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Impact of soil erosion on water treatment cost: Case of Gihira water treatment plant, Rubavu, Rwanda

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ABSTRACT

The study aimed to assess the impact of soil erosion on cost of Gihira Water Treatment Plant (GWTP). Raw water and treated data were gathered from GWTP in different seasons (rain and dry season). The parameters such as TSS, Turbidity and E.coli were determined with standard methods. Documentary review was used to collect data related to annual rainfall, elevation, soil texture, land use and vegetation cover. The results revealed that heavy rainfall impacted negatively quantity of water produced at GWTP with rate of 6.8%, 10.80% and 6.67% in March, April to May and1.57%, 1.73% and 1.66% in June, July and August in 2017. In 2018, the rates of 12.09%, 5.57% and 4.76% in March, April and May and the rates of 1.81%, 1.09% and 1.93% in June, July and August were recorded. The same situation was reproduced in 2019, where the rates were 8.09%, 4.76% and 4.76% in rain season against of 1.38%, 0.85 and 0.55% of dry season. The findings revealed that a high disturbance of the water treatment occurred during the rainy season due to agriculture practices and high steep slope of the areas which lead to high rate of soil erosion in the catchment and more chemicals were used to treat potable water than in dry seasons.

Contribution/Originality: This study contributes to the assessment of the impact of soil erosion on cost of Gihira Water Treatment Plant and characterize the main factors contributing to soil erosion in the Sebeya catchment. This study lays the foundation for further research in this field and baseline for future academics and researchers.

1. INTRODUCTION

One of the greatest difficulties faced by water treatment plants is the soil erosion on the watersheds of public water sources. This erosion is due to the some approaches of land use (Garin & Forster, 1940). According to Issaka and Ashraf (2017) the loss of soil was reported to be an old phenomenon due to humankind and associated activities, it has heightened with human development and the quest for improved live by man. It is either caused by natural agents or persuaded as a consequence of socioeconomic development over the years. Among the foremost reasons of soil erosion is rainwater, which disrupts soil, displaces it from its settings, and washes it then away as runoff. Land use type also has an effect on the soil erosion process (Liu, 2016; Sun, Shao, Liu, & Zhai, 2014). The degradation of soil is a major global problem, the effects of which may be felt most strongly in developing countries where large proportions of the population gain their livings directly from the soil (Tully, Sullivan, Weil, & Sanchez, 2015).

Globally, soil erosion has been recognized as the foremost reasons of land degradation. The forestry, pastures and unpaved roads are affected by erosion. Nevertheless, lands under farming activities are the furthermost affected (Bizimana, 2017). According to Widomski (2011) above 80% of world's farming land is suffered by soil erosion, from the level of moderate to severe which principally leads to the loss of around 0.5 to 400 tons per ha/ year by an average loss of 3 tons per ha/year.

The soil degradation in sub-Saharan Africa (SSA), where increases in farming production have been related to famine and poverty (Sanchez, 2002; Sanchez & Swaminathan, 2005). Although, the truth of famine in sub-Saharan Africa is undisputable, the landscape and extent of soil degradation, and the part it plays in the vicious cycle of deficiency or poverty, is still under discussion (Koning & Smaling, 2005). Across sub-Saharan Africa, 75% of the population depended on survival farming at the end of the last century (Sanchez et al., 2007). Livings are expanding (Barrett, Reardon, & Webb, 2001) and urbanization is on increase, but in the near-term, soils in sub-Sahara Africa must now sustain a largely subsistence population (Tully et al., 2015).

In Rwanda, erosion and land degradation have been extensively presumed to be severe and a main reason for the poverty and food diffidence, as the country is frequently characterized by very high rural population densities, lush flora due to high precipitation, and steeply sloping highlands (Olson & Berry, 2003). The outcomes of investigations conducted by the Rwanda Agricultural Research Institute (RARI) and by other scientists showed that loss of soil due to erosion is severe, fluctuating from 35 to 246 tons/ha/year with most posts computing over 100 tons/ha/year. On five of the seven research stations where erosion was measured, erosion would remove the productive topsoil within 30 years, if no anti-erosion methods were used (Konig, 1994). One estimation was that in 1990 erosion triggered the decrease of productivity equivalent to 8,000 ha/per year, enough to feed 40,000 people (Gasana, 2002).

Expenses of soil degradation are difficulty to quantify, but estimations of the effect of declines in productivity propose a loss of 3.5 per cent minimum of farming Goss domestic product (GDP). Variations in yields are ensuing in decreasing food availability to rural families and a fundamental factor causative to the social conflict and civil war in the regions (Olson & Berry, 2003). On other hand, the land use around the catchment has countless impacts on the water quality of rivers (Huang, Zhan, Yan, Wu, & Deng, 2013).

The quality of surface water, especially rivers may be deteriorated because of the variations in the land cover shapes or land utilization practices around the catchment as human activities rise (Huang et al., 2013; Sliva & Williams, 2001) . This also impact on surface water treatment cost. Human activities such as farming practices and urbanization generally change landscape features, alter run off volume, change water turbidity and generate pollution, increase algal production and decrease concentrations of dissolved oxygen in water bodies (Uwacu, Habanabakize, Adamowski, & Schwinghamer, 2021). Therefore, this study aims to assess the impact of soil erosion on cost of Gihira Water Treatment Plant.

2. MATERIAL AND METHODS

2.1. Soil Erosion in Sebeya Catchment

The catchment area is roughly 360 km^2, and its water drains into Lake Kivu. Sebeya catchment is the greatest of the catchments in western part of Rwanda in the Nile Congo watershed, located in the upper part of the Congo basin. The area of the catchment is about 365 km^2 (1.38% of the whole surface area of the country) (Omar, 2014), an area that is considered by high elevation, abundant and heavy precipitation throughout the year and steep slopes. The region is of the highly populated areas throughout the country where people around are accountable to the obliteration of natural reserves due to looking for of other option of living (Bizimana, 2017; Kisioh, 2015). The environmental problems are at critical level such as soil erosion and land slide triggered by unsuitable mining and agricultural activities, high exploitation of soil, alteration of forest land to cattle grazing areas, cutting trues resulting in Siltation to streams, waterways (Ordway, 2015), ravines, decrease in soil efficiency, land deprivation, obliteration of settlements in zones of high risk (Bizimana, 2017). Figure 1 illustrates the catchment of Sebeya and hydrological watercourse partners.

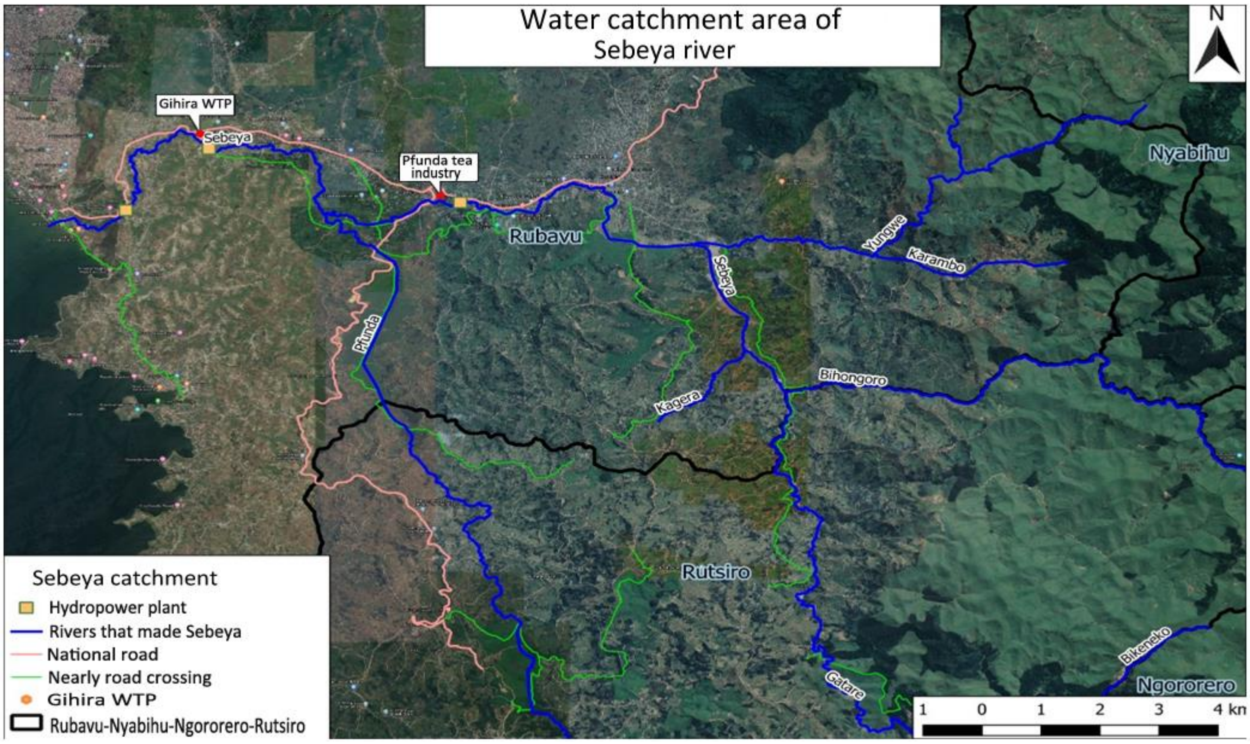

Figure 1. Description of hydrological network in the study area.

Naturally flooding in the catchment occurs in the middle level parts of the sheer portions shaped by rift creation located mostly in area around Nyundo. Such subsequent effect acts as a normal retaining buffer for floods. Although, Pfunda River is one of the main tributaries of Sebeya, with three sub-catchments: Nyaburaro, Nyangirimbiri and Rwankuba. In the Pfunda catchment, all geologic sources appear to be similarly significant. Among these three tributaries, the Nyangirimbiri river drains landscapes with high erosion risk, the Rwankuba River receipts source from Gishwati forest, which is largely a protected area, but some unmaintainable mining and farming activities take place at some places of this sub-catchment and making it also contributing to Pfunda's sedimentation level. The sub-catchment of Pfunda has also mining, agriculture and grazing activities all over (Akayezu et al., 2020).

The Sebeya catchment has Pfunda, Bihongoro, Karimbo, Kagera, Yungwe and Gatare as main watercourses that assemble and transport runoff to the confluents with Sebeya as core River toward intake of raw water of Gihira water treatment plant. The catchment is considered by steep slopes and complex topography which sudden changes of elevation on minor distances, which varies between 1,462 to 2,902 m (Akayezu et al., 2020; Habyarimana, 2018). Figure 1 illustrates the Sebeya catchment slope. The catchment has a major river, Sebeya River of 48 km, flowing and taking its source in the uplands of the Congo-Nile divide, with elevation of 2,660 m above the sea level (Uwacu et al., 2021) and is located geographically at 1.705783°S 29.26083°E.

2.2. Gihira Water Treatment Plant Process

Gihira water treatment processes are conventional surface water treatment plant where typically several steps such as collection or intake, screening and Straining, addition of chemical (coagulant), coagulation and flocculation, sedimentation and clarification, filtration, disinfection, storage and finally distribution are considered.

The surface water sources like rivers, lakes and reservoirs may contain varying amounts of dissolved and suspended materials. These water quality parameters include turbidity, color, odor, taste, microorganisms, plants, fish, trees, trash, etc. They may be also organic or inorganic, dissolved or suspended, inert or biologically active, and vary in size from colloidal to a tree trunk. So, the initial process in conventional water treatment is screening or straining out these larger items.

When the pre-screened raw water is received into the plant, water treatment chemical (coagulant) is added to aid make the suspended materials that are floating in the raw water to form a weightier and greater gelatinous particle frequently called flocs. Once the coagulation process is done, the water then passes over the weir in the flocculator tank and travels to the midpoint of the sedimentation basin or clarifier. As the water is moving towards the weir, the big floc particles are permitted to settle out to the lowest point of the clarifier. The filtration process is done when water enters the filters from the top. After filtration process, a disinfection process is followed to kill or disactivate bacteria and viruses and water is distributed from storage tank or underground storage tank.

2.3. Data Collection and Analysis

This technique provided the required information on impact of soil erosion on the cost of potable water treatment at GWTP and identifies other factors. The datasets related to raw water quality, treatment chemicals used, water produced, annual rainfall, elevation, soil texture, land use and vegetation cover gathered from Gihira WTP, Ministry of Environment and Rwanda meteorological Agency. To develop maps of the research area, the field visits were done and the Geographical Information System (GIS) was employed.

3. RESULTS AND DISCUSSIONS

3.1. The Factors Influencing Soil Erosion in Sebeya Catchment

3.1.1. Agriculture Activities in Sebeya Catchment

Sebeya catchment is situated in high density inhabited area where livelihoods depend typically on agriculture activities. The main source of water quality pollution is due to the use of manure, fertilizers, insecticides and sediment transportation in agriculture practices (Bizimana, 2017). The use of manures is not high due to the fertility of soil compared to the use of pesticides or insecticides for the purpose of increasing land productivity. This resulting to some change in water quality appearances by erosion as chemicals is soluble into surface water.

The well-known case in loss of land cover in Rwanda is the obliteration of Gishwati forestry. There is human settlement and farming of this area which changed soil constancy and structure, and its resistant capacity to soil erosion has been declined. This has caused the problem of flooding of all tributaries around the area with a significant amount of sediments (Bizimana, 2017).

3.1.2. Mining Activities in Sebeya Catchment and their Effects on Sebeya River

The Rwanda subsoil is ironic in granite-related ore deposits that comprise minerals like wolframite, cassiterite, gold, niobotantalite, amblygonite, beryl, monazite, spodumene, etc. Mining is considerable opponent producing the degradation of environmental with respect to water quality pollution, depletion of resources etc. The mining activities conducted around the country have, therefore, affected the soils of mountains and swamplands, where erosion degree has been amplified to excess the wetlands and rivers (Bizimana, 2017). Sebeya river is one of the rivers that are vulnerable to contamination or pollution due to mining activities around, especially in Ngororero District (Akayezu et al., 2020).

3.1.3. Contribution of Rainfall to Soil Erosion in Sebeya Catchment

The northwestern part of Rwanda including the area of Sebeya Catchment has a very high risk of erosion. Soil erosion is high in Sebeya catchment; this is mainly because the rainfall dispersal in the catchment differs among 1,200 to 1,700 mm per year as illustrates on the Figure 2, signifying very wet conditions. These increases the possible soil erosion in the catchment as rainfall is one of the foremost factors contributing to erosion. Sebeya catchment annual average temperature ranges between 15⁰C and 17⁰C.

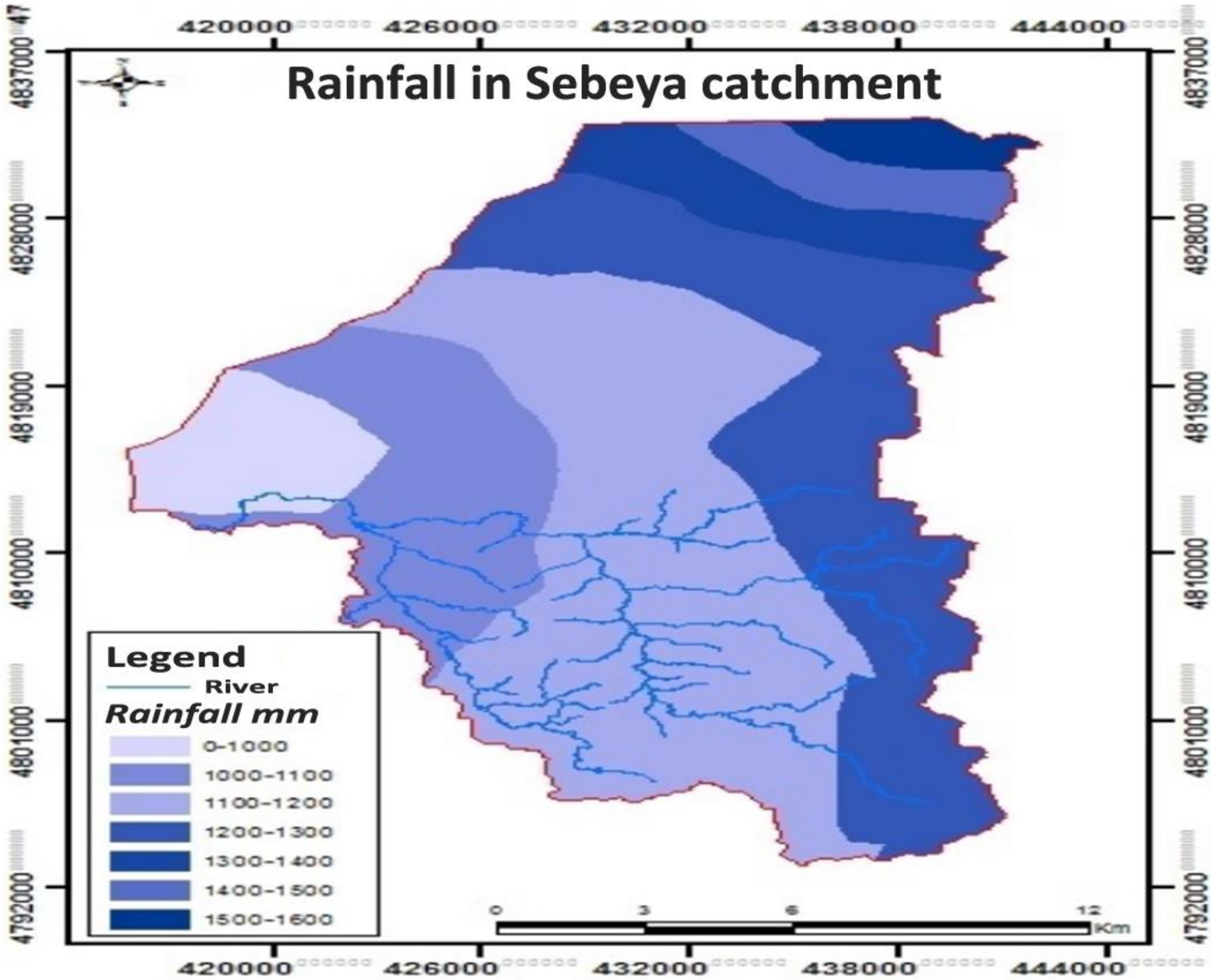

Figure 2. Rainfall distribution in Sebeya catchment.

Source: MIDMAR (2015).

3.1.4. Land Cover/Land Use Variation and Contribution to Soil Erosion in Sebeya Catchment

The main land cover and land use classes along the catchment comprise livestock grazing, forest plantations and agriculture. The several cases of unsustainable agriculture and mining activities are still happening alongside the Sebeya River. Consequently, during heavy rainfall, deposits are washed into the river producing dreadful sedimentation. The 11% of the total area is covered by the forests, and the wetland irrigation is not very significant. Population lives on agriculture, mining and livestock. The Figure 3 shows that landscapes of land use in diverse percentage of occupied area, comprise natural forest, planted forest, natural open land, agriculture in marshland, rain fed agriculture, open water, built-up area, livestock area.

The land-living/use reflects the land cover, the disruption of soil texture and possible erosion (Phuong, Shrestha, & Chuong, 2017). According to Tilahun (2013) the resistance of the soil depends of the land cover since there is high decrease of energy of rain-drop imparting on the soil and speed of the runoff. Efficiency of flora cover depends on the method of management and the level of its accessibility through the year and season type (Telles, Dechen, Souza, & Guimarães, 2013). Studies revealed a high disturbance of the plant cover in the greatest part of Sebeya catchment that occurs throughout or closer to rainy season due to agriculture practices taking places in the area, its mixture with rainfall giving high rate of soil erosion in the catchment (Akayezu et al., 2020).

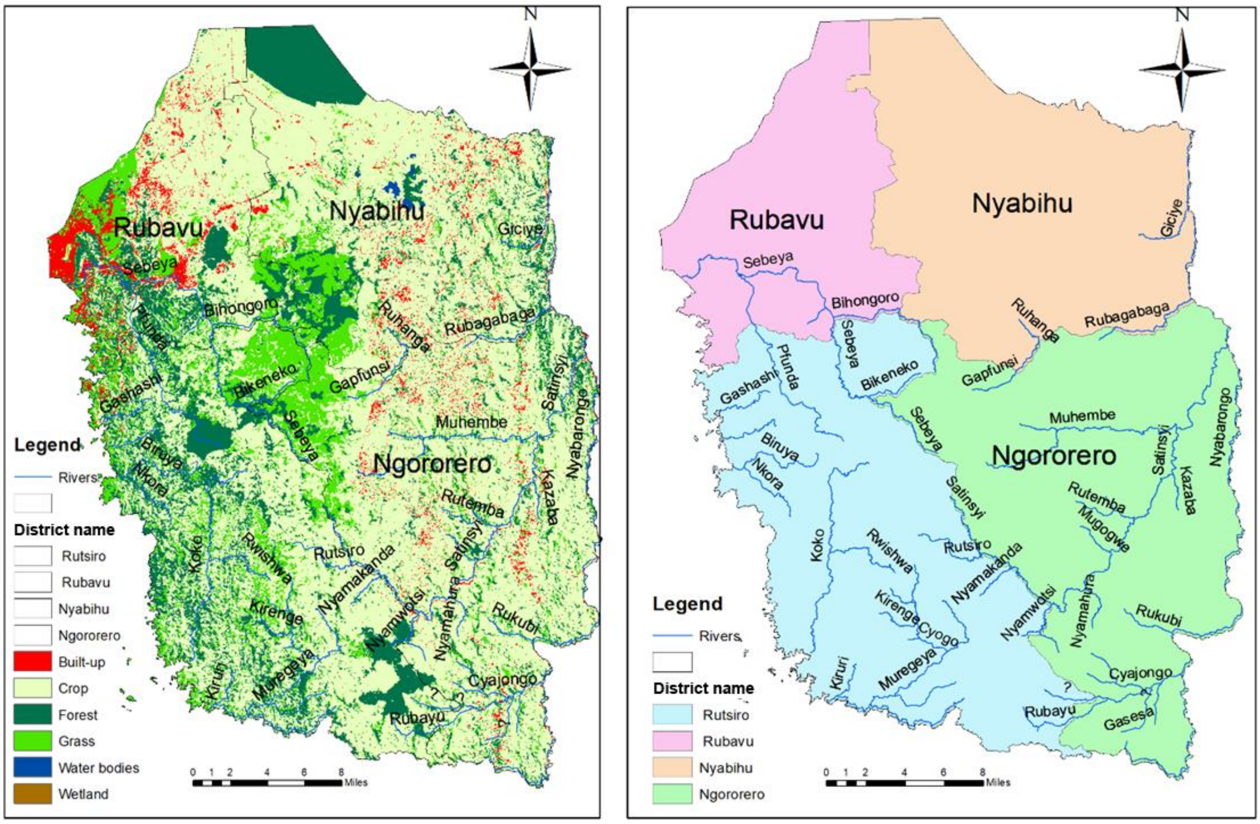

Figure 3. Sebeya land cover and District boundaries.

Source: MIDMAR (2015).

3.1.5. Topography and its Contribution to Soil Erosion in Sebeya Catchment

Sebeya catchment is considered by steep slopes and complex topography which sudden changes of elevation on minor distances which varies between 1,462 to 2,902 m, as illustrates on Figure 4.

The severity of soil erosion depends also on the nature of the slopes/ hills; obviously, as the slope of the ground is steeper the more the quantity of the soil is misplaced or lost by erosion. Furthermore, the length of the slope also impacts on the erosion course (Telles et al., 2013).

3.2. Seasonal Variability of Raw Water Quality of Sebeya River and Its Effects on Gihira WTP Performance

According to Agency (2002) the slope in the sebeya catchment varies from 0 % to 42 % where the greatest part of the catchment is categorized by the slope changing between 6% and 42 %. The nature of topography exposes the sebeya catchment to soil erosion. Furthermore, the 4 districts of sebeya catchment which contribute to flow Sebeya catchment area are amongst the 11 districts that are very extremely vulnerable to the hazards of land slide at nationwide due to slope and slope extent accountable for speed and scrubbing of soil elements (MIDMAR, 2015).

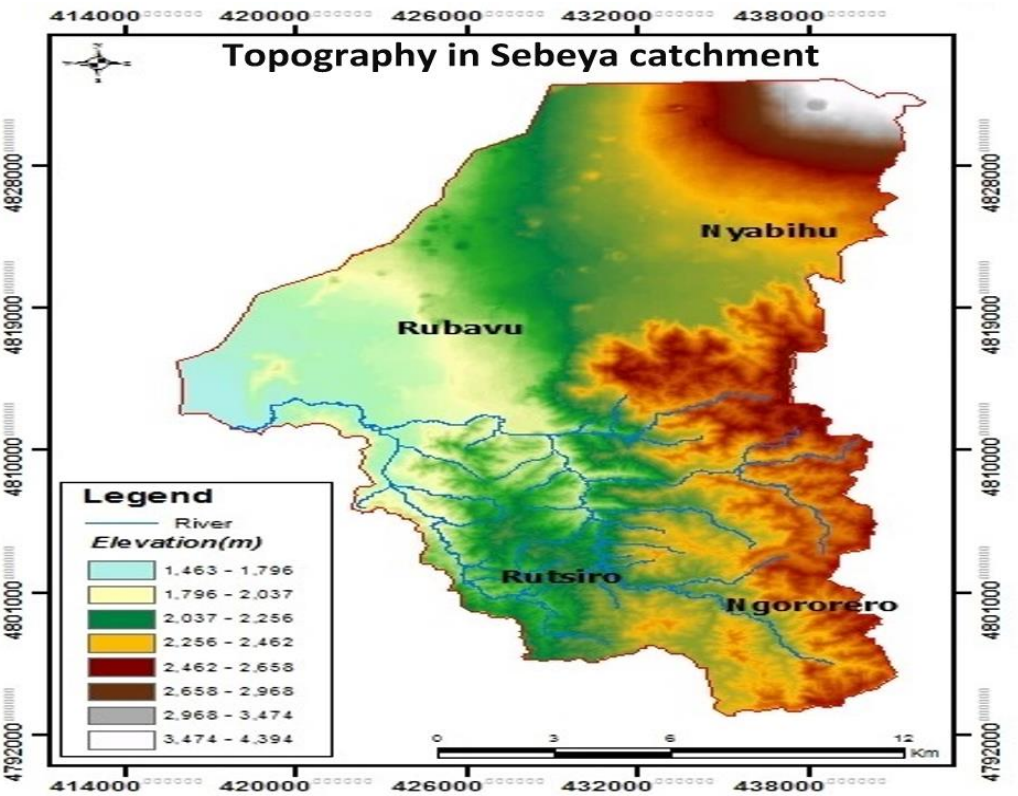

Figure 4. Administrative boundaries, topography, annual rainfall, and land use/land cover maps.
Source: MIDMAR (2015).

Table 1. Seasonal monthly averages for water quality of raw water, chemical quantity and produced water quantity.

Years	Parameters	Rainy season			Dry season		
		March	April	May	June	July	August
2017	Turbidity (NTU)	1653.66	2253.46	1776.6	895	869.92	898.26
	TSS (mg/l)	1239	2305	995	765	324	644
	E. coli (Cfu/100ml)	12450	23870	1120	980	688	876
	Chemicals (Kg)	166.1	163.44	180.15	114.85	114.21	129.29
	Treated water (m^3)	8605.73	8056.63	8945.04	9501.3	9269.11	9058.6
2018	Turbidity (NTU)	1553.66	2353.46	1976.6	934	765	779
	TSS (mg/l)	987	1764	1024	653	435	450.6
	E. coli (Cfu/100ml)	10220	15700	11500	783	654	669
	Chemicals (Kg)	166.1	163.44	180.15	144.85	109.03 (200)	106.23 (600)
	Treated water (m^3)	8605.73	8056.63	8945.04	9501.3	10263.86	9898.66
2019	Turbidity (NTU)	1163.55	1317.63	943.6	642.16	444.39	504.18
	TSS (mg/l)	967.34	897.5	703	324	230	356
	E. coli (Cfu/100ml)	1325	1450	1080	456	350	408
	Chemicals (Kg)	134.1 (500)	144.06	164.11	122.19	102.8	113.51
	Treated water (m^3)	8273.4	7822.73	8685.24	8321.13	9422.89	9004.08

Note: NTU: Nephlometric turbidity units, CFU: Colony forming unit , mg/L: milligram per liter, TSS: Total suspended solids, Kg: Kilogram.

The daily water quality and production reports filed by Gihira WTP operators include information on observed turbidity, total suspended solids, E. coli levels of raw water and treated water, and the quantity in cubic meter of water treated, type and amount of principal chemical(s)/ coagulants used**.** These reports were used to compare seasonal (rain and dry) and monthly averages for each item. The final data set Table 1 consists of three months (March, April and May) of rainy seasons and three months (June, July and August) of dry seasons from 2017 to 2019.

Comparing the month of April for rain seasons and July for dry seasons in year 2017, the data showed that the average turbidity was decreased from 2253.46 NTU to 869.92NTU, while the average quantities of water treatment chemicals have decreased from 163.44Kg to 114.21Kg and the cubic meters of treated water have increased from 8056.63 m^3 to 9269.11 m^3, equivalent to the increasing rate of 13.08% of produced water. The same situation was observed in years 2018 and 2019, where the increasing rate calculated were 21.50% and 16.98% respectively.

Figure 5 illustrates the average variability of raw water quality in different seasons. The improper land management, heavy rainfall and human activities disturbing the soil texture are resulting in high risk of soil erosion which was classified into six classes (very low, low, moderate, high, very high and extremely high) in tons/ha/year where about 8000ha are under high risk, about 6000 ha under very high risk while 4000ha and tremendously high risk of erosion (Bizimana, 2017). The stormwater is the main cause of water pollution. In this study, the quality of raw water for the key parameters was worse in rain seasons compared to dry seasons.

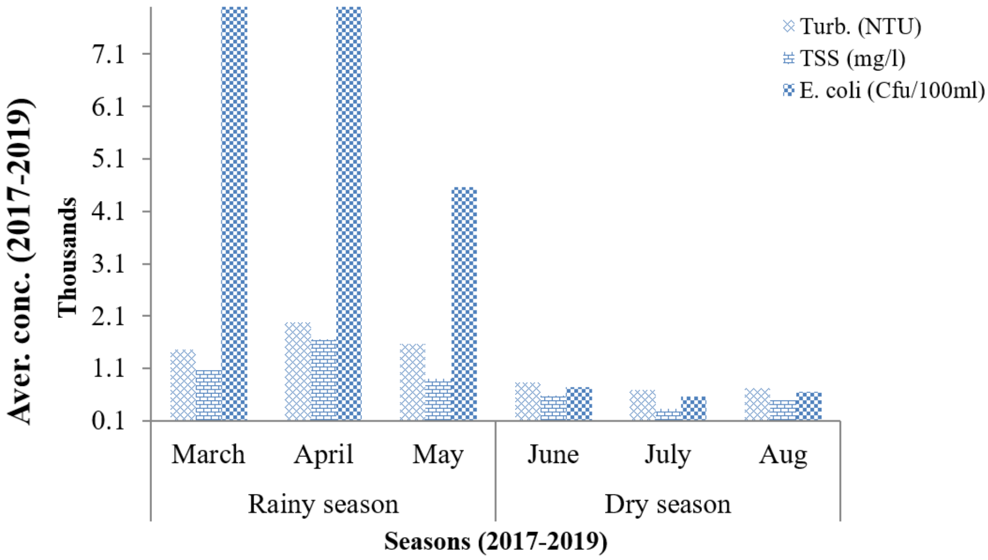

Figure 5. Average variability of raw water quality of Gihira WTP intake.

From Table 1, the average turbidities, total suspended solids (TSS) and E. coli are plotted in the same graph as illustrated Figure 5. The high values of the key parameters of water quality were observed in rain season compared to the dry season.

3.2.1. Sediment Loads and Turbidity Fluctuation in Sebeya River

The Figure 5 shows that the high turbidities, total suspended solids, as well as the sediment loads are observed in rain seasons compared to the dry seasons. This is the effect of soil erosion in uphill areas. In widest context, the soil erosion is accountable for increasing the rate of sediment loading in a river with two main categories of pollution correlated to the chemical and physical composition of the deposit/sediment (Ezugwu, 2013; Omar, 2014). The Turbidity is related to the accessibility of clay, silty and sand from inorganic and organic and substances (Omar, 2014).

Throughout rainy periods, both suspended solids and turbidity rise due to soil erosion and low preservation measures in Sebeya catchment. All values of turbidities and total suspended solids in both seasons are above allowable prescribe limit for potable drinking water requirements (Omar, 2014). This is the main challenge faced by Gihira WTP in terms of excessive chemical costs such as coagulants used to treat high turbid raw water. This research uses turbidity as an indicator of water quality (Moore & McCarl, 1987). Turbidity is determined in Nephelometric Turbidity Units (NTUs), which indicate how the light from a tungsten lamp is scattered in water. High turbidity levels make water unfitting for human drinking. In addition, chemical pollutants frequently find their mean into surface water sources with high turbidity (Dearmont, McCarl, & Tolman, 1998).

3.2.2. Escherichia Coli

E-coli are considered as indicator of fecal matter. These bacteria are very useful in giving us the levels of contamination. From Figure 5, the contamination of raw water was very high in rain seasons compared to dry seasons due to the soil erosion and rainwater runoff from the uphill areas. The pollution of water is enhanced by the rainfall, which naturally burdened sediments and other wastes into water courses, and this in turn, eased to increasing the water pollution probability (Haregeweyn et al., 2017).

3.2.3. Comparison Between Water Loss During the Rain and Dry Season

The results obtained from this study have revealed that the rainy season has influence on produced water. Basing on our observations, from 2017 to 2019 the produced water decreased at the plant level in rainy season to dry season. The decreasing ratio (%) of produced water in March, April and May in 2017 were 8.8%, 10.85 and 6.67% respectively in rain season comparing to 1.56%, 1.73% and 1.66% in dry season (June, July and August) respectively. The same situation was reproduced in 2018 and 2019 respectively. The Figure 6 shows that lost water has been decreased in dry season compared to rain season, hence increasing produced water (supplied water) under the period of study.

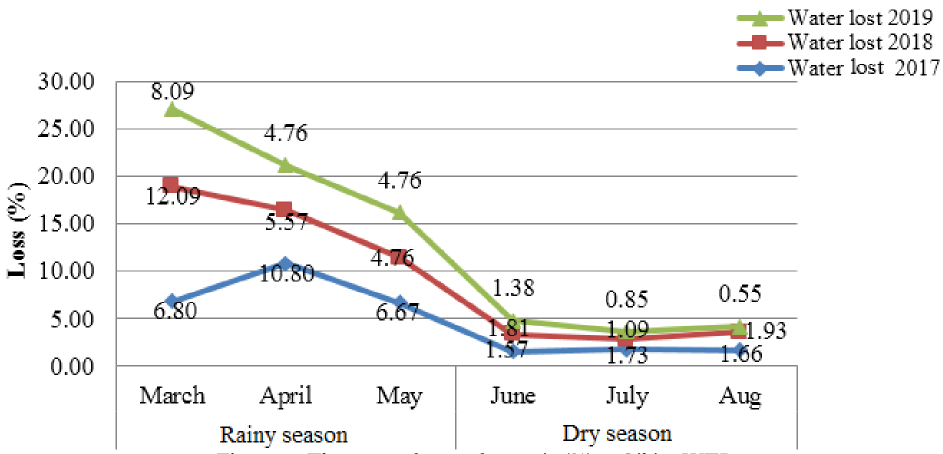

Figure 6. The seasonal water lost ratio (%) at Gihira WTP.

The Figure 6 is showing also that the supplied water is increasing in dry seasons compared to the rain seasons as also lost water is decreased. The sediment loads in terms of high turbidity of raw water from intake of Gihira WTP is changing over considered period. Sebeya river is also polluted by anthropogenic activities as other water resources in Rwanda**.** The topsoil and soil nutrients are washed into rivers, lakes and water reservoirs by soil erosion causing high turbidity. Once, the turbidity rises above some point, the desirable amount of coagulant rise**,** and wen this reaches the maximum the raw water become untreatable; hence plant stops operating. This will be the main reason why treated water will be less in heavy rainy season compared to the dry season.

3.3. Gihira Water Treatment and Treatment Chemical Costs in Different Seasons

3.3.1. Gihira Water Treatment Costs

Gihira water treatment plant functions mainly to take raw water quality to drinkable standards or requirements. In satisfying this role, treatment process charges/costs vary depending on the source and raw water quality and the accessibility of treatment capitals. Among costs comprises opportunity costs of capturing raw water from other usages to the domestic levels; storing and raw water transmission to the municipal area; raw water treatment to drinking water requirement; delivery of finite water within the municipal area to the home and any outstanding costs or compensations forced on others by the treated water. Gihira water treatment cost comprises functioning and capital costs related with the purification of raw water by the plant and delivery costs involve all expenses experienced in distribution of the ended or treated potable water to the end-user. The operation and maintenance cost includes all real cash process, costs of maintenance and administrative linking to the water treatment. For instance, work, energy, treatment chemicals, consumables replacements etc. However, due to present treatment process used at Gihira WTP, the only treatment chemicals cost especially coagulant used are more varied according to the raw water quality and production volume, hence, other remaining costs are considered as constants.

3.3.2. Water Treatment Chemicals Cost Per Unit

Generally, two types of treatment chemicals are used at Gihira WTP: Coagulants (Sudfloc 3870 or Aluminum sulfate and disinfectants. Coagulants bind with impurities to form enough sized particles and mass which are easy to eliminate by sedimentation and filtration and disinfectants is applied to kill bacteria and other organisms. The unit costs (in USD) and the chemicals used at Gihira WTP are presented in Table 2.

Table 2. Water treatment chemical and costs per unit.

Chemical	Cost/unit (USD)	Use
Sudfloc 3870	2.29	Coagulant
Aluminium sulfate (Alum)	0.56	Coagulant
Sodium chlorite	0.42	Disinfectant
Calcium hypochlorite	2.56	Disinfectant

Sources: GWTP annual reports. USD: united states dollar, Alum: Aluminium

3.3.3. Effects of Soil Erosion on Gihira Water Treatment Chemical Consumption (Cost)

The management of natural resources in sustainability way is one of the serious problems that each country must effectively address by observing at past events, having clear data of alteration in land use is very significant in land and water resources management in each country (Nachtergaele, 2002). Soil erosion does not only touch on agriculture productivity, but also off-site consequences are high significant as well in addressed; these consequences are related to the materials that arrive in the watercourses from land surface (Bizimana, 2017).

Table 3. Seasonal characteristics of Gihira water treatment plant and treatment chemical cost.

Years	Season	Month	Raw water turbidity (NTU)	Average TSS (mg/l)	Average monthly treated water(m3)	Average monthly total coagulants used (Kg)	Chemical cost (2.29) USD	Chemical cost per 1000 m3 of treated water (USD)	Chemical cost per 1000 m3 of WT per turbidity unit (USD)
2017	Rain season	March	1653.66	1239	8605.73	166.1	380.369	19.301	0.012
		April	2253.46	2305	8056.63	163.44	374.278	20.286	0.009
		May	1776.6	995	8945.04	180.15	412.544	20.14	0.011
	Dry season	June	895	765	9501.3	114.85	263.007	12.088	0.014
		July	869.92	324	9269.11	114.21	261.541	12.322	0.014
		Aug	898.26	644	9058.6	129.29	296.074	14.273	0.016
2018	Rain season	March	1553.66	987	8605.73	166.1	380.369	19.301	0.012
		April	2353.46	1764	8056.63	163.44	374.278	20.286	0.009
		May	1976.6	1024	8945.04	180.15	412.544	20.14	0.011
	Dry season	June	934	653	9501.3	144.85	331.707	15.245	0.016
		July	765	435	10263.86	146	334.34	14.225	0.019
		Aug	779	450.6	9898.66	142	325.18	14.345	0.018
2019	Rain season	March	1163.55	967.5	8273.4	164	375.56	19.823	0.017
		April	1317.63	897.5	7822.73	144.06	329.897	18.416	0.014
		May	943.6	703	8685.24	164.11	375.812	18.895	0.02
	Dry season	June	642.16	324	8321.13	122.19	279.815	14.684	0.023
		July	444.39	230	9422.89	102.8	235.412	10.91	0.025
		Aug	504.18	356	9004.08	113.51	259.938	12.607	0.025

Note: NTU: Nephlometric turbidity units, mg/L: milligram per liter, TSS: Total suspended solids, Kg: Kilogram, WT: water treatment, USD: United states dollar.

The soil erosion has a negative impact on water production of Gihira WTP. The data presented on Table 3, comprises summary of average seasonal monthly water production (in cubic meter), raw water turbidity (NTU), Average total suspended solids, chemical cost per 1000 cubic meter, and chemical cost per 1000 cubic meter per unit of turbidity.

The data in Table 3, showed that the chemical cost (USD) per 1000 m^3 of treated water in rain season (April 2017) varied from 20.286 USD to 12.322 USD in dry season (July 2017), while the chemical cost per 1000 m^3 of WT per unit of turbidity varied from 0.009 USD to 0.014 USD respectively. In 2018, the cost varied from 20.286 USD in April (rain season) to 14.225 USD in July (dry season), while the cost per unit of turbidity varied from 0.009 USD to 0.019 USD respectively. In 2019, the cost varied from 18.416 USD in rain season (April) to 10.910 USD in dry season (July), while the cost per unit of turbidity changed from 0.014 USD in rain season to 0.025 USD in dry season. The same trends are also observed on the remaining months of rain seasons and dry seasons in three years under study.

Comparing the rain season periods for the three years (2017, 2018 and 2019) under study, the data in Table 3 shows that the chemical cost per 1000 m^3 of treated water has been similarly increased in 2017 and 2018 compared to 2019. The chemical cost per 1000 m^3 of treated water was 19.301 USD, 20.286 USD and 20.14 USD and the chemical cost per 1000 m^3 of treated water per turbidity unit was 0.012 USD, 0.009 USD and 0.011 USD respectively in March, April and May (heavy rain season period of 2017).

GWTP spent the same amount for chemicals used to treat 1000 m^3 in March, April and May (heavy rain season period of 2018); while the chemical cost per 1000 m^3 of treated water was 19.823 USD, 18.416 USD and 18.895 USD, and the chemical cost per 1000 m^3 of treated water per turbidity unit was 0.017 USD, 0.014 USD and 0.02 USD respectively in rain season of 2019 (March, April and May). During rain period of 2019, the costs for treatment chemicals used were decreased in comparison with two previous years (2017 and 2018) and this was anticipated with the decreasing of raw water turbidity (NTU).

The erosion of soil can raise the cost of urban water treatment through acquiring further investments for basins settling, contaminants elimination, filtration, and elimination of numerous minerals from diverse source like sites of mining (Holmes, 1988). According to Omar (2014), the difference in mass movement rates of bed load sediments was found to be increasing during rainy season and diminished considerably during dry season. This is in line with the findings in Table 3, where the concentration of turbidity increased during the rainy season and tends to decrease in the dry season, this moves in line with higher demand of coagulants necessary for water treatment during the rainy season.

One of the main challenges faced by Gihira WTP in terms of excessive chemical costs of coagulant is the high turbidity of raw water. The very high turbidity and TSS values can be linked to unbalanced mining and poor agricultural activities favoring soil erosion that outcomes in high loads of Sebeya river sedimentation (Omar, 2014).

The outcomes of this study have revealed that the cost of treatment chemicals have been increasing in rain seasons compared to the dry seasons over the period under study. This is due to the increase of sediment loads or suspended solids caused by soil erosion in rain seasons. The Figure 7 shows the trends of treatment chemical cost of Gihira Water Treatment Plant in rain seasons against sediments loads in terms of suspended solids in sebeya river.

The results of this study have also shown that over the period of three years (2017-2019) increase in raw water turbidities caused by soil erosion during rain seasons (March, April and May) will increase the amount of coagulants used in the same season and a decrease of raw water turbidities during dry season (June, July and August) will also decrease the amount of coagulants (chemicals) respectively in the same season.

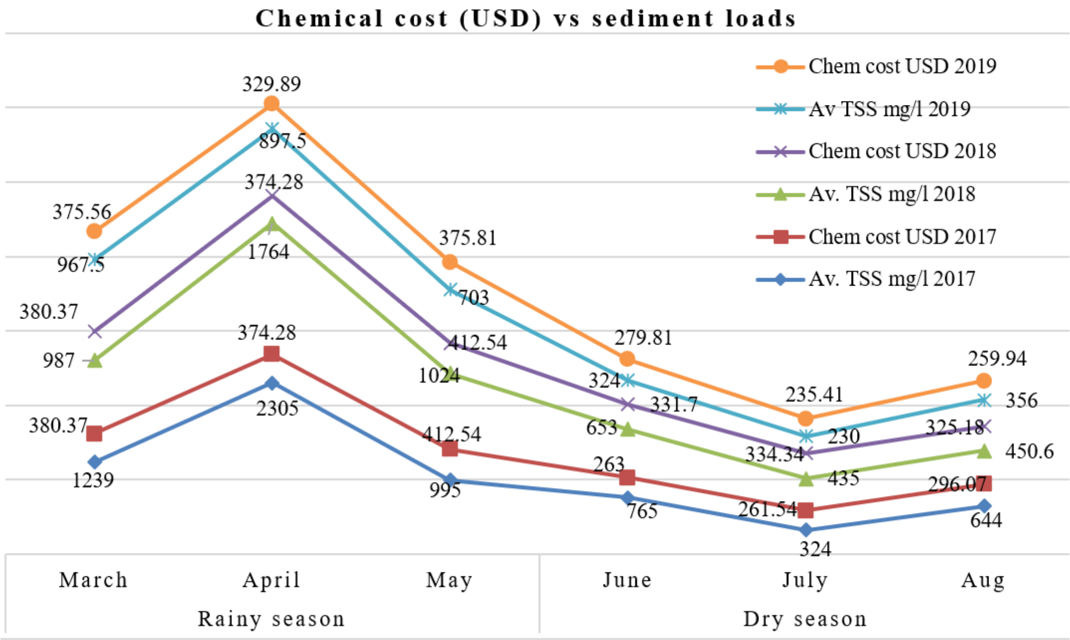

Figure 7. Trends of average chemical cost and sediment loads in terms of suspended solids.

The Figure 8 illustrates the chemical costs against sediment loads in terms raw water turbidities.

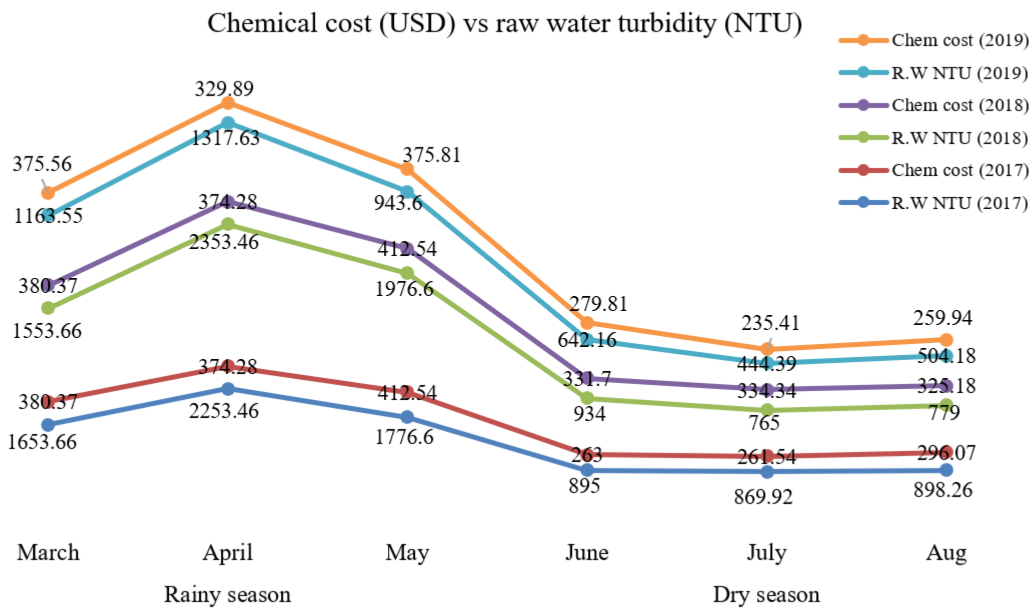

Figure 8. Trends of average chemical cost and average raw water turbidities.

The costs for chemicals and sediment elimination were valued to be USD 20.00 per million gallons and consideration of the effects of high turbidity on nonchemical prices would increase damage estimations (Dearmont et al., 1998). According to Omar (2014), the high turbidity due to high river deposit loads is much more in rainy season than in dry season and if the turbidity of raw water rises, the coagulants consumption will also rise for the same amount of water being treated.

High turbidity can meaningfully diminish the appealing quality of watercourses and lakes, having a damaging influence on recreation and tourism. It can harm aquatic life like fish and others by dropping water food provisions, demeaning depositing beds of lakes and rivers and touching the gill function of fishes (Ezugwu, 2013). As before specified, the cost of water treatment increases when water pollution is present in surface water. Once the raw water quality is remarkably good, numerous treatment processes such as coagulation/flocculation, sedimentation, etc. can be abandoned. For instance, sedimentation procedures are abandoned in direct water filtration treatment (Lintern et al., 2018). This will decrease the cost for treatment. Contrariwise, the quality of the raw water regulates the cost of chemical usage in a water treatment plant. Consequently, raw water quality is a foremost reason of dissimilarity in treatment costs. This was reinforced by the outcomes of Dearmont et al. (1998); Holmes (1988), which state that roughly each 1% rise in turbidity rises the chemical cost by 0.27%.

3.3.4. Effect of Soil Erosion on Treated Water Production of Gihira WTP

In Rwanda throughout rainy season's water treatment plants which treats surface water are forced to temporarily stop treatment process due to higher quantity of soil sediments transported by the water flow. This also affects the amount of supplied water to the consumers. However, the soil erosion has a negative impact on production of Gihira WTP. The data presented on Table 4, have shown that over the period of three years (2017-2019) increase in raw water turbidities caused by soil erosion during rain seasons (March, April and May) will decrease the amount of water produced in the same season and a decrease of raw water turbidities during dry season (June, July and August) will increase the amount of water production respectively in the same season.

The fact that, the turbidity is highly increased during heavy rainfall, the water treatment operators are obliged to reduce incoming raw water at the plant or even to stop treatment operations; this in turn will decrease the amount working hours per day, hence decreasing water produced.

Table 4. Amount of water produced at different turbidities per seasons.

Years	Parameters	Rainy season			Dry season		
		March	April	May	June	July	Aug
2017	Av. Raw water turbidity (NTU)	1653.66	2253.46	1776.6	895	869.92	898.26
	Av. Monthly products (m3)	8605.73	8056.63	8945.04	9501.3	9269.11	9058.6
2018	Av. Raw water turbidity (NTU)	1553.66	2353.46	1976.6	934	765	779
	Av. Monthly products (m3)	8605.73	8056.63	8945.04	9501.3	10263.86	9898.66
2019	Av. Raw water turbidity (NTU)	1163.55	1317.63	943.6	642.16	444.39	504.18
	Av. Monthly products (m3)	8273.4	7822.73	8685.24	8321.13	9422.89	9004.08

Note: NTU: Nephlometric turbidity units, Av.: average.

However, during the rain seasons, the turbidities do not increase on the same rate of decreasing of potable water produced. Figure 9 presents the relationship between decreasing potable water produced and increasing of raw water turbidities according to the seasons.

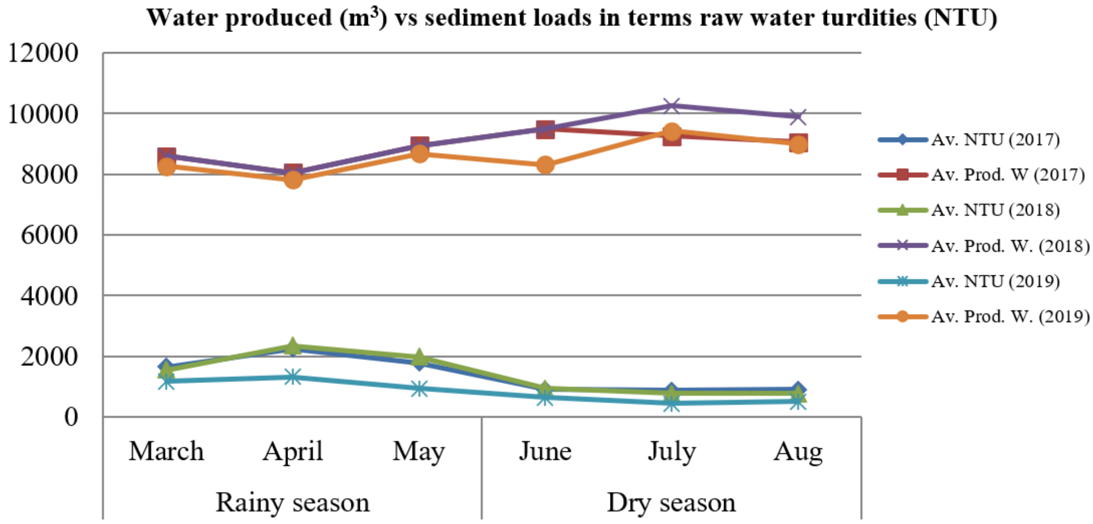

Figure 9. The impact of soil erosion on water production.

According to Bank (1999) the turbidity may be encompassed of inorganic and /or organic substances and it disturbs all water life by blocking sunlight diffusion. The water Plants require also light for photosynthesis. If suspended subsatances block light, photosynthesis and oxygen production and other water life will be lessened. The high turbidity of raw water at intake of Gihira WTP is generally caused by soil erosion which is worldwide known as main among other factors of degradation of environment; the effects of soil erosion comprise: water pollution, decrease of land efficiency, disruption of environmental functions, damage of life (Bizimana, 2017; Tilahun, 2013).

The level of sedimentation reflects the water courses management practices, buildup of deposits in rivers causes the undesirable effects downstream like loss of rivers discharging capacity, reduction of storage reservoir necessary for irrigation and flooding, rise of the cost of producing potable water, deficiency of hydro turbines in hydroelectricity projects (Bizimana, 2017; Burton, 2014).

3.4. Correlation between Factors Influencing Soil Erosion and Water Treatment Cost

Rivers are facing deteriorating water quality, for instance, with changed stages or levels of sediments, salts, and nutrients. Effective management of raw water quality being treated necessitates a comprehensive thoughtful of how and why the quality of water varies crossways space, both inside and among river catchments (Ezugwu, 2013).

Land use, land cover, land administration or management, geology and soil type, atmospheric deposition, weather, landscape, and catchment hydrology are the main features of a catchment that touch on the quantity of suspended sediment, nutrient, and salt concentrations in catchments, the enlistment and the distribution of these ingredients to receiving waters (Ezugwu, 2013) considered as raw water reserved for treatment of potable water. There are, however, complicities in the association between these characteristics and raw water quality.

Deterioration of the raw water quality resulting from farming activities runoff can fallouts in a diversity of economic costs. Nutrients, sediments and other water quality problems can seriously affect marine ecosystems, dropping commercial and recreational activities (Holmes, 1988). Sediment loads rises the cost of Gihira municipal water treatment plant by imposing investment in sedimentation basins, increasing water treatment chemical consumption and filtration costs and in several cases special treatments in screening and removing suspended solids. Pathogenic bacteria load also linked with soil erosion from human activities contribute to the need of disinfectants used for potable water supplies (Holmes, 1988; Lintern et al., 2018).

4. CONCLUSION

The present study highlighted the impact of soil erosion on surface water treatment cost. Water treatment is required before drinking or use to eliminate impurities. Through increasing guidelines and precautionary measures, treatment is becoming severe and costly. It is very significant that the residents of Sebeya catchment recognize the reality of soil erosion and its impacts on livelihoods. Also, the companies running business which are disposed on soil erosion or transport of sediment loads recognize all experienced losses caused by erosion happening in sebeya catchment. The description of the sebeya catchment revealed that the high potential of soil erosion caused by agriculture activities, rainfall, land cover and land use variation, soil categories and steep slopes end of increasing the cost of Gihira potable water production.

The eroded deposits/sediments conveyed in Sebeya River is negatively impacting on surface water treatment for domestic use in the ways of increasing the unit cost of water treatment especially water treatment chemical costs and decreasing the amount of cleaned water per month during the raining season. This is described by the fact that, the cost of water treatment at Gihira WTP in terms of chemical consumption is more increased in rain seasons compared to the dray seasons. Although, the average water treatment chemical costs were varied respectively from 380.369 USD, 374.278 USD and 412.544 USD in rain season (March, April and May) in year 2017 compared to 263.007 USD, 261.541 USD and 296.074 USD in dry season (June, July and August). The same decrease situation was observed from rain seasons to dry seasons in other two remaining years (2018 and 2019)

The soil erosion affects the quality of raw water by increasing its turbidity and numerous measures composed to land management practices still being needed to impact on the reduction of cost of potable water production. Especially in months of heavy rain (March. April and May). To moderate the soil erosion effects, it is imperative that all shareholders collaborate and contribute to governing erosion in the Sebeya catchment. The impact of soil erosion on the cost of surface water treatment and found that this is increased in the periods of rain seasons compared to dry seasons. Any extenuation degree considering the soil erosion control in the catchment would alleviate the contrary effects of Sebeya river sediment loads by decreasing the volume of sediment that is transported to the intake of Gihira WTP, hence reducing the costs on chemicals used by GWTP. However, basing on the results of this study, the following recommendations should be considered by decision makers:

- Instruct the individuals in terms of capacity building on the current laws of environment and imposed them to guarantee an appropriate control of soil erosion.
- Capitalize in several improvements toward lessening soil erosion in the catchment for instance educating resident people how to improve farming activities and shaped human settlements, etc.
- Corporates in knowledgeable and applying new skills that will contribute to soil erosion control.
- Reinforce all actions connected to the catchment management in terms of preserving the storage of rainwater by issuing reservoirs for runoff retaining and this will benefit also to normalize the highest flow in case of high heavy rainfall based on additional investigations.
- Increase the application of soil erosion control actions counting terraces, tillage conservation of forests, numerous measures of slopes stabilization, cover crops and plants, stabilize riverbanks with revetment of stones, regulate buffer zones.

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