinking water standards, due to the high flow rate of the Nyabarongo River, however the lead concentration (0.013 mg/L) was closer to 0.015 mg/L. Nsengimana et al. (2012) recorded fluctuation in pollution levels of nutrients and heavy metals of groundwater (springs, boreholes, wells) which exceeded the standards recommended by WHO. Nkuranga(2007) revealed that direct discharge and overflowing of wastewater from industrial areas surrounding municipal activities contributes to the environmental contamination. Usanzineza et al.(2005) reported a high concentration of Lead (0.113 ± 0.054 mg/L) in the summer season.

Nyabugogo tannery and car park area were associated with the pollutant due to a lot of raw chemical materials from these areas. Lead is not an essential toxic heavy metal that interferes with main trace metals for example Calcium and Zinc. A previous study reported 28.85±23.53 mg / L of Manganese in Nyabarongo stream (Nhapi, 2011).

Harelimana et al.(2020) conducted a cross sectional research on weaknesses in the implementation of EIA in Rwandan industries and reported a higher levels of turbidity and heavy metals such as Fe, Mn, Cd, Pb compared to the standard guidelines for drinking water (WHO, 2006) at Rubyiro river. Significant heavy metal emission sparkling the hostile impact of manufacturing operations and indiscriminate influential and effluent discharge into the Rubyiro River was suggested. Bioaccumulation of heavy metals (Mn, Zn, Cu, Fe, Ni, Pb and Cd) has recently been identified in the edible parts of *Amaranthus spinosus*, *Ipomoea batata,* and *Colocasia esculenta* in industrial-active soils in Kigali, Rwanda(Etale & Drake, 2013).

2.3 Microbiological parameters

The purpose of microbiological analysis of water is to identify water sources contaminated with potential microbial pathogens. Generally, contamination arises either through mistreatment of sewage or inadequately functioning of treatment system. The bacteriological assessment of water and ground water in different part of Rwanda reported a maximum microbial pollution load due to Klebsiella, Enterobacter, Staphylococcus and *Escherichia coli* (Nigatu et al., 2015; Rutanga, 2014; Uwimpuhwe et al., 2014). Olapade (2012) revealed poor microbial status of sampled location of lake Kivu due to the widespread of total heterotrophic bacteria, fecal coliforms, total coliforms, and fecal streptococcus. The high microbial load was associated to anthropogenic wastes of organic origin. Therefore, water is not suitable for domestic use without pretreatment. The microbial load of bioindicators organisms (coliforms) in the Rubyiro river samples showed a strong contamination of fecal origin, completely causing fecal pollution phenomenon in the river system(Harelimana et al., 2020). For more compiled information on wastewater pollution scenario in Rwanda and other African countries, you can check Table 1& 2.

Table 2: Chemical water quality in aquatic ecosystem (water, sediments, and fishes) of African countries

Contaminant	Sample	Ghana	Egypt	Morocco	Zimbabwe	Uganda	Nigeria	SA	Zambia	Tanzania	DRC	WHO
As	*	LOD-28 µg/L	NA	0.7–4.9 µg/L	NA	NA	NA	NA	NA	NA	NA	10 µg/L
Pb	* ** ***	LOD-34 µg/L	11.2 mg/kg	nd–4.5 µg/L	NA	NA	NA	0.1-5 mg/L	3.8±1.0-33± 2.5 mg/kg	4.9 ±3.1 mg/kg	NA	10 µg/L
U	*	>15 µg/L	NA	0.24-3.94 µg/L	NA	NA	NA	NA	NA	NA	NA	15 µg/L
B	*	LOD-2034 µg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	500 µg/L
Mn	* **	LOD-5700 µg/L	280 mg/kg	nd–573 µg/L	10–590 µg/L	NA	0.18 mg/L	NA	NA	NA	NA	100 µg/L
Fe	* **	LOD-82 mg/L	1.2%	NA	0.69–1.34 mg/L	NA	0.2–0.57 mg/L	NA	NA	NA	NA	0.3 mg/L
Cd	* ** ***	NA	0.18 mg/kg	0.01-0.07 µg/L	NA	NA	NA	NA	4.4±0.8 mg/kg	0.39±0.1 mg/kg	NA	3 µg/L
Cr	* ** ***	NA	30.8 mg/kg	0.78–214 µg/L	NA	NA	3-11.3 mg/kg	NA	0.7±0.4 mg/kg	NA	NA	50 µg/L
Cu	* ** ***	NA	21.8 mg/kg	9.8–40.9 µg/L	NA	2.5 ± 1.6 mg/kg	190 µg/L	0.12-0.81 mg/L	9,700±800 mg/kg	5.90±3.4 mg/kg	370.8-47468 mg/kg	2000 µg/L
Co	* **	NA	NA	NA	NA	NA	NA	NA	NA	NA	240.6-13199 mg/kg	1mg/L
Zn	* ** ***	NA	35.4 mg/kg	1.9–285 µg/L	<0.01	64 ±10.9 mg/kg	26.6-148 mg/kg	0.09-81.1 mg/L	300± 23 mg/kg	101±15 mg/kg	NA	3000 µg/L
Ni	***	NA	NA	NA	NA	2.5 ± 0.4 mg/kg	NA	NA	1.5±0.3 mg/kg	NA	NA	2 mg/L
Hg	***	NA	NA	NA	NA	NA	NA	NA	NA	0.063 mg/kg	NA	0.002 mg/L
Al	*	NA	NA	NA	NA	NA	NA	0.12-18.7 mg/L	NA	NA	NA	-

Total ammonia	*	NA	NA	2-40 mg/L	NA	NA	NA	NA	NA	NA	NA	1.5 mg/L
Phosphate (PO_4^{3-})	*	NA	NA	nd–3 mg/L	0.01–0.03 mg/L	NA	NA	NA	NA	NA	NA	3 mg/L
COD	*	NA	NA	NA	NA	NA	NA	36-1038 mg/L	NA	NA	NA	250 mg/L
Fluoride	*	LOD-19 mg/L	NA	NA		NA	1.29 mg/L	NA	NA	NA	NA	1.3 mg/L
Nitrate (NO_3^-)	*	LOD-508 mg/L	NA	nd–11 mg/L	0.1–0.5 mg/L	NA	14.7 mg/L	NA	NA	NA	NA	50 mg/L
Chloride	*	0.14 mg/L-20 g/L	NA	145–219 mg/L	NA	NA	15.8 mg/L	NA	NA	NA	NA	250 mg/L
Sulfate	*	0.14-2184 mg/L	NA	19.4–107 mg/L	NA	NA	5.27 mg/L	NA	NA	NA	NA	500 mg/L
pH	*	3.7–8.9	NA	7.1–8.5	7.4–7.6	NA	7.05	NA	NA	NA	NA	6.5–8.5
References	-	(Schäfer et al., 2009)	(Goher et al., 2014)	(Koukal et al., 2004)	(Meck et al., 2009)	(Lwanga et al., 2003)	(Olalekan et al., 2015)	(Iloms et al., 2020)	(Norrgren et al., 2000; Syakalima et al., 2001)	(Chale, 2002; Harada et al., 1999)	(Atibu et al., 2013)	(WHO, 2004)

LOD: low detection

NA: not detected

*: water sample

**: sediment sample

***: fish sample

3.0 Wastewater treatment

3.1 Background information

The management of the water valves by septic tanks and soak pits was introduced in Rwanda several years ago, the former management of wastewater units constituting a source of industrial pollution were those of CHUK hospital in 1970, and the social fund of Rwanda at Kacyiru in 1985 with a continuous activated sludge technology. Later in 1991, a pilot lagoon station was set up in Ruhengeri town, today is no longer exists. In 1998, the Nyarutarama lagoon was created to treat wastewater from the Nyarutarama Estate. The following year, many Estates and hotels were constructed with related to wastewater treatment plants especially biological treatment system disc each. Then after, biological disc soon reached their limits. According to statistics from the Rwanda Revenue Authority (RRA), motorized wastewater treatment units entered in Rwanda since 2007 and experienced a meteoric rise up until the end of 2014, where 161 wastewater treatment units were distributed throughout the country (*Fig. 1&2*).

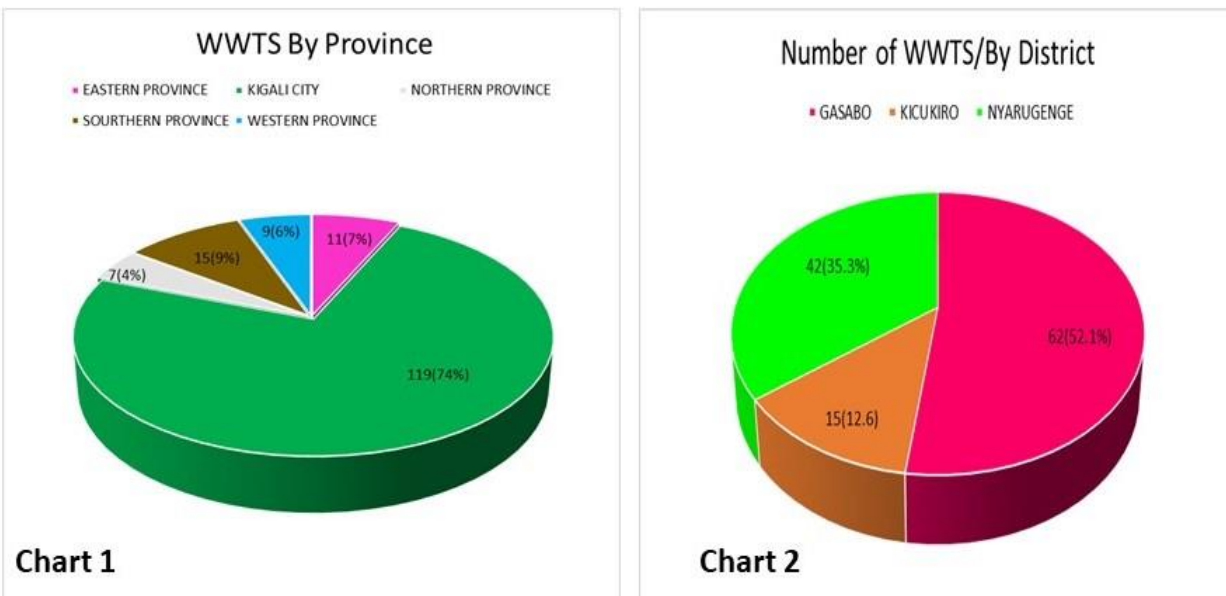

Fig 1. Number of WWTS by Province and Capital City (Chart 1: WWTS by Province, and Chart 2: Kigali City).

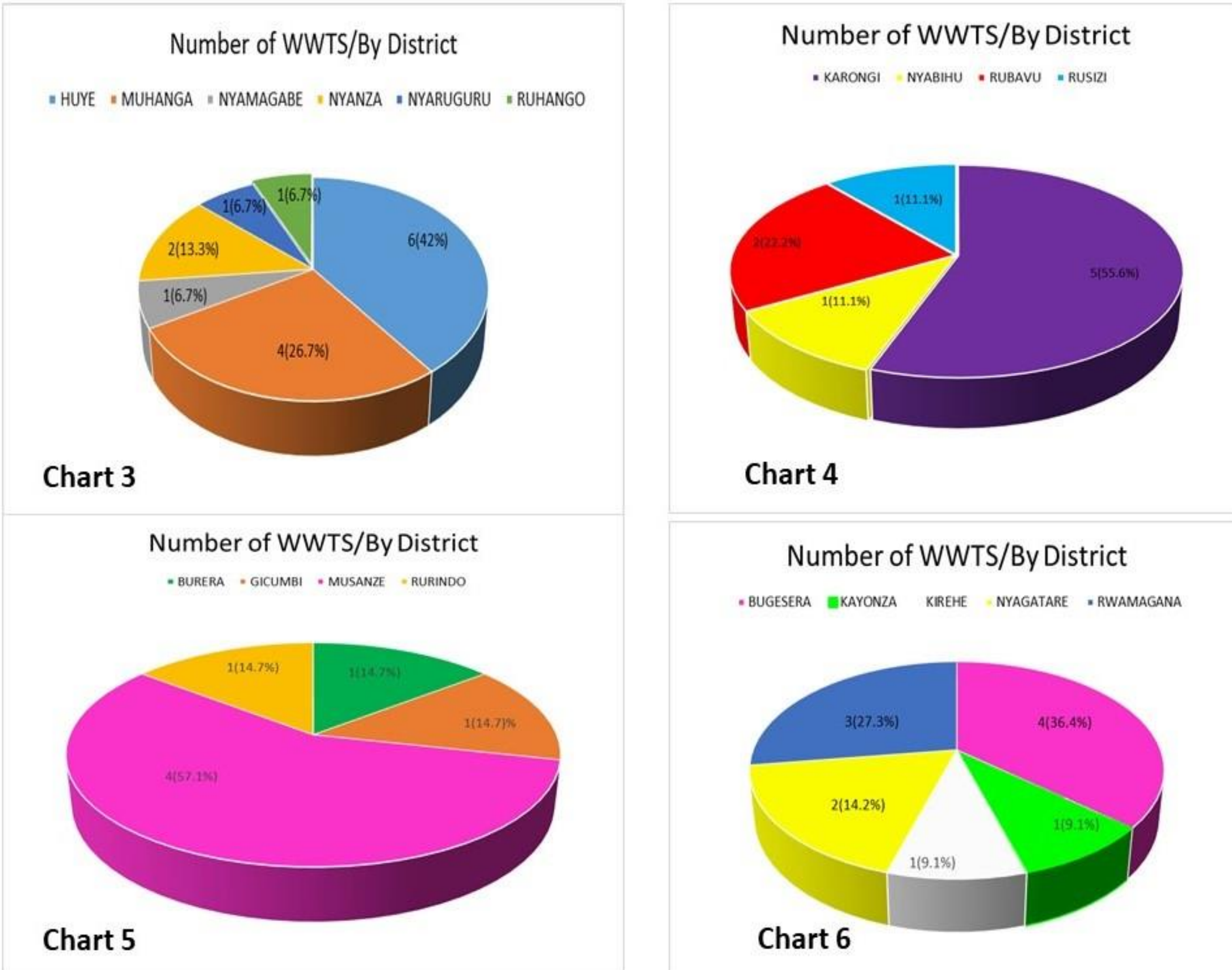

Fig 2: Number of WWTS by Districts (Chart 3: Southern Province, Chart 4: Western Province, Chart 5: Northern Province, and Chart 6: Eastern province)(Entreprise du Génie des Infrastructures, 2015).

3.2 Onsite treatment

Decentralized wastewater treatment systems are in-situ wastewater treatment systems for small volumes of wastewater near the generation site, from individual households, on-site (fully decentralized) systems to semi-centralized wastewater treatment plants(Libralato et al., 2012; van Afferden et al., 2015). The low operating costs and expertise make decentralized wastewater treatment systems a good choice of sanitation particularly for small communities in developing countries(Kazora & Mourad, 2018). There is lack of centralized sewerage in Rwanda(*Fig. 3*) and few existing semi-centralized sewerage systems belongs to hospitals, hotels, government institutions, real estates and large commercial buildings. Kicukiro District have three new real Estates with small network of sewer pipes linked to the treatment plants (Kacyiru SSFR plant, Vision 2020 plant, and Nyarutarama wastewater treatment plant). The population of Kigali city depend on septic tanks and pit latrines for sanitation facilities, with 95% uses in-situ sanitation, with 80% utilize pit latrines (Akumuntu et al., 2017). Moreover, 2% of the households in Kigali city used to empty the sludge from their pit latrines to the Nduba landfill (Tsinda et al., 2013).

Poor maintenance and management of these pit latrines leads to groundwater quality deterioration. Most pit latrines get full and the blackwater flows. This become a source of waterborne diseases transmission. Additionally, there is little data about the technical, environmental, socio-economic and legal conditions of Decentralized Wastewater Treatment Systems at local level and urban scale in low-income countries, including Rwanda. Some wastewater from toilets is collected and transported by public and private companies to Nduba and other landfill sites around the country for disposal. In Rwanda, existing wastewater treatment technologies include Activated Sludge Technology, Trickling Filter Plants, Waste Stabilization Ponds, Sequencing Batch Reactors, Constructed Wetlands, Combined Sewer Treatment, Oxidation Ditches, Rotating Bioreactor Contactor, and Aerated Lagoons. Other technological treatments include (ASPA, BPSTP, JAWTP, Oxyfix, and IST).

3.3 Offsite treatment

Centralized sewage system consists of sewer network that carries wastewater from households to treatment plants and discharges the effluent into the environment. Like other East African cities (Dar es Salaam, Mwanza, Nairobi and Kampala), Kigali City lacks integrated sewage systems for collection and transportation. However, around the country (*Fig. 3*), there are different small-decentralized wastewater treatment plants. The same shortage of centralised sewer system occurs in Uganda, where the country has only two central sewage treatments in Kampala and Masaka cities, while it applies stabilization ponds for the other sewerage treatment plants. The main sewage treatment system in Nairobi known as Dandora stabilization pond has a capacity of over 80 000 m^3/day and receives about 80% of wastewater produced from the city(Pearson et al., 1996). Its main processes comprise anaerobic ponds, facultative ponds, and maturation ponds, according to national water and sewerage corporation (NWSC).

4.0 Key issues of wastewater treatment systems

Only about 2% cent of the daily 300 tons of waste dumped in Nduba sector is recycled. According to a 2016 report by the Auditor General's Office, Kigali City lacks a centralized sewage treatment plant and sewer system. The existing semi-centralized sewerage systems belongs to hospitals, hotels, government institutions, real estates, and large commercial buildings. It is an obligation to build these sewerage systems for their wastewater treatment before being disposed in environment, however in Rwanda numerous decentralized wastewater treatment practices are still unsafe and unreliable (UN, 2014). Such networks typically experience functional issues due to poor network management and erratic maintenance(Akumuntu et al., 2017). The large portion of the effluent produced in the city is partially treated and the other portion is disposed into septic systems or to the open drains built for storm water conveyance.

4.1 Technical and environmental issues

The major technical challenges of decentralized sewer systems include capacity, reliability, wastewater reclamation and reuse, compliance with quality standards, sewer system existence, sewer system and wastewater treatment coverages, non-conventional technologies, hybrid technologies, water demand, wastewater supply, and wastewater composition, while environmental key issues include environmental protection, resources consumption and, environmental benefits(Bernal et al., 2012). Poor operation and maintenance is a challenge for wastewater treatment plants (WWTPs). Due to a limited available information and experiences, most manufacturers in Africa do not have access of the applicable technologies to treat pollutants from industrial effluents. Disinfection is a crucial step for wastewater treatment, but the effluent is discharged into the rivers or lakes without disinfection by WWTPs. Effluent from stabilization pond from Dandora WWTP is conveyed into the Nairobi River, where livestock drink the polluted river water. This might affect livestock and human health in the long term. Much high level of *Escherichia coli* was recorded in the effluent of Bugolobi wastewater treatment than the discharge standard according to national water and sewerage corporation (NWSC).

Stabilization ponds and lagoons present critical problem of the heavy load of influent. The influent concentration is high due to inadequate pretreatment of industrial effluents. Example in point is the Dandora wastewater treatment plant(WWTP), Kenya (Li et al., 2011). The influent COD and BOD in WWTP were 2030 and 1500 mg/L, respectively. While the average removal of organic pollutants covered was 70%. Additionally, the average removal efficiency of ammonia nitrogen (NH_3-N), total nitrogen (TN), and total phosphorus (TP) was only 46, 36, and 16%, respectively. The effluent from the treatment system was severely colored due to algae(Wang et al., 2014). In Ethiopia, Addis Ababa, <3% of wastewater is linked to the wastewater treatment facilities (Abiye et al., 2009). Another case in Kenya, Kisumu District, the three existing pump stations were broken down and caused the overflow of sewage at manholes upstream of the pump stations, as well as the direct disposal of sewage to Lake Victoria(Parkman et al., 2008). Absence of power supply in Africa also hampers water and wastewater treatment to a gigantic proportion (Wang et al., 2012).

The compiled information from unpublished baseline data report on general working conditions and effluent disposal of decentralized wastewater treatment plants revealed the technological and environmental key issues of wastewater and their treatment systems in Kigali City (Tables 3 and *Fig.4&5*) and other Districts around the country (Table 4).(Entreprise du Génie des Infrastructures, 2015; Ingegneria et al., 2019). Technically, treatment plants deal with power cuts and the high energy costs have been cited as key constraint in different countries (Josiane et al., 2013). Low operation and maintenance due in part to lack of capital, high cost of energy, and lack of re-investment. Pipeline defects such as deflections, punctures, fractures, corrosion, degradation of grouts and joints, root penetration, thermal and non-thermal stress or pressure, and soil subsidence may occur during installation or over time (Tafuri & Selvakumar, 2002).

In addition, Tafuri et al.(2002) reported that rainfall-induced storm water runoff infiltration cause fast groundwater drainage around sewers, including manholes and building connections, which then enter the network through damaged pipes, pipe joints, or manhole walls(Tafuri & Selvakumar, 2002). Usually, sewerage network systems carry both sanitary sewage and most of storm water from the estate houses, unfortunately were primarily designed to carry only sanitary sewage. The inhabitants who unlawfully convey storm water into the sewerage network system cause this. Furthermore, most of the grease removal units on households' networks were clogged and others sealed which confirms lack of monitoring. The effluent disposed from the plant into the environment is unfrequently tested. Moreover, there is irregular record keeping system for activities carried out at the treatment plants.

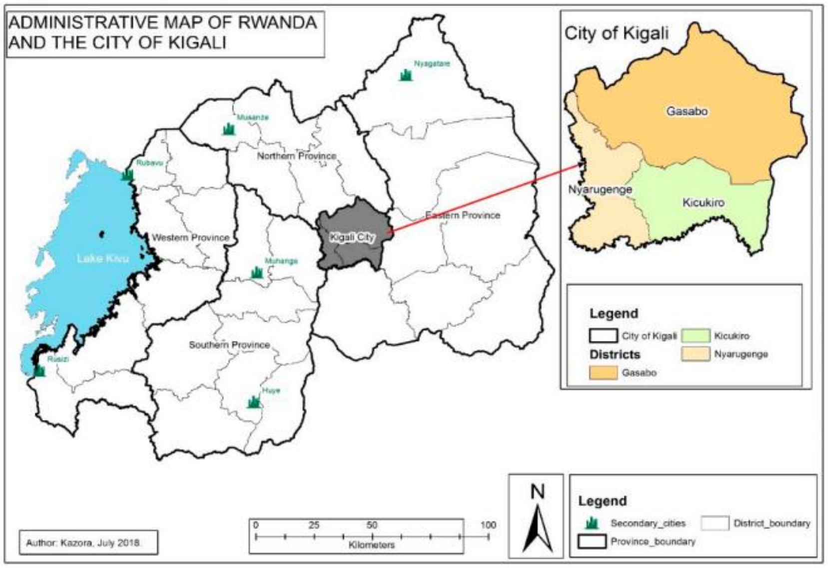

Figure 3: Administrative map of Rwanda, Kigali city(National Institute of Statistics Rwanda (NISR), 2012)

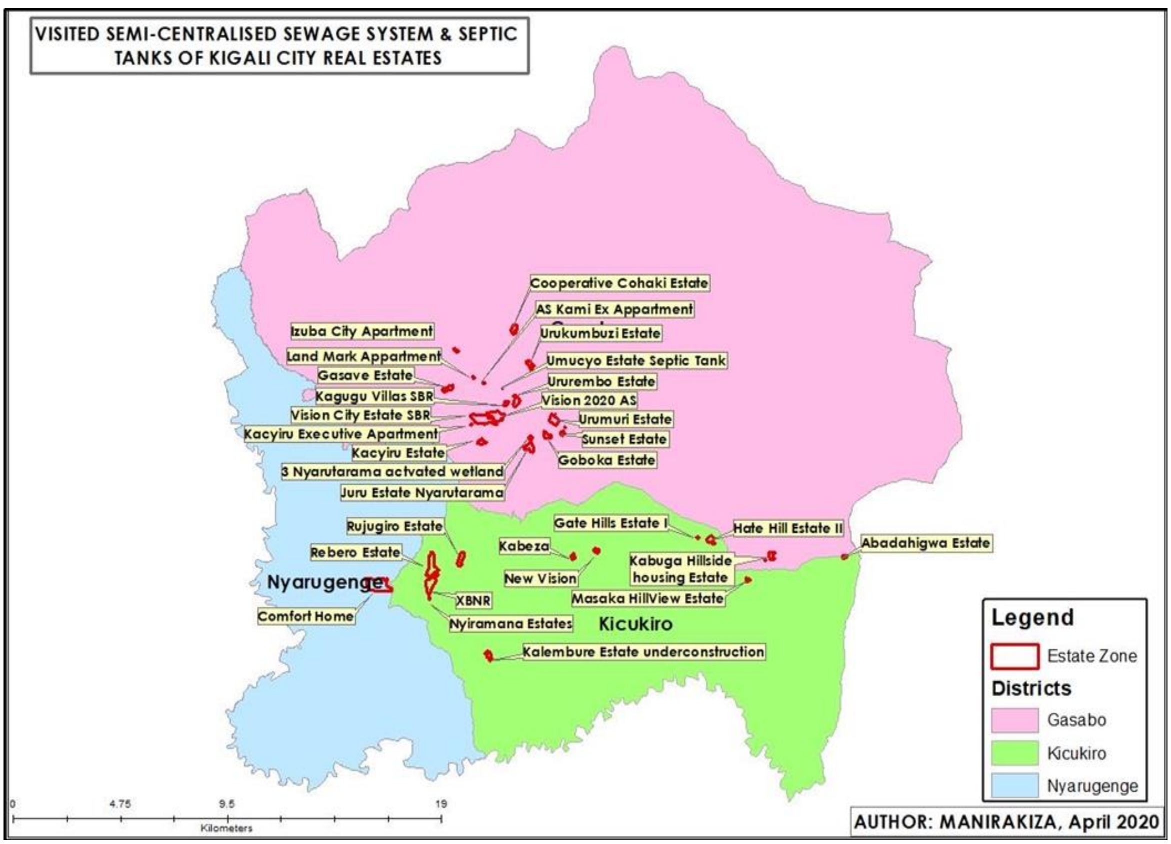

Fig 4: Semi-Centralised Sewage System and Septic Tanks of Kigali City Real Estates

Table 3: Technical and Environmental problems of Kigali Real Estate's Wastewater Treatment Systems(Ingegneria et al., 2019)

Centralized/decentralized Wastewater treatment plant	GPS coordinates	Technology	Technological/Environmental problems
Kacyiru Estate	1°54'56.6"S 30°04'19.1"E	ASP	- Mixing of Storm water and Wastewater - Old appurtenances - Poor aeration and electrical motor failure as prime causes of bad smell at the plant
Sunset	1°55'51.54"S 30°07'07.30"E	ASP	-Clogged manholes overflows and lead to bad smelling - Lack of Wastewater treatment plant - Bad Location of the sewer system
Kami executive Apartment	1°54'48.82"S 30° 5'10.13"E	ASP	-Absence of soak pit that receives final effluents
Niboyi New Vision Estates	1°58'56.45"S 30° 7'18.53"E	ASP	-High electricity bills to power the plant - Foul-smelling pool with black water - Irregular connection of grey water into Storm water drainage System
Vision 2020 Estates	1°55'44.17" S 30°05'26.21"E	RBC	- Foul-smell - Noise pollution during maintenance
Land Mark Apartment (Kirenga)	1°54'40.08"S 30° 4'56.47"E	ASPA	-Grey water disposal in an open space -Bad smelling caused by improper maintenance of the manholes
Izuba City Apartment	1°54'2.98"S 30° 4'31.81"E	BPSTP	-Oily-smelling observed during site visit - Non-compliance of REMA standards - Wastewater overflow in the surrounding areas - Lack of technician in charge of the site - The WWTP was not working properly
Gate Hills Estate II (Sekimondo)	1°58'31.80" S 30°10'40.45" E	JAWTP	-Absence of fence to keep away trespassers -The plant presented a potential source of nuisance to the resident and agriculture area nearby.
Kabuga Hillside Housing Estate	1°59'03.81" S 30°12'02.59" E	JWTP	- Foul-smell - Noise pollution during maintenance

Mountain Ridge Estate	1°59'36.10"S 30° 2'35.51"E	Oxyfix	- Groundwater pollution by polluted effluent - Absence of the technician in charge of WWTP operation and maintenance
R&B Estate(Martin Estates)	1°59’55.43” S 30°03’51.57’E	Oxyfix	-Bad smelling, bad Location of WWTP, and lack of plant maintenance
Vision City Estate	1°55’47.77” S 30°04’53.21” E	SBR	-Groundwater and soil contamination
Kagugu Villas Housing Estates	1°55’12.49” S 30°06’01.74” E	SBR	-Groundwater and soil contamination
Juru Estates (Nyarutarama Lagoons)	1°56'21.24"S 30° 6'19.08"E	WSP	- No management and maintenance of the facility, which make new houses to connect their septic tanks and toilets to the lagoon, all these resulted in floating of fresh faeces - Groundwater and soil contamination
Comfort Home Estate	1°59'6.74"S 30° 3'54.90"E	ASP	-Groundwater and soil contamination
Stipp Estate (Gaposho)	1°54’56.6” S 30°04’19.1” E	IST	-Groundwater and soil contamination
Gasave Estates (Gaposho I)	1°54'58.60"S 30° 4'13.80"E	IST	-Groundwater and soil contamination
Goboka Estate	1°56’08.23” S 30°05’08.43” E	IST	-Groundwater and soil contamination
Ururembo	1°55'14.41"S 30° 5'58.27"E	IST	-Groundwater and soil contamination
Urukumbuzi II	1°54'20.31"S 30° 6'16.00"E	IST	-Groundwater and soil contamination

Rujugiro Estate	1°59'2.39"S 30° 4'36.84"E	IST	-Groundwater and soil contamination
Abadahigwa	1°58'56.45"S 30°13'48.01"E	IST	-Groundwater and soil contamination
Masaka Hill view	1°59’27.70” S 30°11’31.91” E	IST	-Groundwater and soil contamination
EX-BNR	1°59'38.95"S 30° 3'52.11"E	IST	-Groundwater and soil contamination
Karumeyi Village Estate	1°58'48.37"S 30° 7'54.18"E	IST	- Groundwater and soil contamination
Cooperative COHAKI Estate	1°53'31.67"S 30° 5'52.64"E	IST	- Groundwater and soil contamination
Nyiramana Estate	1°59’53.16”S 30°03’52.48”E	CST	- Bad smelling during the emptying - Storm water is combined with wastewater - Overflow of the septic tank during heavy rain
Umucyo Estate	1°54’56.57”S 30°05’37.56”E	CST	-Effluent from septic tanks is discharged in downstream wetland through an open channel, causing bad smelling -Lack of WWTP causing downstream water pollution

Table 4: Technical and Environmental problems of Districts Wastewater Treatment Systems (Ingegneria et al., 2019)

No	District	Liquid waste management infrastructures	Major problems
1K 2K 3K	Nyarugenge Gasabo Kicukiro	- NDUBA is the only landfill site receiving all kinds of waste (liquid and solid). -There is an abandoned dumpsite that the city of Kigali previously used (Nyanza Sector) -There is no faecal sludge treatment system	- Liquid waste into pits have become like small lakes. - The system of collection in pits does not give a fair and sustainable solution, as many pits are required to accommodate that liquid waste. The 5 pits were already full and they were digging a fourth one. - These pits are located on the top of the hill and if it rains heavily, they are likely to overflow and spread in the neighborhood and contaminate water and crops. This leads to spread of disease to the neighboring population. - Lack of leachate management and treatment system
4N	Burera	-Soak pits and septic tanks are used as liquid waste infrastructures, for HHs level, when the soak pits get full, they dig new pit. -Hospitals are using semi centralized sewage system where all liquid waste are treated at the point by means of septic tank and soak pit.	-Burera lacks most of the wastewater infrastructures to treat effluents for reuse purpose - There is no private company operating in the district for liquid waste collection and transportation -No information about the annual, weekly, monthly or per-capita liquid waste generation
5N	Gakenke	-Soak pits and septic tanks are used as liquid waste infrastructures, for HHs level, when the soak pits get full their dig new pit. - Hospitals are using semi centralized sewage system where all liquid waste are treated at the point by means of septic tank and soak pit.	-Lack of leachate management system, unskilled cooperatives provide the wastewater collection and transportation service - There is no private company operating in the district for liquid waste collection and transportation -No information about the annual, weekly, monthly or per-capita liquid waste generation

No	District	Liquid waste management infrastructures	Major problems
6N	Gicumbi	-Use of pit latrines and conventional septic tanks for the liquid waste (sewage). There is a system that receives and treats the sewage emptied from septic tanks from different parts of Gicumbi District. -Wastewater is collected, transported, and deposited into DEFAST located at Rukomo -There is a faecal sludge (liquid waste) treatment plant and is not integrated with the solid waste leachate.	-No integrated system for the management of the leachate and the sludge. -They do not know the quality of the effluent after passing through all treatment steps in the DAFEST -No information about the annual, weekly, monthly or per-capita liquid waste generation
7N	Musanze	-Wastewater treatment and disposal is characterized by the use of pit latrines, and septic tanks. For the liquid waste (sewage), there is no system that receives and treats liquid waste coming from community. -Currently, Musanze District does not have a place reserved for liquid waste. -There is no faecal sludge treatment system.	-Lack of leachate management and treatment system. - There is no private company operating in the District for liquid waste collection and transportation. -No information about the annual, weekly, monthly or per-capita liquid waste generation
8N	Rulindo	-Soak pits and septic tanks are used as liquid waste infrastructures. For HHs level, when the soak pits get full, they dig new pit. -Hospitals are using semi centralized sewage system where all liquid waste are treated at the point by means of septic tank and soak pit.	-No leachate management leading to contamination of groundwater. - There is no private company operating in the district for liquid waste collection and transportation -No information about the annual, weekly, monthly or per-capita liquid waste generation
9E	Bugesera	-Liquid waste is being collected and transported to NDUBA landfill (Kigali City, Gasabo District).	-Liquid waste soak pits are located on the top of the hill and if it rains heavily, they are likely to overflow and spread in the neighborhood and contaminate water and crops. This leads to spread of disease to the neighboring population.

No	District	Liquid waste management infrastructures	Major problems
			- There is no private company operating in the district for liquid waste collection and transportation -No information about the annual, weekly, monthly or per-capita liquid waste generation
10E	Gatsibo	-The soak pits and septic tanks are only the infrastructures use to manage all liquid waste coming from community. -Hospitals and government institutions use their own way for liquid waste treatment and/or storage system	-There is no faecal sludge treatment system -Soak pits contaminates downstream springs. -No information about the annual, weekly, monthly or per-capita liquid waste generation
11E	Kayonza	-There is a faecal sludge treatment plant integrated with solid waste composting -The effluent is discharged into the soak pit (diameter: 3m, depth: 25m) after the treatment.	-Groundwater contamination at downstream wetland with the faecal sludge treatment system -No information about the annual, weekly, monthly or per-capita liquid waste generation
12E	Kirehe	-Soak pits and septic tanks are used as liquid waste infrastructures. For HHs level, when the soak pits get full, they dig new pit. -Hospitals are using semi centralized sewage system where all liquid waste are treated at the point by means of septic tank and soak pit. -There is no faecal sludge treatment system	-When the soak pit get full, they closed it for two years, empty it and used in cultivation of crops. No research has been done to check the quality of liquid or solid sewage in the pit before applying them on the crops. - There is no private company operating in the district for liquid waste collection and transportation -No information about the annual, weekly, monthly or per-capita liquid waste generation

No	District	Liquid waste management infrastructures	Major problems
13E	Ngoma	-Soak pits and septic tanks are used as liquid waste infrastructures. For HHs level, when the soak pits get full, they dig new pit. -Hospitals are using semi centralized sewage system where all liquid waste are treated at the point by means of septic tank and soak pit. -There is no faecal sludge treatment system.	-When the soak pit get full, they closed it for two years, empty it and used in cultivation of crops. No research has been done to check the quality of liquid or solid sewage in the pit before applying them on the crops. -Groundwater contamination at downstream wetland with the faecal sludge treatment system - There is no private company operating in the district for liquid waste collection and transportation -No information about the annual, weekly, monthly or per-capita liquid waste generation
14E	Nyagatare	-There is a faecal sludge treatment plant integrated with solid waste composting. - The effluent is discharged into the soak pit (diameter: 3m, depth: 25m) after the treatment. -There is a faecal sludge treatment plant integrated with solid waste composting.	-Groundwater contamination at downstream wetland with the faecal sludge treatment system -No information about the annual, weekly, monthly or per-capita liquid waste generation
15E	Rwamagana	-Soak pits and septic tanks are used as liquid waste infrastructures. For HHs level, when the soak pits get full, they dig new pit. -Hospitals are using semi centralized sewage system where all liquid waste are treated at the point by means of septic tank and soak pit. -There is no faecal sludge treatment system	- When the soak pit get full, they closed it for two years, empty it and used in cultivation of crops. No research has been done to check the quality of liquid or solid sewage in the pit before applying them on the crops. -Groundwater contamination at downstream wetland with the faecal sludge treatment system

No	District	Liquid waste management infrastructures	Major problems
16S	Gisagara	-There is no faecal sludge treatment system plants -Hospitals use their own liquid waste treatment -There is a landfill and liquid waste disposal and natural treatment area for the refugee community living in Gisagara District	-There is a liquid waste disposal area for the refugee community that belongs to a private owner in Mugantwa sector. The land owner gets the natural compost (mix of liquid waste/faecal sludge and biodegradable waste) and used for his banana farm - There is no private company operating in the district for liquid waste collection and transportation -No information about the annual, weekly, monthly or per-capita liquid waste generation
17S	Huye	-Soak pits and septic tanks are used as liquid waste infrastructures. For HHs level, when the soak pits get full, they dig new pit. -The liquid waste is transported to Nyanza. -Hospitals use their own, liquid waste treatment and/or storage system. -There is no faecal sludge treatment system.	- -When the soak pit get full, they closed it for two years, empty it and used in cultivation of crops. No research has been done to check the quality of liquid or solid sewage in the pit before applying them on the crops. -Groundwater contamination at downstream wetland with the faecal sludge treatment system -No information about the annual, weekly, monthly or per-capita liquid waste generation
18S	Kamonyi	-Soak pits and septic tanks are used as liquid waste infrastructures. For HHs level, when the soak pits get full, they dig new pit. -Hospitals use their own, liquid waste treatment and/or storage system. -There is no faecal sludge treatment system.	- When the soak pit get full, they closed it for two years, empty it and used in cultivation of crops. No research has been done to check the quality of liquid or solid sewage in the pit before applying them on the crops. -Groundwater contamination at downstream wetland with the faecal sludge treatment system -No information about the annual, weekly, monthly or per-capita liquid waste generation

No	District	Liquid waste management infrastructures	Major problems
19S	Muhanga	-There is no faecal sludge treatment system. -Hospitals use their own, liquid waste treatment and/or storage system -The district office has a plan to construct a sanitary landfill and feacal sludge treatment plants in (Nganzo cell and Muhanga sector).	- When the soak pit get full, they closed it for two years, empty it and used in cultivation of crops. No research has been done to check the quality of liquid or solid sewage in the pit before applying them on the crops. -Groundwater contamination at downstream wetland with the faecal sludge treatment system - There is no private company operating in the district for liquid waste collection and transportation -No information about the annual, weekly, monthly or per-capita liquid waste generation
20S	Nyamagabe	-Soak pits and septic tanks are used as liquid waste infrastructures. For HHs level, when the soak pits get full their dig new pit. -Hospitals are using semi centralized sewage system where all liquid waste are treated at the point by means of septic tank and soak pit. -There is no faecal sludge treatment system	-There is not facilities or infrastructure to treat wastewater for reuse purpose - There is no private company operating in the district for liquid waste collection and transportation -No information about the annual, weekly, monthly or per-capita liquid waste generation
21S	Nyanza	-There is a modern faecal sludge treatment plant integrated with solid waste composting -The faecal sludge treatment is designed to receive all the liquid waste from urban and rural areas of nyanza district, but mayor of suggested that all nearby district will be using this FSTP instead of constructing new ones in the entire province.	-No information about the annual, weekly, monthly or per-capita liquid waste generation
22S	Nyaruguru	-There is no faecal sludge treatment system. -The system for liquid waste handling is septic tank combined with soak pits -Hospitals, public institutions and hotels use their own semi centralized liquid waste treatment / or by septic tank.	-There is not facilities or infrastructure to treat wastewater for reuse purpose - There is no private company operating in the district for liquid waste collection and transportation -No information about the annual, weekly, monthly or per-capita liquid waste generation

No	District	Liquid waste management infrastructures	Major problems
23S	Ruhango	-There is no faecal sludge treatment system. -Hospitals use their own liquid waste treatment and/or storage system. -The District office has a plan to construct a sanitary landfill and feacal sludge treatment plants in (Nganzo cell and Muhanga sector)	- When the soak pit get full, they closed it for two years, empty it and used in cultivation of crops. No research has been done to check the quality of liquid or solid sewage in the pit before applying them on the crops. -Groundwater contamination at downstream wetland with the faecal sludge treatment system -No information about the annual, weekly, monthly or per-capita liquid waste generation
24W	Karongi	-There is no faecal sludge treatment system. -Hospitals use their own liquid waste treatment and/or storage system. -Mubuga dumpsite also receives the liquid waste from Rubengera and Karongi cities. -There is a cascade-dug pit to receive liquid waste in Bwishyura Sector.	-When the soak pit get full, they closed it for two years, empty it and used in cultivation of crops. No research has been done to check the quality of liquid or solid sewage in the pit before applying them on the crops. -These cascade pits are located on the top of the hill and if it rains heavily, they are likely to overflow and spread into the neighborhood and contaminate water and crops. This leads to spread of disease to the neighboring population.
25W	Ngororero	-There is no faecal sludge treatment system -Soak pits and septic tanks are used as liquid waste infrastructures. For HHs level, when the soak pits get full their dig new pit. -Hospitals are using semi centralized sewage system where all liquid waste are treated at the point by means of septic tank and soak pit.	-There is not facilities or infrastructure to treat wastewater for reuse purpose
26W	Nyabihu	-Soak pits and septic tanks are used as liquid waste infrastructures. For HHs level, when the soak pits get full their dig new pit. -There is no faecal sludge treatment system -Hospitals are using semi centralized sewage system where all liquid waste are treated at the point by means of septic tank and soak pit.	-There is not facilities or infrastructure to treat wastewater for reuse purpose -No information about the annual, weekly, monthly or per-capita liquid waste generation

No	District	Liquid waste management infrastructures	Major problems
27W	Nyamasheke	-There is no faecal sludge treatment system -Hospitals use their own liquid waste treatment and/or storage system	-There is not facilities or infrastructure to treat wastewater for reuse purpose -No information about the annual, weekly, monthly or per-capita liquid waste generation
28W	Rubavu	-The site is a volcanic rock area with underground water potential and with risks to pollution. Wastewater treatment and disposal is characterized by the use of pit latrines, septic tanks. -Hospitals use their own liquid waste treatment and/or storage system -There is no faecal sludge treatment system. -Currently, Rubavu District does not have a place reserved for liquid waste.	-Lack of leachate management and treatment system -For the liquid waste (sewage), there is no system that receives and treats liquid waste coming from community. -No information about the annual, weekly, monthly or per-capita liquid waste generation
29W	Rusizi	-Soak pits and septic tanks are used as liquid waste infrastructures. For HHs level, when the soak pits get full their dig new pit. -There is no faecal sludge treatment system. -There is a pipeline initiative and plan to establish a sanitary landfill and faecal sludge (liquid waste) treatment system.	-There is not facilities or infrastructure to treat wastewater for reuse purpose -Lack of leachate management and treatment system -Groundwater contamination at downstream wetland with the faecal sludge treatment system - There is no private company operating in the district for liquid waste collection and transportation -No information about the annual, weekly, monthly or per-capita liquid waste generation
30W	Rutsiro	-There is no faecal sludge treatment system -Hospitals use their own liquid waste treatment and/or storage system	-There is not facilities or infrastructure to treat wastewater for reuse purpose -No information about the annual, weekly, monthly or per-capita liquid waste generation

			
a. Nyabugogo wastewater	b. Muhima wastewater	c. Main wastewater channel from commercial center in Kigali city	d. Kigali Special Economic zone wastewater
			
e. Ruriba wastewater	f. Izuba City Apartment wastewater	j. Sunset Estate septic tanks	h. Kimisagara wastewater

i. WWTP screen

j. Comfort Home Estate wastewater sedimentation tank

K. Urukumbuzi II sewer pipes

l. Old pump from WWTP

Fig 5: Wastewater pollution (a-h) and technical issues of their treatment systems (i-l) in Kigali city

4.2 Socio-economic issues

The key socio-economic problems of decentralized wastewater treatment systems include acceptance, environmental awareness, environmental education , health effects, water culture, scale, population distribution, density, growth rate, cost of collecting and transporting wastewater, treatment cost, construction cost , maintenance cost and operation, cost of materials, environmental cost, and planned urban area(Bernal et al., 2012).

Lack of financial resources in current wastewater treatment restricts upgrading of treatment facilities or monitoring instruments. The citizens claim that it is the government or landlord's task to build sanitation facilities in peri-urban and slums areas. Many Rwandans depend on in-situ sanitation, and this appears to be affordable, but approximately 2/3 have been shown to be improved sanitation facilities that confer on international standards definitions of amenities, especially SDG.

The socio-economic evaluation is based on costs, community and service satisfaction. The cost includes capital expenditures, operational expenditures, depreciation of fixed costs, and extension costs for service coverage. The community covers social awareness and understanding of Semi-Centralized Sewer System (SCSS) and their specific treatment units, social acceptance and expectancy, community involvement in planning, development and management of SCSS Service. Lastly, service satisfaction has reliability of the services and affordability of the service (Bernal et al., 2012). The parameters for the economic sustainability of household wastewater treatment systems proposes the financing value that is accepted by the community for their interests without surpassing the benefits and these comprise affordability, investment, operating and maintenance costs(Bahar et al., 2017). For the sustainability and successful public acceptance of the system, the technology must take into consideration the local values and more significantly ensure basic understanding of the technology for all residents of the entire local community(TTZ Bremerhaven, 2012). Community participation in the planning, development and implementation should be considered for the better management of domestic wastewater treatment systems. For the case study, the community awareness and their contribution should be considered in hiring and purchasing of the houses for sustainable management of wastewater treatment facilities.

4.3 Legal and institutional issues

The effect of three major instruments in sanitation sector when addressing the development and management of decentralized wastewater treatment systems for the public include sanitation policy, law and regulations on decentralized wastewater treatment systems and institutional framework in management of semi-centralized sewerage systems. Decentralized wastewater treatment systems in rural areas are considered a viable option but local authorities should track and provide guidance(Mourad, 2012). Discharge issue is on various magnitudes however; The article 18 explicitly deal with the domestic and industrial wastewater disposal into sanitary sewers, and it states that "No person shall dispose or deposit or permit the discharge of various pollutants into or in land drainage works, private branch drains or connections to any sanitary sewer or combined sewer". In contrast, article 19 talks on acceptable limits of domestic wastewater disposal.(Marie-Claire, 2009) It states among other things that these tolerance limits are applied to the physical, chemical and microbiological domestic wastewater discharged from households, business buildings, institutions etc.(WHO, 2006). Nevertheless, the discharge standards are available but no laboratory tests in place to examine whether the standards are followed. In Rwanda, wastewater disposal standards seem meaningless because of bad monitoring and failure to prove the scientific method by laboratory testing and update the articles. The art. 18 and art. 19 also need to be updated, conferring to their source, indicated that they were published in 1992 (Tsinda et al., 2013). Similarly, article 20 notifies on tolerance limits of industrial wastewater disposal, and it states that discharge limits are applied to the physical, chemical and microbiological wastewater generated from industrial processes and manufacturing (Akumuntu et al., 2017).

Monitoring system presents an important problem and may result in challenges if not well managed. In the monitoring of wastewater, article 29 states that "The supervisory authority has the right to monitor the service delivery by the licensee whenever working hours and he/she has to collaborate with inspectors and provide all relevant documents as requested". The article 28 states that the licensee should submit to the regulatory authority an annual report highlighting technical aspects as well as the financial statements. The service provider shall follow the reporting format provided by the regulatory authority and the annual report must be submitted not later than 31 March of each year. Penalties were established as a preventive mechanism and warning to people degrading the environment.

5.0 Recommendations

a. Comprehensive in-situ and off-site sewer systems construction and management aspects by sustainable legislation, and the use of best inexpensive technology. Wastewater treatment and disposal practices should be site specific, accounting for social, cultural, technical, environmental, political, and economic aspects in the target area.

Currently, available wastewater treatment methods are frequently chemically, energetically, and operationally rigorous, which are not applied in many places in Africa due to the lack of suitable infrastructure(Shannon et al., 2009). Consequently, it is significant to develop wastewater technologies by considering the unique characteristics of Rwanda.

So, we should adopt innovative technologies for wastewater treatment with cost-effective measures, low energy consumption treatment (recover energy from waste sludge and utilization of solar energy), affordable in-situ sanitation construction, combination of pond system with biological treatment, and constructed wetland system, proper disinfection for wastewater, groundwater purification, water reuse and rainwater harvesting. In addition, there must be a shift to ecofriendly economy and cleaner production which are employed to reduce wastewater disposal and to recycle resources from wastewater (www.grida. no/publications/green-economy/).

b. Improving operation and maintenance of treatment facilities by providing training and enhance expertise. Provide capacity building of the workers in this sector but competent and efficient operators and managers must ensure the smooth performance of these treatment systems.

c. Efficient management and control of wastewater treatment systems by the use and mobilization of environmental and environmental units as a mechanism to ensure successful implementation of mitigation measures

d. Wastewater treatment facilities should be established with the necessary maintenance mechanisms in order to run sustainably.

e. Improving governance and management by restructuring local planning processes so that local politicians pledge more strongly to improve wastewater management. Establish good governance with a better mechanism and institutional framework to promote political will and commitment for wastewater treatment. The management of wastewater disposal should be enhanced.

f. Promoting public engagement by improving collaborative efforts among various stakeholders to find their own way of maintaining water quality among depending on internal efforts rather than any international aid and assistance. Enhancing civic engagement that will increase public support's political power. To endorse public knowledge about the link between water and energy, water and safety, as well as training and education requirements.

g. Revise wastewater quality requirements by upgrading our own national wastewater quality control program without sacrificing main health concerns in Rwanda. The principles regulating SCSSs in Rwanda need to be redefined, revised and implemented, because of less support for the legal and institutional structure for SCSSs in small communities. Some of the guidelines legalizing wastewater management are clearly developed but their efficiency is determined by good implementation and enforcement.

6.0 Conclusion

The water quality in Rwanda is facing severe challenges. Several environmental studies showed an alarming water pollution due to illegal wastewater discharge. Moreover, wastewater treatment systems revealed poor technical aspect, socioeconomic status, institutional, and legal magnitudes characterized by inadequate coverage of wastewater treatment facilities in both urban and rural areas, poor operational state of wastewater infrastructure, design weaknesses, expertise, and insufficient funds allocated for wastewater treatment, overloaded capacities of existing facilities, and inefficient monitoring for compliance with recommended guidelines.

Access to basic sanitation and improvement of wastewater treatment are of crucial importance to achieve the Sustainable Development Goals. Therefore, contributions from all stakeholders are needed to revolutionize wastewater quality standards and laws by updating our own standard system for monitoring wastewater; develop innovative and best affordable technology suitable to Rwandan terrain; encourage public participation and investment in wastewater treatment systems and improve governance; operation and maintenance of treatment facilities. Lastly, this review will serve as a state of the art document for other developing countries to report their wastewater pollution and treatment systems statuses.

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Conflicts of Interest

The authors declared no conflict of interest.