Impact associated with the lack of sewerage and treatment systems, a source of emerging contaminants in urban water resources. A review case study of Kigali city Rwanda.

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Abstract- According to the census report of household living conditions of March 2016, showed that 81.6% of the improved sanitation in Rwanda, uses pit latrines with solid slabs, as a result of the absence of a sewerage system/network in the country. Topography at high altitudes has caused significant surface and groundwater contamination in various areas, including Kigali, the capital city. Additionally, the high standard of living in the region and the lack of government funding to develop different projects for centralized sanitation have contributed to the complexity of wastewater management. A count of 1.3 million people in Kigali city has neither centralized sewage treatment nor central sewage networks. Due to untreated sewage being disposed inappropriately into the environment, they may have potential negative impacts on surface and groundwater resources. The problem of water pollution is getting worse as anthropogenic contaminants enter the water cycle. Emerging organic contaminants (EOCs) are of particular concern. For example, pharmaceutical and personal care products are not regulated under current environmental laws. Therefore, they may cause ecological or human health impacts. The paper reviewed the major sources of water pollution in densely populated areas of Rwanda specifically in capital Kigali; impacts that may be associated with the lack of urban centralized sewerage systems and inadequate operation of available decentralized technologies to human life and ecosystem as well as by providing snapshot information about awareness of the emerging organic water contaminants. Moreover, some of the best management practices in protecting Rwanda's water resources were also recommended.

Index Terms- Sewerage system, Sanitation, Water pollution, Emerging contaminants, Rwanda

I. Introduction

Water pollution has become a serious environmental problem as well as an increasing worldwide concern**.** Wastewater effluents are major contributors to a variety of water pollution problems. Sewage is one of the main causes of several water pollution problems. Most cities in developing countries produce an average of 30 to 70 cubic millimeters of wastewater per person per year [1]. Due to the lack of wastewater treatment plants or inadequate treatment, wastewater is often discharged into surface water sources that are subject to domestic and industrial waste, causing pollution [1].

A 2015 report by the United Nations Economic and Social Commission for Asia and the Pacific states that 80-90% of the wastewater generated in developing countries is discharged directly into water bodies [2]. The UN World Water Development Report 2017 found that 62% of urban dwellers in sub-Saharan Africa discharge wastewater directly into bodies of water due to a lack of sanitation infrastructure [3].

The urban areas of Rwanda are the first to experience this problem. For example, the current wastewater situation in Kigali poses a direct threat to the environment and public health. This problem mainly concerns the Ruganawa River in the east and Rwanzekuma in the north. These rivers are a tributary of the Nyabugogo River, which flows east into the Nyabarongo River. The river's biological oxygen demand (BOD5) ranges from 10 to 20 mg/L in the wet season and 25 to 35 mg/L in the dry season. [4].

Unlike other cities in East Africa, which have sewer networks and sewage treatment facilities that cover a small part of the population, Kigali has no centralized sewage treatment facilities or sewage networks. As a result, large amounts of wastewater generated in the city can either be discharged untreated into wetlands around the city or infiltrate into groundwater and contaminate both freshwater resources and soil [5]. Current way of handling wastewater in Kigali relies on the use septic tanks and soak-away, or in some cases leads to open waterways. Currently, septic tanks are emptied by tankers that dump fecal sludge into ponds intended to bury the city's central solid waste, but the wastewater from these ponds seeps into the ground [4].

Decentralized wastewater treatment systems are considered a good alternative in rural areas. However, local governments should monitor and offer guidelines [6, 7]. The decentralized wastewater treatment systems are in two main categories: on-site and off-site sanitation systems. On-site decentralized sanitation systems include wastewater management systems at the level of the individual or collective communities while off-site decentralized sanitation systems include treatment of fecal sludge collected from individual families before their treatment and disposal into the environment [8].

The majority of Rwandans rely on affordable local sanitation systems, of which 65% have visibly improved sanitation facilities by international standards for the Millennium Development Goals [9]. Flush toilets are rare in Rwanda as a country. This means that water is used primarily for washing and cooking and then drained to the surface, while feces are drained or publicly disposed of in waterless toilets [9]. Moreover, [10] also studied the environmental impact of the local sewage system in the city of Kigali and found that soak pits are commonly used in slums settlement and planned housing as a system of wastewater disposal at 73.5% and 63.2%, respectively. The sewage treatment rate for slums and planned dwellings was 22.1% and 36.8%, respectively. These soak pits can slowly infiltrate the soil layer with effluents, causing some buildings to collapse and increasing groundwater pollution.

The absence of a sewer network and centralized wastewater treatment systems has made the Kigali population dependent on septic tanks and pit latrines for their facilities, with 95% using on-site sanitation systems, of which 80% are pit latrines[11]. However, this exacerbated sewage problems and poor sanitation in septic tanks, and improved pit latrines. This is because only 2% of Kigali households empty sludge from their pit latrines[12]. The emptied sludge is then disposed of in pits at a site (Nduba site located in Kigali city). Because the latter does not fulfill the requirement of a sanitary site, the disposed of sewage is now like a small sewage lake (pond) [13].

Due to rapid population growth, urbanization, increasing demand for industrial development, and limited financial resources to provide reliable wastewater infrastructure to cater to the increasing quantity of wastewater generated from different sources (households, industries, hospitals, businesses, among others), there is a perception that Rwanda is still having a low advancement concerning wastewater management and water pollution control infrastructure. As a result, the so-called emerging organic contaminants might be already in our surface and groundwater and unexpectedly inducing their effect on human life and the aquatic environment.

Therefore, the paper aims to review the impact that is associated with the absence of sewerage systems/networks and their centralized sewage treatment systems; inadequate operation of available decentralized sewage treatment systems; poor disposal of solid and liquid (sewage mixed with other harmful processed chemicals from septic tank or toilets) waste on an aquatic environment (surface water& groundwater), and human life. Our main focus is the current situation in Rwanda’s s urban area, especially Kigali city. The paper will also provide insights and a good perception to policymakers of what should proactively be done in the countryside’s fast-growing satellite cities of Kigali to protect Rwanda’s water resources for a safer aquatic ecosystem and human life. Additionally, the case study is a reflection of other East African country’s cities where the paper provides a big picture of what could be done to protect water resources in the fast developing cities in the region.

II. Water resources in Rwanda

Rwanda is located in the Great Lakes region of Africa. The total area of Rwanda is 26,338 square kilometers. Its topography increases gradually from east to north with an average height of 1250 m. It culminates in a mountain range called Congo-Nile Divide in the west region, which ranges from 2200 m to 3000 m. Rwanda has a dense network of waterways, with approximately 1881.90 square kilometers of lakes; rivers occupied by 72.6 square kilometers and 770 square kilometers of wetlands [14]. Furthermore, there are approximately 22,300 springs [15]. The country is divided into two main basins: The Congo River Basin in the west and the Congo-Nile Divide (which covers 33% of the country territory and receives 10% of the total national waters). The Nile River Basin in the east covering 67% of the territory) receive 90% of national waters [16].

III. Main water pollution sources in Rwanda

Water quality is affected by anthropogenic source pollutants, including domestic and industrial activities, agriculture, and climate change which create severe storms and alter precipitation patterns, which in turn affect the quality of runoff. [17-19]. In Rwanda, high population density, industrialization and urbanization, poor waste management, heavy rains, and high altitudes are among the main sources of water pollution [14, 20]. This pollution goes hand in hand with travel costs to and back from piped water in rural areas, which cause people to use unsafe water. There are also poor sewage systems and the common use of public latrines and septic tanks in both rural and urban areas.

3.1. Population growth

According to the United Nations, (U N) report showed that in the next 15 years, the world population will increase by over 1.1 billion, and more than 6.3 billion people around the world will increase by 2050 in urban centers [21-23]. In urban settlements, there is a high and rapid expansion of a large number of the population moving from rural to urban areas, as a result of obtaining basic infrastructure and improving their living conditions [24]. The reports of the United Nations [25] and the National Institute of Statistics of Rwanda [26] revealed that both Rwandan rural and urban dwellers increased rapidly. The current population of Rwanda is about 13.5 million with population densities of 512.5 per kilometers. This number is predicted to be about 25 to 28 million [14] in 2050 and 2095 respectively. Noting that population growth is associated with daily water demands such as bathing, cooking, and other social and economic development activities that require the use of water such as agriculture, industry, public utilities among others.

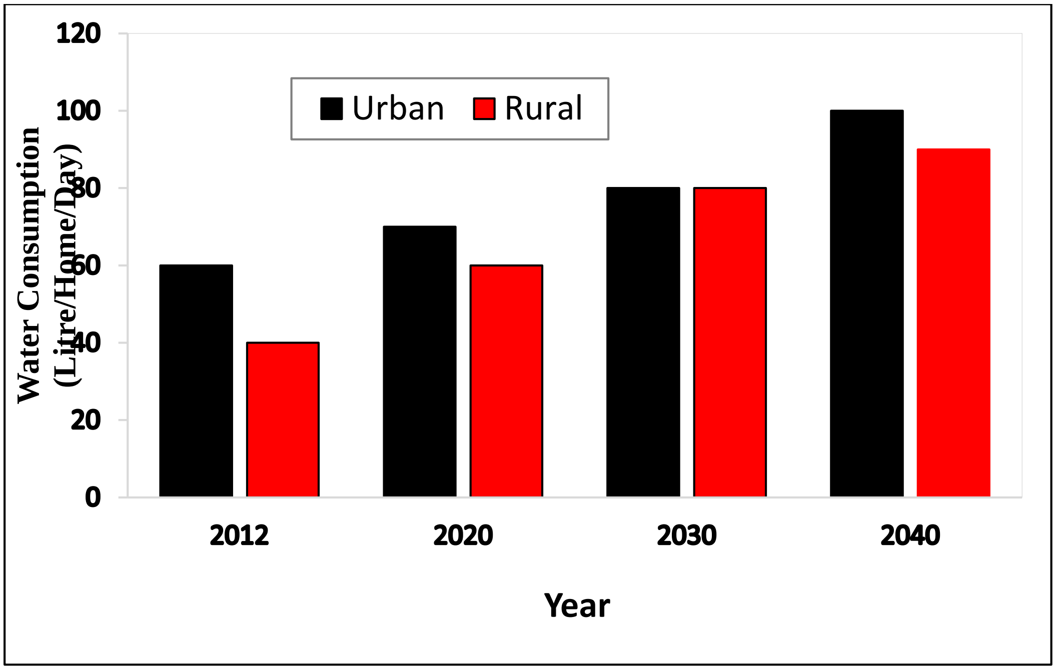

Figure. 1. Water demand per settlements in Rwanda between 2012 and 2040 (liter/home/day) [27]

3.2 Urbanization and industrialization

A United Nations report [28] showed that the world's urban population will increase from 746 million in 1950 to 3.9 billion in 2014 and exceed 6 billion in 2045. The majority of this planned urbanization will mainly be observed in developing countries especially African countries. Therefore, the urban population's demand for water and the sources of water expected to be used in the future remains unknown [29].

Most of Africa's big cities are crowded because of the charm of the city. Poor management of urban development leads to poor management of solid and liquid waste from cities [13]. This causes many related sanitation problems. In these cities, sanitation is usually dominated by self-purification works (for example disinfection of drinking water). They often move sewage that flows through the streets of residential areas and emits a strong unpleasant odor [30].

The total population of Kigali, the capital of Rwanda, gradually increased from 357 in 1907 to 236,000 in 1991, reaching 1,000,000 in 2010 and was predicted to be 1,132 million in 2020 [26]. However, it impacts municipal waste management due to informal settlements, urban expansion of the city, and industrialization. This also resulted in water quality degradation and pollution [31].

Nearly 22% of the world's water is used by industries as well as their improper wastewater management impact the water quality [32-34]. This lack of proper determination of water sources that could be used due to the growing industrialization era and improper wastes management affects its quantity and quality management. The industries in Rwanda have been dislocated to wetlands areas or near the watershed and this has adversely led to wetland and biodiversity degradation. Although the government has taken the initiative of re-allocating these industries in a well-equipped and environmentally friendly place (Rwanda Special Economic Zone), it hasn't completed yet to reduce the continuous health hazard of the aquatic ecosystem. [35, 36].

3.3 Solid and liquid wastes generation

The city of Kigali is dominated by slums built in previous years before the completion of the Kigali City Master Plan in 2006. Kigali has an estimated daily solid waste production of over 400 tons mainly dominated by food wastes [13]. In addition, homes produce 3,240 m^3 of wastewater per day, 50% of which is released into the environment without treatment [37]. When the septic tanks or pit latrines are full, they are discharged and the sewage is only treated by the crude dumpsite site, which comes in contact with an open environment without further treatment [38]. Not all dwellers can empty their pit latrines. However, the little quantity of sludge that is emptied by some dwellers is not environmentally friendly disposed of at the Nduba site. In addition, instead of sludge disposal, the site also receives solid wastes. Nduba dumpsite daily receives 400 tonnes of solid waste. Because the site is unsanitary, the sewage sludge from pit latrines and solid wastes is not handled efficiently. Therefore, the site bears environmental problems. For example, the displacement of the neighborhood population due to the bad smell from dumpsite [13].

3.4. Food demand and topography (steep-slope)

In Rwanda, agriculture employs about 80% of the total population. It suffered a decline due to the 1994 genocide and caused several socioeconomic failures [36]. However, as the United Nations International Children's Emergency Fund (UNICEF) reports demonstrated in 2015 after the 1994 genocide, high food demand-imposed cropland expansion from 13,150 to 18,425 km^2 in 1990 and 2013, respectively. The crop expansion was about growing crops in suitable and productive areas (Crop Intensification Program (CIP) with selected seeds and fertilizers, which increased from 6,537 tons in 2000 to 44,264 tons in 2012 [27].

However, despite these advances in agriculture, this practice is known to pollute the watershed [27, 39, 40]. As the majority of Rwandans survive by Agriculture, farmers own small plots of cultivated land for local consumption, mostly near or inland watersheds. In addition, agricultural land is also found on steep soils that are easily subject to erosion, floods, and landslides, which is a major soil and water quality problem in Rwanda [41-43]. Furthermore, the over-exploitations of marshland, large quantities of agrochemicals, and the lack of a better approach to farmers on the suitable and timely use of fertilizers are the major watershed degradation and pollution drivers [44, 45]. As a result, it refers to water quality management on the increase in food demand, therefore it is necessary to consider agriculture-environmentally best practices for the management of Rwanda water quality. Also, as reported by [28], periodic changes in personal agriculture land area are predicted to mean that only 0.10 hectares will be used by a single person by 2050. It showed that the lack of arable land will increase the demand for food as well as deplete water resources.

3.5. Climate change

The effect of climate change on water quality is attributed to air temperature change and hydrology [46, 47]. From 1970, climate change kept rising the air temperature by 1.4°C and the prediction showed that the air temperature will increase by 2.5°C with more impacts on the water resource. Currently, climate change is known to severely impact Rwanda's s water resources in different ways. For example, heavy rainfall patterns that cause flooding, landslides, and periodic droughts, all discharge pollutants into water resources. Rwanda's water quality is being mostly influenced by both natural and man-made degrading and polluting forces. According to the findings from the past reports about physicochemical water quality parameters, showed the low pH level of 5.9 in the Nyabugogo river compared to the standard of the World Health Organization and European (pH 6.0-8.0) [48-52]. Moreover, the total suspended solids of the Rweru-Mugesera wetland, Congo, and Nile basins (Rwandan side), 67.91, 920.90, and 162.86 mg/L, respectively, were above the standards (<30 mg/L). Whilst, the estimated concentration of Iron, Manganese, and Lead were higher in the Lake Muhazi, Cyohoha, Akagera Transboundary, and Nyabugogo rivers compared to the WHO water quality standards [40, 53].

IV. Drinking water treatment in Rwanda

To ensure pre-treatment of water and improve access to clean drinking water, more than 16 drinking water treatment plants are running across the country. These initiatives increased public access to safe drinking water from 23% in 1990 to 82% in 2016 [54]. Access to water supply in Rwanda is still inadequate. More than 38% of the population of Rwanda uses natural water sources, including springs and boreholes. In Africa, as in Rwanda, there are two main drinking water supply systems; Centralization and decentralization [55]. In centralized systems, raw water is collected, treated, and distributed by a network of pipes. In general, conventional water treatment techniques are widely used to combine treatment processes such as coagulation, sedimentation, filtration, and disinfection to provide clean and safe drinking water to the public [56]. For decentralized systems, this could be a borehole where groundwater is abstracted or fetched directly from the wells/springs. However, the information on the water quality of these springs is currently unknown.

V. Wastewater in Rwanda

Most developing cities do not have good wastewater management due to aging, missing or insufficient, and inadequately operated infrastructure. According to the 4th World Water Development Report, only 20% of wastewater produced worldwide is adequately treated [57]. Global sewage treatment is failing and as a result, most sewage and fecal sludge are discharged into the environment untreated, spreading disease and polluting ecosystems [58]. Rwanda faces challenges related to land use, water scarcity, sludge management, and climate change [58-60]. Despite the achievement of the Millennium Development Goals related to improving sanitation by the government of Rwanda, it is easy to see that Rwanda, as a country, has unsafe and inadequate operated decentralized wastewater treatment systems for wastewater and fecal sludge before discharge into the environment [61].

VI. Centralized and decentralized wastewater treatment systems in Rwanda

5.1. Centralized sewage treatment systems (off-site)

Except for a few developed sewerage systems constructed or installed by estate developers (cluster of houses) for small communities of high-income household levels in Kigali city, there are no installed sewerage systems in Rwanda's densely populated urban areas, including Kigali. Furthermore, some semi-centralized sewerage systems have been developed by business owners in public areas such as hospitals, hotels, and governmental institutions by government regulations [11]. There are plans to construct a sewage treatment plant, but funding remains a significant challenge. The government lacks financial resources and, as a result, cannot afford a centralized sanitation system due to the high cost of associated physical infrastructures such as a network of pipes, treatment plants, and maintenance [62]. Although it is well known that well-managed systems for piped water, sanitation, drainage, and garbage removal would improve city residents' health, introducing and maintaining centralized treatment systems in developing cities has been hampered by political and economic situations in various regions of the African continent [13].

5.2. Decentralized (on-site)

Decentralized Wastewater Treatment Systems (DWWTSs) are on-site wastewater treatment systems that treat small volumes of wastewater generated by individual homes, clusters of dwellings, or businesses [63]. Because of the low required costs and expertise, DWWTSs is an excellent choice for sanitation in developing countries, particularly in small communities [7, 58].
As aforementioned, there are currently no central sewerage systems in Rwanda's urban areas, including the capital city of Kigali. Kigali continues to rely on a few decentralized wastewater

treatment systems. In Kigali, semi-centralized wastewater treatment plants (SCWWTPs) or semi-centralized sewerage systems(SCSSs) are examples of such decentralized wastewater treatment systems. SCSSs transport sewage from households to wastewater treatment plants units (WWTUs). SCSSs are common in some of Kigali's high-income estates, as well as in other institutions. Hotels, hospitals, and large commercial buildings, for example, are required to install private semi-centralized sewerage systems (SCSSs) to treat their wastewater before it is discharged into the environment.

Recently, approximately 18 estates have semi-centralized sewerage treatment plants that connect approximately 150 households. However, due to insufficient government oversight, the standards for their discharged treated wastewater do not meet national standards [11]. SCSSs are more advantageous in densely populated small community areas. However, the findings of a study conducted by [61] revealed that the levels of sustainability for the evaluated systems were low in the technical, socioeconomic, institutional, and legal dimensions. The dimensions associated with community involvement and institutional framework were the ones that reduced SCSS and STP efficiency. As a result, the case study's decentralized wastewater treatment demonstrated significant performance failures in terms of effluent quality requirements.

Pit latrines in informal settlements are frequently overlooked and rarely emptied; the pits are not typically lined with bricks and can collapse after a period of use [63]. Besides that, few suction trucks are available to empty soakage pits and septic tanks, and many sites are inaccessible due to the narrow, steep roads that lead to the latrines. Even when it is possible to empty liquid from pits, sludge is not always disposed of properly. As a result, there is still a significant lack of required knowledge on decentralized wastewater treatment systems, as well as a critical need for good implementation strategies based on wastewater management policy initiatives that can ensure the long-term viability of wastewater treatment systems [62].

VII. Comparison between centralized and decentralized treatment systems

When compared to decentralized systems, centralized wastewater treatment systems are more expensive. [64] stated that sewage collection systems typically account for 60–70% of total project costs for a conventional centralized system, implying that decentralized systems are more cost-effective. According to a study conducted by the United Nations for South-East Asia, the decentralized system is more cost-effective than the centralized system because treatment facilities for decentralized treatment facilities can be built incrementally and require less initial capital investment than centralized treatment, which requires millions of dollars [2].

Table. 1. Comparison between centralized and decentralized systems

[1] Parameter	[2] Centralized system	[3] Decentralized system
[4] Collecting system	[5] Large diameters, long distances	[6] Small diameters, short distances
[7] Requirements space	[8] Large area in one place	[9] Small areas in places
[10] Operation and maintenance	[11] Full-time technical staff requirements	[12] Less demanding, can be monitored remotely
[13] Uniformity of water	[14] Many types of water	[15] More uniform water
[16] Dilution grade	[17] Less control over the storm water, more dilution	[18] More control over the storm water, more concentrate
[19] Risk	[20] Risk on a larger scale	[21] Risk distributed
[22] Water transfer	[23] Increase the need for water transfer	[24] Water is used and reused in the same area
[25] Social control	[26] Social control is lost	[27] More social control
[28] Ease of expansion	[29] High costs, more complexity to the implementation	[30] Low cost, less complexity to the implementation
[31] Potential to reuse	[32] All water is concentrated in one point	[33] Water can be reused locally

Source [65]

VIII. Impacts that might be linked with the lack of centralized and inadequate operation of decentralized systems for wastewater treatment and management in Rwanda.

Inadequate sludge management and disposal practices caused by a lack of a clear fecal sludge management (FSM) system have been identified as a problem in densely populated areas, as they generate resilient environmental pollution and associated health risks [66]. In developing countries, urban wastewater management systems are increasingly failing due to a lack of scientific knowledge in both technology selection and the design of the most appropriate and sustainable wastewater treatment plants, particularly for semi-centralized wastewater treatment systems. Furthermore, the lack of sanitation infrastructure in rapidly growing cities and emerging urban and peri-urban areas has significantly increased water source contamination [62]. As a result, our surface and groundwater may be exposed to microorganisms (e.g., bacteria, viruses) that can cause diseases, as well as emerging contaminants (e.g., pharmaceuticals and personal care products (PPCPs), etc...) that can have serious consequences for aquatic ecosystems and human life.

7.1 Surface water pollution in Rwanda

More than 2 billion people worldwide drink feces-contaminated water, facilitating the spread of diseases such as diarrhea, cholera, dysentery, typhus, and polio [67].

Even though the Rwandan government's strong efforts to improve access to clean water, sanitation, and hygiene [68], surface water in Rwanda is still severely polluted by anthropogenic sources such as agricultural fertilizers and pesticides use (MINIRENA, 2011). Moreover, dwellings and farms in Rwanda are frequently located along valley slopes where water run-off flushes manure, human excretions, and wastewater into rivers and streams, resulting in increased levels of dissolved nitrogen. These agricultural and domestic activities pollute surface water, causing eutrophication and serious public health problems in various regions of Rwanda [40].

Furthermore, some wastewater is discharged directly into open waterways without treatment, eventually ending up in streams and rivers. For example, in Kigali, rivers such as the Ruganwa, Rwanzekuma, Yanze, and Mpazi, as well as all tributaries of the Nyabugogo river, are currently receiving improperly disposed sewerage [4].

According to World HealthOrganization(WHO) drinking water quality ,standardsa recent studyon drinking waterquality that analyzed heavy metals pollution in theEastern province revealedthat drinking wateris primarily pollutedduring the rainy .season This exposes consumers to several risks because some parameters, such as iron (0.35 mg/L) and manganese (0.25 mg/L) have been detected in Nyagatare, Eastern Province of Rwanda. Their concentrations were found higher than WHO-recommended standards for drinking water quality. WHO-recommended that the concentration of iron and Manganese should not exceed 0.30 and 0.10 mg /L respectively [27]. As a result, consumers may develop cancer, liver disease, heart disease, or pancreatitis. This is consistent with the findings of [40] who found that drinking water sources are more polluted during the rainy season than during the dry season when sediments and other wastes easily accumulate in bodies of water.

These water pollution phenomena have a variety of effects on the quantity and quality of water, such as reducing river flows and lake levels, drying up some water sources, and undermining water biodiversity. As a result, despite its abundance, this expresses the problem of water quality in Rwanda and calls for appropriate adaptation measures.

7.2 Groundwater pollution in Rwanda

According to the thematic report utilities and amenities approved in March 2012, EICV4, there were 13.5 percent pit latrines without solid slab (unimproved sanitation), 3.1 percent with no toilet facility, and 83.4 percent of the improved sanitation (flush toilet and pit latrines with solid slab). Among the 83.4 percent of the improved sanitation in Rwanda, only 1.8 used flush toilet and 81.6 percent used pit latrines with solid slab due to the country's lack of sewage system/network [69].

Therefore, the high dependence on use of pit latrines raise concerns about groundwater pollution. Full pits is the potential for groundwater pollution under or near pit latrines, particularly in areas with high water tables [70], as is the case in the majority of Kigali's informal settlements. This is a serious issue because it has an impact on the quality of drinking water. Botswana, for example, experienced high groundwater pollution as a result of its high water table, which could be linked to the widespread use of pit latrines as a sanitation option [70-72].

7.3 Human life and Aquatic ecosystem

Human life and aquatic ecosystems are expected to be jeopardized due to pollution of surface and groundwater from direct wastewater discharges, improper management of solid wastes and fecal sludge (unimproved sanitation, poor pit emptying services, and disposal) as afore-mentioned.

Pit latrines with slabs represent improved sanitation in its most basic form; however, once the pit is full, it no longer provides this service, and the pit must either be covered over and a new latrine built, or the existing pit emptied [20, 21]. Nevertheless, unlike other developing cities such as Kampala(Uganda), Nairobi (Kenya), and Dar-es-Salaam (Tanzania), Kigali lacks a clear strategy for pit latrine emptying with only 2% of households emptying sludge from their pits [5, 12]. As a result, there is a risk that the latrine will overflow, contaminating the environment with large amounts of excreta containing harmful pathogens and causing offensive odors [73]. Neglecting pit emptying or using low-quality emptying services, on the other hand, could have serious health and environmental consequences. Flies and insects are serious issues because they are reported to be responsible for the propagation of fecal-oral diseases such as diarrhea or intestinal worms [74, 75]. The quantitative results of the survey indicated low percentages for insect nuisance (32.4 percent) [74, 75].

Children are especially vulnerable because they are accustomed to playing in stagnant wastewater. Poor quality pit emptying services, for example, in Freetown, Sierra Leone, have contributed to diarrhoeal disease, cholera outbreaks, and high infant mortality, particularly in informal settlements and poor unplanned areas [76, 77]. As a result, controlling odors, flies, and mosquitoes are a top priority for reducing household and environmental health hazards.

IX. Overview of Emerging Organic Contaminants in the Context of the Aquatic Environment

Pharmaceuticals and personal care products and other contaminants such as endocrine-disrupting chemicals among others are commonly found in surface and groundwater primarily from the main sources for example; urban wastewater, industrial effluents, and agricultural runoff. The situation is especially critical in developing countries, where large amounts of insufficiently treated or untreated municipal wastewater and industrial effluent are discharged into surface waters and coastal zones daily. This is in conformity to the fact that the pharmaceutical concentrations in surface water bodies of developing countries are higher than those in developed countries [78]. Due to the lack of centralized or well adequate decentralized wastewater treatment technologies, the Rwanda water resource might be experiencing emerging water contaminants either from households or industrial effluents that are directly poured into rivers and streams. Figure (2) shown below typically provides a

good understanding of how these emerging contaminants could be reaching the aquatic environment (surface and groundwater) even in drinking water. However, their occurrence, detection, and removal haven't been taken yet into account in Rwanda's surface water quality parameters and even in waterworks. This is because most emerging contaminants (e.g. Pharmaceuticals and personal care products etc.,) are not regulated by wastewater discharge standards. Therefore, their monitoring data and information on their presence in water resources and wastewater are very scarce. Moreover, even in some of the developed countries that use centralized WWTPs with other advanced technologies, these kinds of contaminants are still being detected in their wastewater effluents which in turn reach streams, rivers and are finally detected in their drinking water [79-81]. This is due to that most WWTPs might not be designed to remove this kind of pollutants.
According to the study [82], it is now established that Emerging Organic Contaminants (EOCs) enter the environment from a wide range of sources and pathways, including WWTPs that are not equipped to remove them (effluents from municipal treatment plants), septic tanks, hospital effluents, livestock activities (e.g., waste lagoons and manure application to soil), and subsurface storage of household and industrial waste among others. As a result, current technologies are ineffective, particularly against novel contaminants [81, 82]. For example, the elimination of selected pharmaceuticals (clofibric acid, diclofenac, carbamazepine, bezafibrate) during drinking water treatment processes was investigated at lab and pilot scale and in real waterworks in Germany [83]. The results showed that sand filtration under aerobic and anoxic conditions, as well as flocculation with iron(III)chloride, did not eliminate the target pharmaceuticals significantly.

Following the findings of [84], the presence of a wide range of pharmaceutical and personal care products (PPCPs) in water and wastewater has been widely reported [85]. PPCPs account for an increasing proportion of the trace organic micropollutants found in urban and domestic wastewaters that reach sewage treatment plants (STP), whether metabolized or not [86]. Many of these substances evade conventional activated sludge wastewater treatment plants, allowing them to enter surface water streams and spread throughout the environment [87]. Acidic pharmaceuticals, surfactant degradation, and acidic pesticides are among the various compounds considered emerging organic contaminants, both because of their ubiquity in the aquatic environment and potential impacts.

The presence of low levels of PPCPs has been linked to chronic toxicity, endocrine disruption, and pathogen resistance development. Because aquatic organisms are subjected to multigenerational exposure, the consequences are especially concerning [88]. The need for treatment technologies capable of producing safely treated effluents prompted proposals to upgrade STP and implement new competing technologies for biological degradation of organic matter, such as membrane bioreactors [89]. Although advanced technologies such as membrane filtration, ultrafiltration, nanofiltration, and reverse osmosis can remove some endocrine-disrupting chemicals and pharmaceutically active compounds, they can only do so partially. Even if these technologies exist, their use is limited due to high costs that many developing countries cannot afford. As a result, humans and ecosystems may be continuously exposed to these new and emerging pollutants through drinking water and agricultural products, as wastewater is widely used to irrigate crops in water-stressed areas, primarily in Sub-Saharan Africa, including Rwanda.

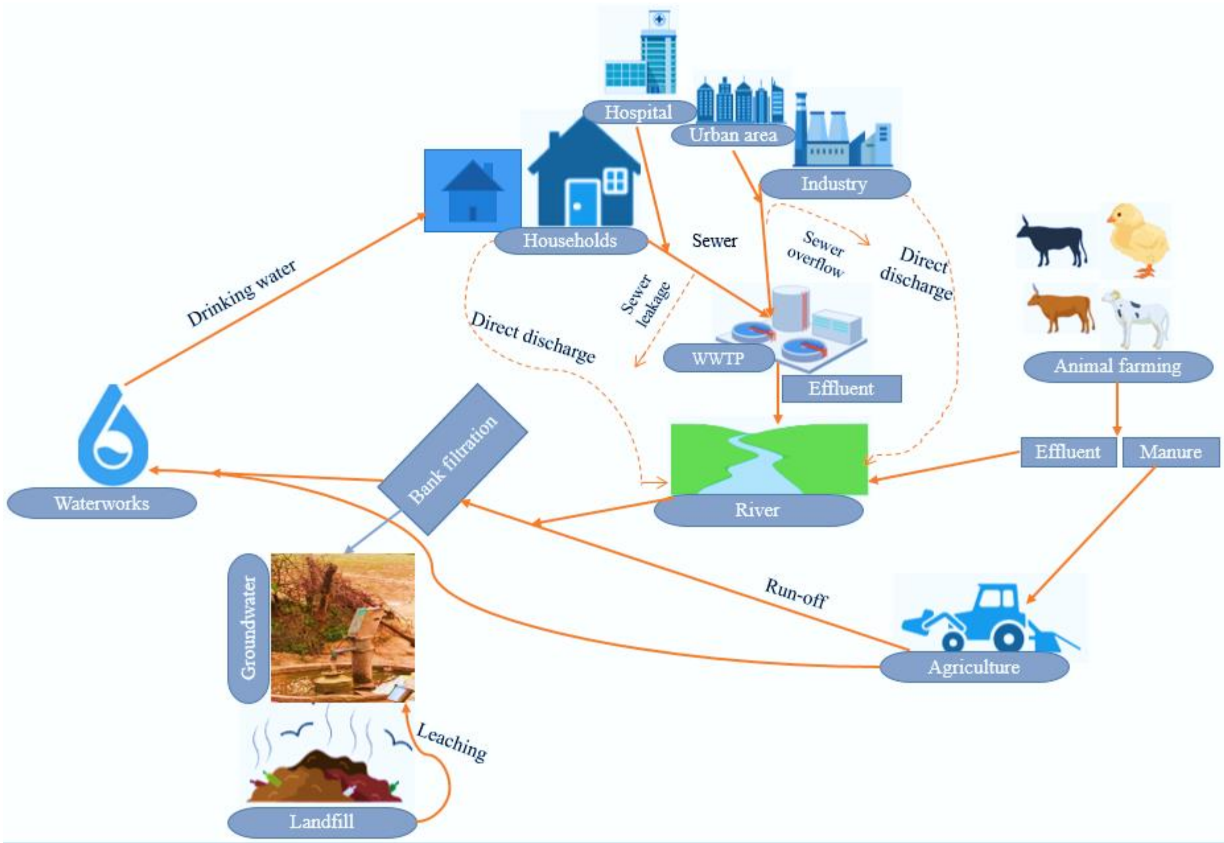

Figure.2. Transport and fate of emerging organic contaminants in the aquatic environment

X. CONCLUSION

Water quality and scarcity are widespread issues, and long-term management is proving difficult. Rwanda as a country has ambitious targets with good strategies to sustain improved access to both household and collective sanitation coverage, as evidenced by the achievement of MDG No. 7 in 2015. However, it does not make sense to have 100 percent coverage of improved sanitation facilities that are not sustainable and safe for public health and the environment because, whether directly or indirectly, these facilities and poor practices of wastewater and excreta disposal will generate both health and environmental costs, limiting economic development and poverty reduction. As a result, the long-term viability of municipal wastewater treatment systems (WWTSs) in densely populated areas of rapidly developing cities such as Kigali necessitates a sustainable sanitation policy that focuses on various wastewater management practices such as storm water management, among others.

According to the 2007 Kigali City Conceptual Master Plan report, the city will continue to grow in size and its population will nearly triple in the next 25 years. As a result, it is prudent to plan for appropriate municipal wastewater treatment facilities as well as adaptive measures to improve water quality. This can be accomplished through the comprehensive development and management of both on-site and off-site sanitation systems, as well as the use of the best available technology.

Rwanda's government has launched Integrated Water Resources Management, a strategy for developing, monitoring, and managing water resources. Nevertheless, for the policy to be fruitful and sustainable, there is a significant need for wastewater management, as well as the rapid expansion of urbanization and informal settlements, as well as industrial and mining activities. According to poor solid and liquid wastes treatment, management, disposal, and to low operation and inadequacy of the available decentralized treatment systems, the novel emerging contaminants for example active pharmaceuticals, including those with endocrine-disrupting properties (EDCs) might have reached Rwanda’s water resources therefore, special measures might be taken especially for drinking water treatment plants and in irrigation for food crops.

XI. RECOMMENDATION

The global population is expected to reach 8.1 billion by 2025, and together with the effects of climate change, the world may face the greatest scarcity of freshwater ever. According to recent research, two-thirds of the world's population currently lives in areas where water is scarce. As a result, wastewater treatment should become a valuable water resource, with reuse being a critical issue that should be addressed quickly. Water quality preservation and improvement are critical for survival.
Sediment flows into watersheds is a major pollution problem in Rwanda. It could be addressed by ensuring maximum rain harvesting to increase underground storage and allowing local communities to supply water to their infrastructure because Rwanda receives a lot of precipitation throughout the year.

Due to climate change and dramatic population growth, irrigation is proposed to boost the agricultural production for enough food, however, it would be good to first check on the quality of water to be used in any irrigation technique concerning foods crops to prevent bioaccumulation of some emerging pollutants and heavy metals in plants and aquatic organisms.

Centralized sewerage systems are too expensive and require high monitoring, management as well as very skilled operators and technician to extent that some developing countries couldn't afford it. However, decentralized sewerage systems have been found cost-effective and low maintenance cost. Therefore, if their performance is improved in Rwanda, water quality and safety will be highly expected in streams and rivers as in underground water.

Pharmaceutical inputs to the aquatic environment should be reduced at all stages of the product lifecycle, from production to consumption to waste management. Such initiatives should include both technological solutions and policy tools for preventing pharmaceuticals and their metabolite released into wastewater.

Rwanda's legal and institutional regulation or framework on solid and liquid waste should be reinforced to achieve well-informed and sustainable management policies that are strictly applicable to all institutions. In addition, community change behavior mobilization regarding solid and liquid wastes disposal is needed in different areas to ensure knowledge and safety first which might result as one of the best management practices.

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