Institute of Water and Energy Sciences (Including Climate Change)

Assessment of Soil Erosion Potential and Its Impacts on Hydroelectricity Generation and Potable Water Treatment in Sebeya catchment, Rwanda

Anthère Bizimana

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*Master in **Water, Engineering track***

President: Prof. Benguella Belkacem

Supervisor: Prof. Umaru Garba Wali

External Examiner: Dr. Joseph K. Sang

Internal Examiner: Dr. Chewki Ziani-Cherif

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DECLARATION

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

ABSTRACT

This study assessed the potential of erosion and its impact on Gihira Water Treatment Plant and Gisenyi Hydropower Plant in Sebeya catchment, Rwanda. The study determined the perception of the population on the existence of erosion, its impacts, major contributing factors, and organisations that contribute in its control in Sebeya catchment; it also characterized the catchment for risk of erosion potential, and determined the impact of erosion on Gihira WTP and Gisenyi HPP. Questionnaire was used in determining the perception of the population about erosion in the catchment. Digital Elevation Models (DEM), different digitized land uses, soil types, rainfall and available maps were used to characterize the catchment for erosion potential. Statistical tests were used to assess the differences in electricity generation between the raining seasons and dry seasons and how sediment transported in Sebeya River influences clean water production and the cost of its treatment. Water turbidity was used to characterize the variability of water quality. The results show that both local population and relevant administration perceive the existence of soil erosion in the catchment and considered deforestation, soil types, steep slopes, rainfall, farming methods, mining activities, and informal settlement as the major factors contributing to erosion in the catchment. The obtained maps during characterization indicate high potential for erosion especially because of poor agricultural practices, deforestation, soil types and steep slopes at upstream end of the catchment. The Gisenyi HPP was found to be more efficient in power generation during the dry season than in the raining season. The level of variability of turbidity was found to be statistically significant with the value of F greater than Fc. Production of potable water affairs to be high in some dry months than some months in the raining season and the cost of production of cubic meter of water is lower during the dry season than the raining season as expected. It was concluded that erosion is an issue in Sebeya catchment; it is leading to loss of soil fertility and agricultural lands and it is negatively impacting on hydropower generation and clean water production. The initiatives put in place to control erosion are producing results. It is recommended that more of these initiatives be put in place.

RÉSUMÉ

Cette étude a évalué le potentiel de l'érosion et son impact sur l'usine de traitement de l'eau de Gihira et l'usine hydroélectrique de Gisenyi dans le bassin versant de Sebeya, au Rwanda. L'étude a déterminé la perception de la population sur l'existence de l'érosion, ses impacts, ses principaux facteurs contributifs et les organisations qui contribuent à son contrôle dans le bassin versant de Sebeya; Il a également caractérisé le bassin versant pour le risque de potentiel d'érosion et a déterminé l'impact de l'érosion sur Gihira WTP et Gisenyi HPP. Un questionnaire a été utilisé pour déterminer la perception de la population de l'érosion dans le bassin versant. Les modèles d'élévation numérique (DEM), les différentes utilisations des terres numérisées, les types de sols, les précipitations et les cartes disponibles ont été utilisés pour caractériser le bassin versant pour le potentiel d'érosion. Des tests statistiques ont été utilisés pour évaluer les différences de production d'électricité entre les saisons de pluie et les saisons sèches et la façon dont les sédiments transportés dans la rivière Sebeya influencent la production d'eau propre et le coût de son traitement. La turbidité de l'eau a été utilisée pour caractériser la variabilité de la qualité de l'eau. Les résultats montrent que la population locale et l'administration concernée perçoivent l'existence de l'érosion des sols dans le bassin versant et considèrent la déforestation, les types de sols, les pentes abruptes, les précipitations, les méthodes agricoles, les activités minières et le règlement informel comme facteurs majeurs contribuant à l'érosion dans le bassin versant. Les cartes obtenues lors de la caractérisation indiquent un fort potentiel d'érosion, notamment en raison des mauvaises pratiques agricoles, de la déforestation, des types de sols et des pentes abruptes en amont du bassin versant. Le HPP de Gisenyi a été jugé plus efficace dans la production d'électricité pendant la saison sèche que dans la saison des pluies. Le niveau de variabilité de la turbidité a été statistiquement significatif avec la valeur de F supérieure à Fc. La production de l'eau potable est élevée pendant quelques mois secs pendant quelques mois dans la saison des pluies et le coût de production du mètre cube d'eau est plus faible pendant la saison sèche que la saison des pluies comme prévu. On a conclu que l'érosion est un problème dans le bassin versant de Sebeya; Il entraîne une perte de fertilité des sols et des terres agricoles et affecte négativement la production d'hydroélectricité et la production d'eau potable. Les initiatives mises en place pour contrôler l'érosion produisent des résultats. Il est recommandé de mettre en place plus de ces initiatives.

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I take this special moment to acknowledge the contribution of each and everyone in this achievement; God, PAUWES, Supervisor, Governmental and non-governmental institutions located in Rwanda and my wife.

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Knowing the impacts of data in the research work, I know how it was crucial to get allocated in Rwanda Water and Forestry Authority for one month of internship where I was able to collect part of the data for this study. The companies like WASAC (water and sanitation corporation) and Prime Energy Limited are also appreciated for their easy facilitation during data collection, here I meet gentle employees with customer care and interested in my research topic.

Finally, I am very grateful to my precious wife for her daily commitment in knowing any step of the work, moral support, encouragement and daily prayer.

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LIST OF ABBREVIATIONS

REMA: Rwanda Environmental Management Authority

MIDIMAR: Ministry of Disaster Management and Refuges Affairs

WTP: Water Treatment Plant

HPP: Hydropower plant

EDPRS: Economic Development and Poverty Deduction Strategies

MDGs: Millennium Development Goals

SDGs: Sustainable Development Goals

ANOVA: Analysis of Variances

OAGSF: Office of the Auditor General of State Finances

NPK: Nitrogen, phosphorus and potash

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Chapter one

INTRODUCTION

1.1 Background

1.1.1 General

Soil erosion by water is recognized as one of the major causes of land degradation globally. Though lands under activities such as pastures, forestry, mining, unpaved roads, and construction sites are usually affected by erosion, lands under agricultural activities are the most affected. More than 80% of world's agricultural land suffers soil erosion, from moderate to severe level leading to the loss of about 0.5 to 400 tons per hectare per year with an average loss of 3 tons per hectare per year, Widomski, (2011). Rwanda is one of the African countries that are severely affected by erosion; the soils of the country is naturally fragile and are generated by physico-chemical alteration of basic schistose, quartzite, gneissic, granite and volcanic rocks that make up the superficial geology of the country (MIDMAR, 2015) In Rwanda, the degradation of the natural environment is particularly linked with soil erosion that affects the important portion of agricultural land. Some of the contributing factors to soil erosion in Rwanda includes: mountainous nature of the terrain, High population density, rapid population growth and demand for more natural resources, poor agricultural practices, short time high intensity rainfall, deforestation, poor management of mining sites, uncontrolled river sand mining etc. Though series of initiatives are being implemented country wide to control erosion with the aim of curtailing it negative impacts, still its consequences are very obvious and they include the followings:

i. Loss of soil and fertility by the eroded land leading to reduction in crop yield and loss of agricultural land;
ii. Sediment transport leading to poor water quality as well as affecting infrastructural performance e.g. water treatment for domestic supply, hydropower generation, etc.

iii. Sedimentation resulting in blockage drainages leading to flooding and destruction of agricultural crops, houses, infrastructures (road, bridges, etc.) sometimes even leading to loss of life for example Gishiwati flood of 2007 about 24 people died, many crops were washed away and a lot of houses were destroyed.

Among the above-mentioned consequences of erosion in Rwanda this study focused on the impact of erosion on Gihira Water Treatment Plant, and Gisenyi hydropower Plant located in Sebeya catchment.

Rwanda “land of thousand hills” as it is referred to is small country of about 26,338 square kilometers. It is located in the Central/ East Africa. It is boarded by Uganda to the north, Tanzania to the east, Burundi to the south and Democratic Republic of Congo to west. It is located between $1^{0}04$” and $2^{0}51$” latitude south and between $28^{0}53$” and $30^{0}53$” longitude east RoR, 2004. Rwanda is the head water of two major African River Basins, Congo Basin and Nile Basing. The Congo Basin covers about 30% of the territory of the country and drains about 10% of water while the Nile Basin covers about 70% of the territory and drains about 90% of the water, see Figure 1. Sebeya catchment is a sub-catchment of Congo Basin in Rwanda (REMA, 2015).

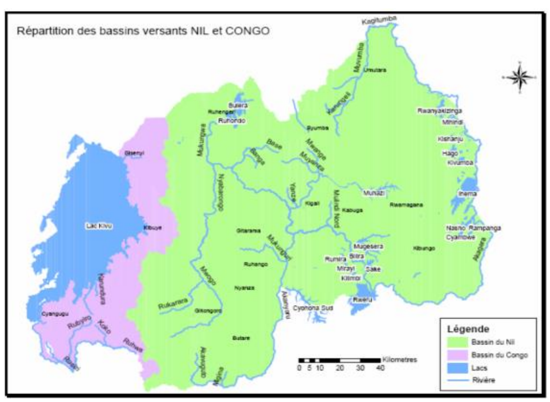


Figure 1.1 Repartition of Nile and Congo Basins

Rwanda with an estimated population of twelve million people and population density of about 456 persons per square kilometer is the densest country in African. The population growth is at 2.6 %. The country is water stress and with about 0.5 hectares per household it is also experiencing shortage of land resources (REMA, 2015: NISR, 2016).

Rwanda target to achieved 100% access to water and sanitation and 70% access to electricity in hydropower is expected to make substantial contribution. by the 2020 (Vision 2020, 2015). Currently access to improved water supply is about 85%, while access to electricity is about 35%. To achieve the above-mentioned targets and maintain the level is a serious challenge considering the rapid population growth (see Figure 1.2), water scarce state of the country and the level land degradation that is impending water resources development.

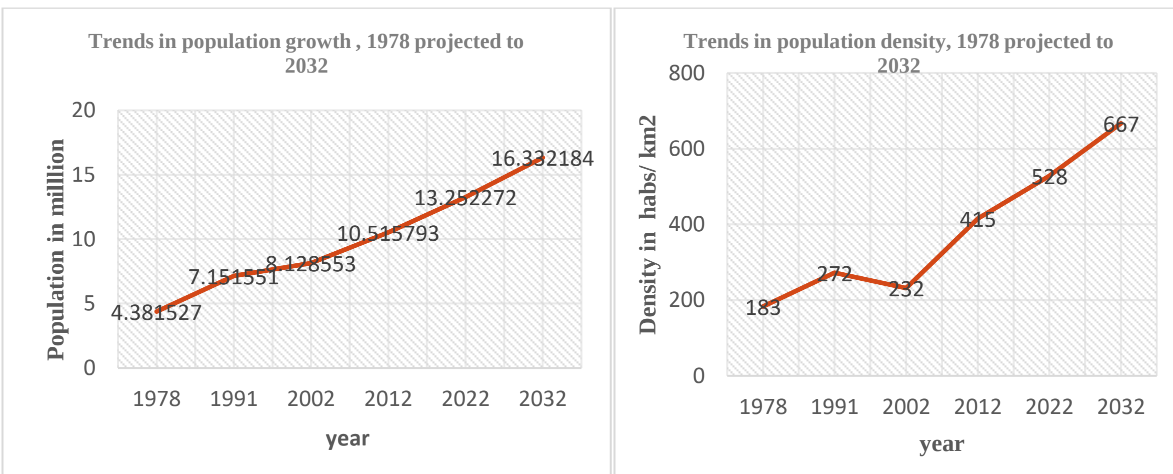


Figure 1.2 Trends in population growth from 1978 to 2032
Source: (REMA, 2015)

It worse to mention that in 2012 86.3 percent of the energy used was derived from wood. Though the domestic hydropower potential of Rwanda is about 400 MW only about 98.5 MW was utilized 2015 (REMA, 2015). Total hydropower production has been decreasing from 1960 to 2006, after this period it has revived again. The government has increased investments in energy production including domestic and regional hydropower projects Figure 2.3 and Table 1.1 (African Development Bank Group, 2013).

Table 1.1 Hydropower production in 2014

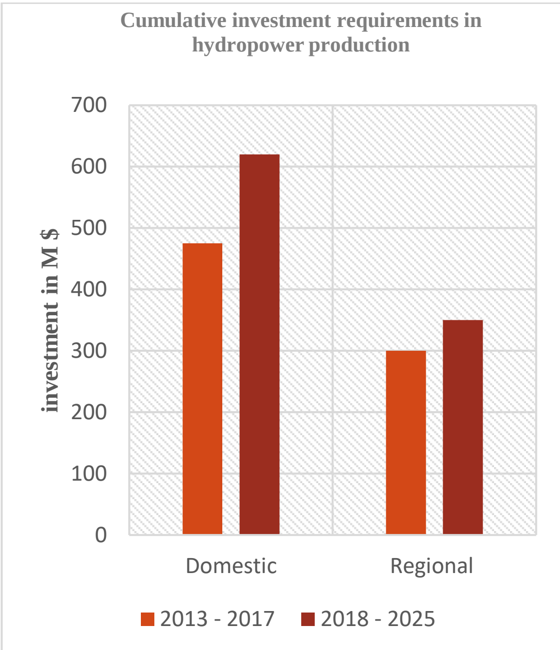


Figure 1.3 Investment in energy production
Source:(African Development Bank Group, 2013)

Category	Name	Installed Capacity in MW
Domestic	Mukungwa 1	12
	Ntaruka	11.25
	Gisenyi	1.2
	Gihira	1.8
	Murunda	0.1
	Rukarara 1	9
	Rugezi	2.2
	Keya	2.2
	Nkora	0.68
	Cyimbili	0.3
	Mazimeru	0.5
	Nshili 1	0.4
	Musarara	0.5
	Mukungwa 2	2.5
	Rukarara 2	2
	Giciye	4
Imported	Rusizi 1	3.5
	Rusizi 2	12

Source: (REMA, 2015)

Rwanda is a water scare country and because only 2.23 percent of its available water resources is being utilized with irrigation activities consuming between 80 and 90 of available water there is still possibility expansion of water resources development. The main source of drinking water is protected springs water because it represents 38 percent of potable water usage, the second is public taps with 26 percent; only 5 percent of the population have piped water supply system running to their dwellings. Water resources face threats related to management, population growth, urbanization, erosion, droughts and floods; this has resulted in water pollution where E-coli, Coliforms, high organic matters, and sediments loads are the main elements of water quality issues. (REMA, 2015).

1.1.2 Problem Statement

Management of water resources has become a critical problem in Rwanda due to climate change, soil type, topography, population pressure and lack of other alternatives of livelihood options for sustainable use of natural resource (REMA, 2015)**.** Population growth, declining resources and poverty are causing over exploitation of the natural resources and this has resulted in environmental issues such as land degradation, water pollution, floods, erosion, deforestation, loss of biodiversity, reduction in hydropower generation due to siltation, difficulty in purification of surface water for domestic use and use of buffer zones of water bodies. Climate change projections show that there will be increase severity of the above-mentioned issues mostly in northwest of the country. Erosion is one of the major land degradation issues in Rwanda. Erosion and its consequent sediment transportation and deposition is leading to loss of soil fertility and agricultural lands, as well as surface water pollution causing negative impacts on hydropower generation and clean water production among others. By 2015, more than 50 percent of the land in Rwanda has been put into crop production to increase food security, this has increases the severity of soil erosion resulting in loss of about 250 tons/ ha / year, with a yearly losses of nutrients of about 945,200 tons of organic materials, 41,210 tons of nitrogen, 200 tons of phosphorus and 3055 tons of potash. (K. Fidele et al., 2016). Agriculture employs about 70% of the population of Rwanda and it is main contributor to GDP in the country (REMA, 2015).

Sebeya sub-catchment one of the main sub-catchments of Congo Basin in Rwanda is one of the sub-catchments that are mostly affected by erosion that is generating a lot of sediments that is transported and deposited within the stream and rivers of the catchment. In addition, Gishwati Forest located in Sebeya catchment was subjected to massive deforestation just adding to land deterioration and surface water pollution. In 1933 the forest covers about 100,000 ha and by 2002 remains only about 600 ha just about 2% of its original area (Kisioh. H, 2015). The impacts of this degradation are felt on the infrastructures performance in the catchment example performance of water treatment plants and hydropower plants in the catchment. The impacts of erosion on other components of the catchment have not been quantified. Therefore, it is important to understand the perception of the people in the catchment about erosion, determine the main factors contributing to erosion and quantify its impact on the population and infrastructures in the catchment.

The main aim of this study was to assess the potential of soil erosion in Sebeya catchment and quantify its impacts on Gihira Water Treatment Plant and Gisenyi Hydropower Plant.

1.2 Objective of the research

1.2.1 Main objective

The main objective of this study was to assess the potential of soil erosion in Sebeya catchment and quantify it impacts on water treatment for domestic use and hydropower generation.

1.2.2 Specific objectives

Different activities were done in order to achieve the main objective; they specifically include:

1. To determine the perception of the local people and administration on the existence of erosion and its impacts on the population and the surrounding environment;
2. To characterize the catchment in term of the major factors contributing to erosion;
3. To assess the impacts of sediments transport on the power production of Gisenyi HPP;
4. To assess the impacts of sediments transports on potable water production at Gihira WTP.

1.3 Research questions

- What are the perceptions of the local people and administration on the existence of erosion and its impacts on the population and the surrounding environment in Sebeya catchment?
- What are the characteristics of Sebeya catchment that support erosion?
- How does erosion and consequence sediment transport in Sebeya catchment is impacting on hydropower generation of Gisenyi Hydropower Plant?
- How does erosion and consequence sediment transport in Sebeya catchment is impacting on potable water production at Gihira WTP?

1.4 Research Motivation

What do planners understand on human activities and developed water resources interaction? I hope the research results will rise up level of awareness in planning of water resources development for stakeholders in domain, bearing in mind the adverse effects of erosion; mostly when it comes to the country where land is becoming more and scarcer, population pressure on natural resources is increasing because their economic activities rely on it. It is crucial to bring concept of win – win situation between water companies and the community and enhance decentralization of water resources management institutions at catchment level.

Government of Rwanda puts in place many programs related to conservation of water resources, like water related 2020 goal considers continuous investments in protecting and management as well as water infrastructures development, and they point out some challenges centered by land scarcity, population pressure and poverty. In addition, high percentage of the population rely on agriculture, this requires to think out of the box where different scenarios must be studied and implemented; one of them is payment for ecosystem services and it is form of land use likely to secure the service.

Different initiatives in the domain like EDPRS I and II, Vision 2020, MDGs and SDGs have contributed in improved drinking water accessibility but there is still much to perform. Internationally, proper management of the catchment is linked to proper water resources management, the latter requires proper and continuous cooperation of the farmers and water and energy companies. Best land use practices must be adopted to reduce erosion rate which is the main source of water pollution (sedimentation, eutrophication, organic matter transport, etc).

1.5 Scope of the study

The research quantified the potential of soil erosion in Sebeya catchment assessed its impacts on potable water production at Gihira Water Treatment Plant and electricity generation at Gisenyi Hydropower Plant. The study determined the perception of the population on the existence of erosion, its impacts, major contributing factors, and organisations that contribute in its control in Sebeya catchment; it also characterized the catchment for risk of erosion potential, and determined the impact of erosion on Gihira WTP and Gisenyi HPP.

Chapter two

LITERATURE REVIEW

2.1 Introduction

2.1.1 Theory of soil erosion

Soil erosion is physical phenomena that combines detachment, transport and deposition of soil particles from the land surface by eroding agent such as water, wind and man (Telles, Dechen, Souza, & Guimarães, 2013). Potential of soil erosion is a function rainfall intensity, soil type, slope and slope length, land use, and soil conservation practices (N. Haregeweyn, A. Tsunekawa, & D. T Meshesha, 2016). In addition, it highly depends on political and institutional factors (R.P.C Morgan, 2005). Worldwide, soil erosion is among the main factors of environmental degradation; effects of soil erosion include: reduction of land productivity, water pollution, destabilization of ecological functions, loss of life, etc. (B.Tilahun, 2013).

Meaningful and effective preservation of water resources is among the key factors of social and economic development (K. Fidele et al., 2016; REMA, 2011). Erosion is source of water pollution and sedimentation of water bodies around the world and inadequate land use practices has accelerated the severity of the problem where water resources developments are affected (A.G.Adeogun, B. F. Sule, & A. W. Salami, 2016).

Sedimentation level reflects the watershed management practices, accumulation of sediments in rivers causes the negative effects downstream like reduction of storage reservoir necessary for irrigation or hydropower systems, loss of rivers discharging capacity and flooding, increase of the cost of producing potable water, deficiency of hydro turbines in hydroelectricity projects (A.G.Adeogun et al., 2016).

Sediments

Soil particles following within water in the river having specific gravity of 2.6 approximately in the form of clay, silt, sand and gravel are recognized as sediments; their main sources weathering of the rock. Some of them are suspended (suspended load) or in river bed (bed load), they decrease from the river bed to the water surface generally. A given portion settles down in basins and the remaining part pass directly to the hydraulic machines downstream. Sediments are of several classes based on their sizes (H.P. Neopane, 2010).

Table 2.1 Classification of river sediments

Particle	Clay	Silt	Sand	Gravel	Cobbles	Boulders
Size (mm)	< 0.002	0.002 - 0.06	0.06 - 2	2 – 60	60 - 250	> 250

Source: (H.P. Neopane, 2010)

2.1.2 River sedimentation and hydropower development

Sediments are brought into rivers by runoff or flood water, their quantity depends on erosion rate. The later has several factors like soil type, slope, soil management practices, rainfall intensity and land use of the catchment drained by the river; human pressure on land has increased the load of sediments in rivers (K. Fidele et al., 2016). Turbine is the crucial component of hydropower plant; its function is to convert potential energy of flowing water into mechanical energy , sediments erosion damage in turbine results from their dynamic action on metal surface (H. N. Patel, S. K. Singal, & , R. P. Saini, 2013).

From design and maintenance points of view, sediment erosion is among the key challenges in hydraulic turbines (S. Chitrakar, C. Michel and B. S Thapa, 2014). Sediments flowing in the river through the turbine are responsible for sediments erosion in its components by wear and abrasive forces which affect the operating conditions in terms of reduced life span, increased maintenance costs, high frequency of repair periods and decreases of total energy production (H. N. Patel et al., 2013; M-W. Kang, N. Park, S-H Suh, 2016). These particles are of specific gravity of 2.6 approximately and in form of clay, silt, sand and gravels (H.P. Neopane, 2010). Hydropower is of high importance for sustainability in power generation. Unfortunately, most of water contains silts which cause abrasive degradation to the machine components; stay, guide vanes, turbine blades and labyrinth seals are at risks where runner blades of the turbines are most affected (H. N. Patel et al., 2013).

Different researches using different models and laboratory tests in domain showed that sediments erosion rate in hydro turbines depends on their concentration, type, hardness, potential energy of water and size distribution (A.K. Bastola & H. P. Neopane, 2014; M-W. Kang, N.Park, S-H Suh, 2016). Sediment control at upstream is crucial to sustain infrastructure development, it requires proper erosion control methods which applies the principles of integrated watershed management with critical awareness and cooperation of stakeholders from all levels (A.G.Adeogun et al., 2016).

2.2 Theory of abrasive and erosive wear in hydro turbines

When hard particles pass on the surface they cause a certain loss of material, it is defined as abrasive wear; The surface suffers from micro cutting, fatigue, gain detachment then brittle fracture. When hard particle of microscopic size is causing erosion, angle of impingement is low and impingement speed is of 100m/s approximately, in this case erosive wear is similar to abrasive wear. In the remaining conditions, abrasive and erosive wears do not resemble and erosive mechanisms dominate (H.P. Neopane, 2010; Thapa, Dahlhaug, & Thapa, 2015). In 1960, Finnie has studied erosion on surfaces and he has classified the material into two categories as brittle and ductile. It was found that the ductile material losing particles by plastic deformation where material is removed by eroding particle by means of displacing or cutting action with maximum erosion at the jet angle of 30° approximately; whereas impacting particles create cracks which in turn removes material by their interaction for brittle material with maximum erosion at angle 90° of the jet (Thapa et al., 2015).

2.2.1 Sediment erosion in hydro turbines

Abrasive and erosive wear forces impart on the hydraulic machine functioning in water containing sediments where the severity depends mostly on their concentration and quartz content. The wear causes tremendous economic loss that is demonstrated in operation and maintenance costs. Moreover, sediments erosion rate is of many factors to be taken into account for better its study like characteristics of sediments (size, concentration, shape, hardness, material, etc.); characteristics of fluids (flow rate, head, rotational speed, velocity, turbulence, acceleration, impingement angle, temperature, etc.) and the material the turbine is made from (chemistry, elastic property, hardness, surface morphology) (H.P. Neopane, 2010).

2.2.2 Factors of sediments erosion in hydraulic machines

1. Fluid characteristics

i. Velocity of water carrying sediments

Mechanical deformation of the turbine varies in function of both velocity of water and particles, the latter depends on the speed of water in which sediments move. At critical or threshold velocity, the friction and cutting action do not take place, there is no effect; the damage comes like plastic deformation and cutting at the velocity higher than critical (H. N. Patel et al., 2013; H.P. Neopane, 2010).

ii. Impingement Angle

Angle between eroded surface and trajectory of the particle before hitting the surface is known as impingement angle, in practical purpose jet angle is taken as impingement angle of particle which is not the true impacting angle. At angle of 0° the trajectory of the particles is parallel to the material surface and erosion is minor (H.P. Neopane, 2010)

iii. Effects of erosion media

Water or air is referred as conveying media, erosive particles and liquid medium is known as slurry. Influence of media in sediments erosion depends on its properties as viscosity, density, turbulence and microscopic properties (corrosivity and lubrication capacity). Mixing small quantity of lubricants with erosive slurries can reduce its effects. Collision efficiency is used to assess effect of the medium, it is the ratio of particles that hit a wearing surface to the theoretical number of particles without the presence of any medium (H.P. Neopane, 2010)

iv. Temperature and erosive wear

Temperature alone is not sufficient to cause erosive wear in turbine, it just softens the eroded material to accelerate the erosion wearing process rates because of its big correlation with mechanical properties of the material. At higher temperatures in an oxidizing medium, corrosion issues occur which further speedup wear process (H.P. Neopane, 2010).

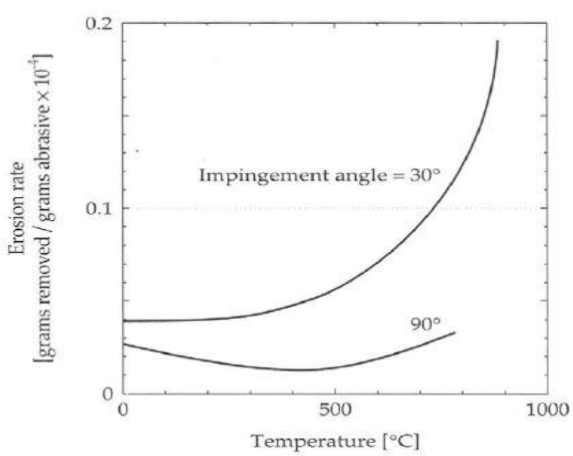


Figure 2.1 Effect of temperature on erosive wear rate of stainless steel

v. Turbulence and erosive wear

The level of the medium turbulence reflects the particles content as they are likely to be present more in turbulent than laminar flow. Within the latter, the path of the sediments is parallel to the surface and their impacts become less than in any other type of trajectory which many be vertical or inclined (H.P. Neopane, 2010).

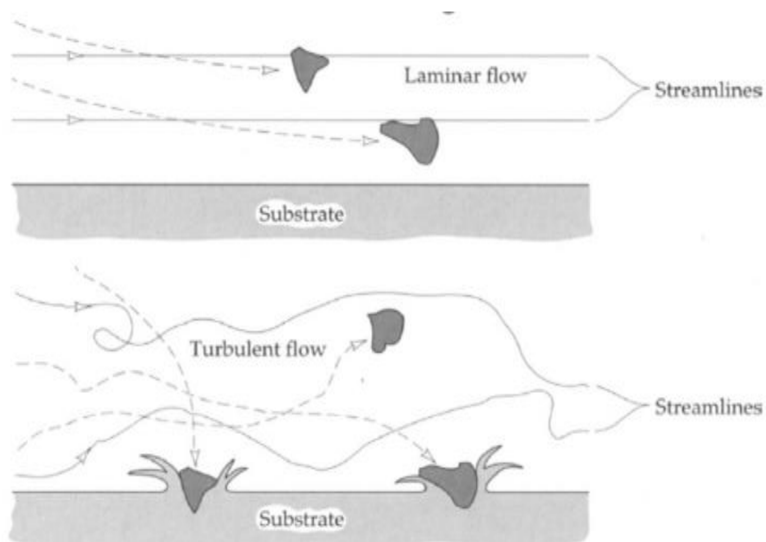


Figure 2.2 Effect flow on erosive wear

2. Characteristics of base material

Life span of the turbine depends on the material it is made from. The base material constitutes the main factor in sediment erosion and its choice must be made with care so that the purpose of the machine or machine component is met. That is why it is very crucial to consider some properties like hardness, chemical composition, and microstructure. For the components that are subjected to abrasion, such as spiral casings, nozzle pipes draft tubes, are made of plain structural steel or castings with enough strength; in addition, if their wetted surfaces are protected with elastic coating (epoxy, polyurethane based plastics have assessed appropriate to play this role). Coating is applicable to new or eroded components (H.P. Neopane, 2010).

3. Characteristics of the sediments

Aspect of sediment properties is very important in erosion analysis but it is not studied deeply. For example, the harder – sharper sediment is more erosive wear occurs; the ratio of sediment hardness to substrate's one plays a big role. Influence of hardness depends on mode of erosive wear taking place whether ductile or brittle, effect is more in brittle than ductile mode (H.P. Neopane, 2010).

i. Size and shape of the particle

Magnitude of erosion in hydraulic machine is proportional to the particle size distribution in the material. This means that, lager particles are aggressive than small particles; the material containing quartz even of small size (0.05 to 1mm) also does wear away some particles of the machine components that are in contact with the flow. in fact, sharp and angular particles are responsible to cause more erosion compared to rounded ones. Impacts of sediment is a function of its energy; the latter depends on speed, head and mass of the discharge (A.K. Bastola & H. P. Neopane, 2014).

ii. Hardness of the particle

Hardness of the particle is also one of the most factors favorizing erosion rate. It is danger when the hardness value is more than 5 in Moh's scale. When the hardness of the particles is greater than metal's one, the wear increases because the stronger the deeper in can penetrate in the surface (Padhy & Saini, 2008)

iii. Concentration

Generally, the most important factor in sediment erosion in hydraulic machines is concentration of the particles in the flow. The ratio of sediments to the total mass of the fluid imparting on the turbine per unit time; for river sedimentation, it is expressed in grams per liter (g/l) or parts per million (ppm) by weight is often used that is equal to mg/l, 1000ppm is approximately equal to 1kg of water. Based on several studies, there is interference between rebounding and arriving particles, that is why erosive wear is proportional to sediment dose up to a certain limit; at certain limit wear rates decreases (H.P. Neopane, 2010; Padhy & Saini, 2008)

2.3 Rotating disc apparatus for sediment erosion measurement

Study of Sediment erosion in several parts of hydro turbine use models and laboratory tests (Thapa et al., 2015). Some of these models are Computational Fluid Dynamics, Mathematical models etc. (H. N. Patel et al., 2013; Thapa et al., 2015). In laboratory tests (high velocity type, rotating disc/arm type, centrifugal type), the famous equipment for this work is rotating disc apparatus (RDA). The latter has disc or arm that is rotated using high-velocity motor; specimen to be tasted is fixed on the disc and submerged into the mixture of eroding material and fluid medium (water) (Rajkarnikar, Neopane, & Thapa, 2013). Water circulates continuously to cool the housing, after operation erosion can be seen on the specimen disc because of its weight loss. RDA has mainly four components rotating disc with blade attachments, housing and supporting structure, cover and shaft connected to motor (A.K. Bastola & H. P. Neopane, 2014).

According to A.K. Bastola & H. P. Neopane (2014), erosion rate is the weight of the specimen lost per second, it calculated by the following mathematical expression,

$E = (W_i – W_j) / (W_i * T) * 1000$ (mg/g per hour)

W_i = weight of the specimen in grams before testing

W_j = weight of the specimen in grams after testing

T = Operation time in hours

2.4 Effects of soil erosion on water treatment

Soil erosion does not only affect agricultural production but also off-site effects are very important as well in addressed; offsite impacts are associated to the materials that enter the waterways from land surface. Soil erosion can increase the cost of municipal water treatment by acquiring additional investments in settling basins, pesticides and pathogens removal, filtration, and removal of several minerals from different source like mining sites (Holmes, 1988).

Variability in water quality impose several economic impacts on human and ecosystems health, agriculture and fishery production, recreational activities and so on (Andrew. M, 2012).

The factors governing the cost of water treatment system mainly include the quality of water source or to be produced, the quantity of water required, the lifespan of the plant; moreover, some others factors are advised like space requirements, plant location and land acquisition, installation rates, level of system automation needed, operation costs (Holmes, 1988).

2.5 Multivariate analysis

Analysis of data requires the use of statistical techniques where most of them use one or two variables of data. It was found that dataset may have more than two variables (complex set of data), to analyze such a dataset is possible with multivariate analysis which consists of set of methods that can be used when many measurements are taken on each individual or object in one or more samples. Measurements are considered as variables and individuals as units or observations (Alvin C.R, 2002).

Historically, Multivariate analysis techniques found to be applied in behavioral and biological science with a goal of simplification. With the time, interest of multivariate analysis is spread in several fields like engineering, policy making or any other kind of decision making, environmental studies, finance, project management, medicine, ecology, business, education, literature, mining nursing, psychology, religion, etc. (Alvin C.R, 2002). In this approach which uses multivariate statistics dataset is composed of values that are function several variables for a given number of treatments. Datsets are organized in different format such as, a data matrix, a correlation, a variancecovariance matrix, a sum of squares and cross -products matrix, or a sequence of residuals (Alvin C.R, 2002).

In general, multivariate analysis has mainly two main techniques; the first is analysis of dependence where one or more variables are dependent variables (e.g: Multiple regression), the second is analysis of interdependence where variables are not dependent and it is used for relationships between cases, objects or variables (Khalik, W. M. A. W. M., Abdullah, M. P., Amerudin, N. A., & Padli, N, 2013).

2.5.1 Analysis of Variance – ANOVA

Analysis of variance (ANOVA) is one of multivariate analysis techniques which uses statistical principles (analysis) for testing null hypothesis that considers no difference between two or more population means of different groups**,** this method is often used for treatments. The groups correspond to treatments applied by the researcher to judge the level of statistical significance (Eleisa.H, 2009).

The aim of ANOVA is to judge the statistical significance between groups using F-tests, for example $\alpha=0.05$ is actually the type I error rate. This means that there is a statistical significance when the possibility of getting finding difference associated to the mistake between two groups is less than two groups; furthermore, it means that once you run two-sample tests 100 times, 5 out of 100 have high probability of resulting the long values. By several tests between the both groups you may find a statistically significant difference which may not be different actually. This is the principal reason of using ANOVA in simultaneous analysis of several groups (Alvin C.R, 2002).

In ANOVA, random sample of n observations is taken from each k normal population with the same variances, the layout is as follow (Alvin C.R, 2002).

	Sample 1 from N (μ_1, σ^2)	Sample 2 from N (μ_2, σ^2)	……………………	Sample k from N (μ_k, σ^2)
	y_{11}	y_{21}	……………………..	y_{k1}
	y_{12}	y_{22}	……………………...	y_{k2}
	.	.		.
	.	.		.
	.	.		.
	Y_{1n}	y_{2n}	………………………	y_{kn}
Total	$y_{1.}$	$y_{2.}$		$y_{k.}$
Mean	$\bar{y}_{1.}$	$\bar{y}_{2.}$		$\bar{y}_{k.}$
Variance	S_1^2	S_2^2		S_k^2

The k population is sometimes considered as groups, and groups correspond to the treatments considered by the researchers in the experiment.

In the previous layout;

$y_{1.} = \sum_{j=1}^{n} yij$ and $\bar{y}_{i.} = \frac{1}{n}\sum_{j=1}^{n} yij$

i = 1, 2, 3, 4…....................k and j = 1, 2, 3, 4 ………………n

According to (Alvin C.R, 2002) in one way models, k groups or samples are considered to be independent, the assumption of independence and common variance are necessary to work on F-test. The model of each observation is

$y_{ij} = \mu + \alpha_i + \varepsilon_{ij}$

$= \mu_i + \varepsilon_{ij}$

$\mu_i = \mu + \alpha_i$ is the mean in the i^{th} population we wish to compare the sample means $\bar{y}_i$, with i = 1,2,3….k to see if they are sufficiently different to conclude that the population means are different. The null hypothesis to test is expressed as H_o: $\mu_1 = \mu_2 = \mu_3 \ldots\ldots\ldots\ldots = \mu_k$. If the null hypothesis is true all y_{ij} are produced from same population, and we can estimate easily two values σ^2. The first is the calculated from sample variances (S_1^2, S_2^2 .... S_k^2) the population of the group (sample), in other words it means within the groups, the second is computed from all sample (group) means ($\bar{y}_{1.}$, $\bar{y}_{2.}$ ………………. $\bar{y}_{k.}$), the σ^2 is calculated as:

$$S_e^2 = \frac{1}{k}\sum_{i=1}^{k} S_i^2 = \frac{\sum_{i=1}^{k}\sum_{j=1}^{n}(yij - \bar{y}i.)^2}{k(n-1)} \quad \text{(first value)}$$

The second estimate of the σ^2 which is based on sample means as

$$s_{\bar{y}}^2 = \frac{\sum_{i=1}^{k}(\bar{y}i. - \bar{y}..)^2}{k-1} \quad \text{and} \quad ns_{\bar{y}}^2 = \frac{n\sum_{i=1}^{k}(\bar{y}i. - \bar{y}..)^2}{k-1} \quad \text{(second value)}$$

Overall mean $\bar{y}.. = \frac{1}{k}\sum_{j=1}^{n} \bar{y}i.$

During sampling from the normal distribution k samples, $\bar{y}i.$, s_i^2 are independent in each sample, s_e^2, the first value that is of function of s_i^2 values is independent of $s_{\bar{y}}^2$ which is function $\bar{y}_i$ values. It means that s_e^2 depends on the variability within each sample, that is the reason why s_e^2 estimate σ^2 whatever the null hypothesis (Ho) is true or not, consequently E (s_e^2) = σ^2 in any case. Definitely, the ratio of s_e^2 and $ns_{\bar{y}}^2$ results in F – statistics because they are independent from each other.

$$F = \frac{ns_{\bar{y}}^2}{s_e^2}$$

2.5.2 Tukey Test

Tukey test is the Post Hoc Analysis for ANOVA where the samples are of the same size, its suitable when the analysis of variance proved the statistical significance of the population of different treatments. This test is very important because it helps to conclude which treatments are different from others that the ANOVA does come across. This test compares means of population using Q, where Q is calculated and compared to Qcv; if the Q is greater than Qcv the means of pair are significantly different (Tukey, Ciminera, & Heyse, 1985)

Q = $\frac{Mean\ X - Mean\ Y}{\sqrt{s_e^2/n}}$, Mean X represents large mean and mean Y represent small mean in pair of means under consideration. Qcv is obtained from its distribution table. This table uses number of means and degree of freedom within groups to be able to draw the value of Qcv. Tukey Test in one-sided because only the positive side is considered (Tukey et al., 1985).

Chapter three

MATERIALS AND METHODS

Research findings depend on many factors, among which data availability and used methods are perceived to play a big role. The study used primary and secondary that was collected either on site or from institutions (B.Tilahun, 2013). Desk review/Documentation technique was used to collect data on the study areas through consulting different sources such as books, internet, statistical bulletins, governmental publications, information published or, data available from previous research, case studies and library records, online data analysis offered by the media, web sites, and the internet.

3.1 Description of study area

Sebeya catchment is one of the sub-catchments of Congo Basin located the western part of Rwanda. It has an area of 365 km^2 approximately (1.38 percent of country area) (M. Omar, 2014), (REMA, 2011), a region that is characterized by high altitude, heavy and abundant rainfall throughout the year and steep slopes (REMA, 2015). Itis one of the densely populated areas in the country where people around the natural reserves are responsible of their destruction due to seeking of other option of livelihood (Kisioh. H, 2015). High percentage of the population is under poverty line in Sebeya catchment. Environment issues are at critical point and some of them are erosion and land slide which are caused by inappropriate mining (artisanal), inappropriate agricultural practices/overexploitation of soil, conversion of forest land to livestock grazing areas (Gishwati), deforestation which has resulted in Siltation to rivers (M.O. Elsa, 2015), gullies, reduction in soil productivity, land degradation, damages of hydropower plants, destruction of settlements in high risk zones. Flooding, for example occurs in Kanama and Nyundo sectors in in Ribavu Distrtict which causes Road and bridges destruction, river bank destruction, flooding of agricultural areas (MIDMAR, 2015; REMA, 2015). Figure 3.1 shows the location of Sebeya catchment in Rwanda.

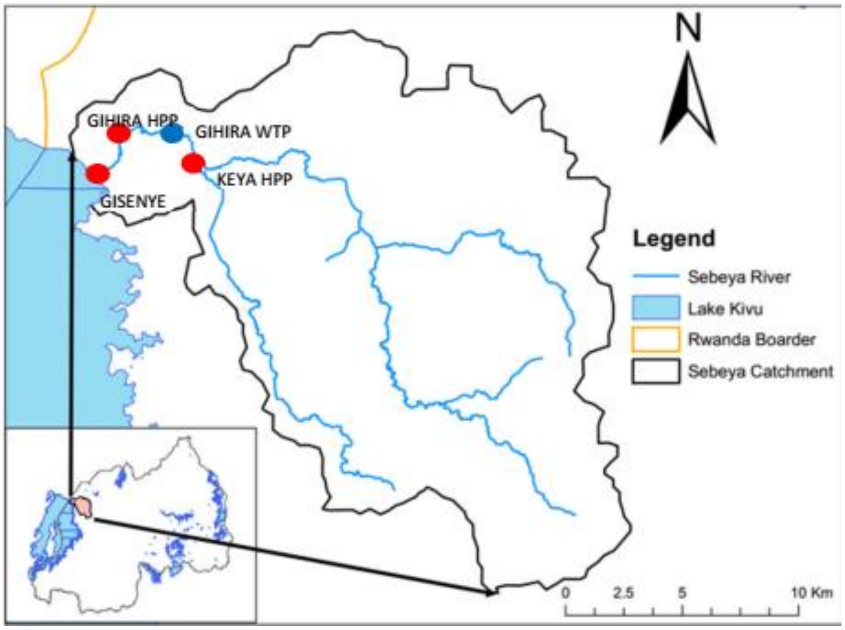


Figure 3.1 Location of Sebeya Catchment in Rwanda.

Sebeya catchment contains two main rivers: Sebeya and Pfunda. These rivers are the source of water supply for Gihira water treatment plant, Gihira, Keya & Sebeya hydropower plants; and indirectly (through WASAC) for the brewery of BRALIRWA in Ruvabu. The catchment includes the district capital of Rubavu (Gisenyi) which is one of the six secondary cities of Rwanda with increasing demands for potable water and energy. Apart from the main paved road, other roads are of varying quality, and the majority of them are vulnerable to damage from heavy rainfall, floods and landslides (M. Omar, 2014). The catchment cut across four districts: Rubavu, Rutsiro, Ngororrero and Nyabihu. Sebeya catchment is strongly reliant on rain-fed agriculture both for rural livelihoods and exports of tea and coffee because fishery activities in Lake Kivu are not part of major economic activities (M. Omar, 2014; M.O. Elsa, 2015)

3.1.1 Issues and challenges of water resources in sebeya catchment

3.1.1.1 Quality of water in Sebeya River

Pollution point of view, surface water in Rwanda is polluted by human activities (anthropogenic) like agriculture, mining and unformal settlement and unsafe waste disposal methods. For Sebeya river system, the first three are the most concerned.

3.1.1.1.1 Agricultural activities

Sebeya River is located in populated area where people livelihood depends mostly on agriculture**.** The cause of water quality pollution due to agriculture is related to the use of fertilizers, insecticide, manure and sediment transport. The rate of fertilizers use is not high due to the soil fertility compared to insecticides for the purpose of increasing land productivity (NPK, urea, etc.), but this has resulted in some kind of change in water characteristics, of course by erosion because these chemicals are soluble to get into surface water indirectly by runoff. Nutrients like nitrogen content in the manure also get into the rivers easily where the buffers zones are very small. (NUR, 2012).

The famous case in loss of land cover in Rwanda is the destruction of Gishwati forest. A given part of this has been occupied by human in terms settlement and farming; this has changed soil stability and structure so its capacity to soil erosion resistance has decreased. This natural forest is the most and best in Sebeya river catchment; unfortunately, due to the stated problem areas around the tributaries of this river become flooded with a considerable amount of sediments (NUR, 2012).

3.1.1.1.2 Deforestation of Gishwati Forest Reserve

Gishwati forest is located in one of populated areas of western province just in south of volcano park at the altitude ranging from 2000 to 3000 meters above sea level. Moreover, the big part of Gishwati forest if found in Rutsiro District within its four sectors: Kigeyo, Ruhango, Nyabirasi and Mushonyi (Kisioh. H, 2015). From 1933, Gishwati has been put on list of main forests in Rwanda. About one hundred years ago, Gishwati was at the second class in size amongst indigenous forests in Rwanda with an area of 100,000 hectares. In 1970's', its area was only 28,000 ha (approximately one fourth of original area) and 61.1% of its area was depleted due to anthropogenic causes (cattle grazing and resettlement of refugees, farming). Deforestation of the forest continued seriously because the covered area by 2002 was 2 % (600ha) of its area in 1970's. Figure 3.1 gives an over view of deforestation of Gishiwati forest. The forest plays several functions such as ecological, biodiversity, social–economic values, buffer for water resources and soil erosion and with the time these functions have been decreasing (Kisioh. H, 2015).

According to Kisioh. H (2015), ecological function of this forest is for Rwanda but also for many of African country because Gishwati intercepts precipitation for Nile and Congo Basins knowing that forests regulate the river flow to ensure the annual flow this forest is essential for water and electricity provision for several factory and communities in north-western of the country. It also buffers Sebeya River system by filtering agricultural runoff. In addition, this national reserve produces organic material to fertilize soil and recycle soil nutrient, this is very important for water pollution control and it decreases the quantity of chemical that could been in use in water treatment process. Shelter of bird species was a part of it, but number of them has kept on decreasing within the time.

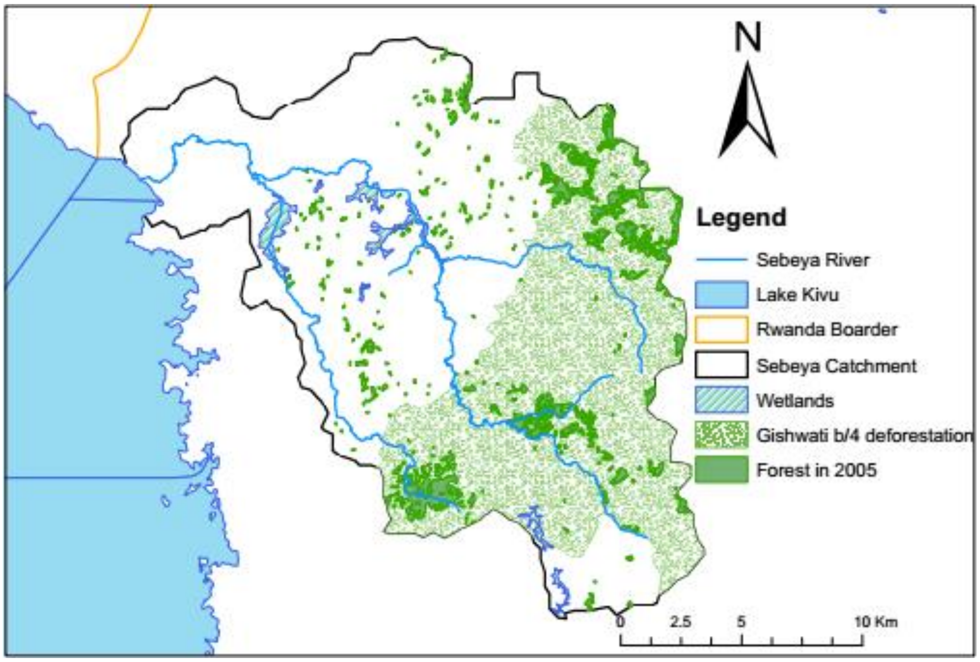


Figure 3.2 Showing the magnitude of deforestation of Gishiwati forest

Impacts of deforestation of Gishwati forest are not only experienced on the site but also at several kilometers downstream. Truly speaking, Sebeya River is water source for Gisenyi hydropower plant, Gihira water treatment plant and BRALIRWA brewery (main brewery in the country) which in turn most of people in the locality depend on these infrastructures are located in this area apart from the beer and electrical power produced (Kisioh. H, 2015).

One the of examples is where soil erosion has polluted river and its tributaries at coffee-brown level, this has forced hydraulic and water-dependent factories to close for several months each for maintenance purpose, mostly cleaning the mud out equipments; a such case has been noted at Gihira Water Treatment Plant in Rubavu District (Kisioh. H, 2015).

From 2002 the Government of Rwanda took initiative to restore the forest (for example the area of the forest has been increased to 1484 ha between 2008 and 2011) but it still faces some challenges like demographic pressure in the locality, high dependence on agriculture, mining activities, charcoal making, firewood collection, animal grazing and timber harvesting (Kisioh. H, 2015; NUR, 2012)

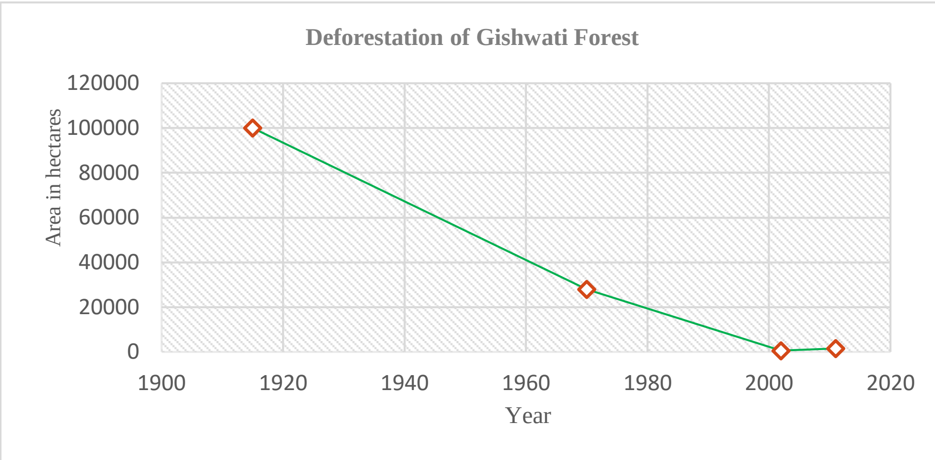


Figure 3.3 Timely area shrinkage of Gishwati forest
Source: Kisioh. H (2015)

3.1.1.1.3 Afforestation of Gishwati forest

After several disasters like floods and landslides which carried away many lives including human beings in the area, different projects have been initiated to restore the forest functions. The projects have been implemented by the government of Rwanda or by cooperation of the country and international organization. Many techniques have been adopted like agro-forestry, radical terracing, progressive terracing and live mulch from that moment the forest is regenerated progressively. Some of these projects are: the first is PAFOR Project which has used agro-forestry to increase Gishwati size from 600 hectares to 886 hectares between 2005 to 2008; the second is Giswati Water and Land Management Project that has been launched by MINAGRI and funder by the Government of Rwanda, its goal was to restore the fragile ecosystem and to improve the community involvement in sustainable land use by application of modern agricultural and animal husbandry methods; the third was Gishwati Area Conservation Program from 2008 to 2012 to expand the real area of Gishwati forest, the project was implemented though the cooperation of Rwanda Environmental Management Authority and Great Ape Trust where the expected outcome was about Rwanda Conservation Park creation, restoration of ecosystem services in safeguarding the quality of water, decreases soil erosion rate and flooding, increase the number of biodiversity with special interest of chimpazees and boost rate of income from ecotourism without ignoring the priority of investment and community employment in the area; the fourth is The Forest of Hope Association (FHA) which Non-Governmental Organization at Rwanda Nation level was established in 2012 for the conservation purposes, it focuses local communities engagement to rise up the level of their ownership and participation in the management of the forest. Activities of FHA include education on conservation, mitigating crop raiding, increasing the level of the living standards and favorizing research (Kisioh. H, 2015).

3.1.1.1.4 Mining activities in Sebeya catchment and their effects on Sebeya River

According to OAGSF (2015), work that acquires excavation of the surface and subsurface for the purpose of exploiting and processing minerals is known as mining. The subsoil of Rwanda is rich in granite-related ore deposits that contain minerals like cassiterite, niobotantalite, wolframite, beryl, spodumene, amblygonite, monazite, gold, etc. mining activity has started in 1930's with Belgians and expanded over the years. Today private investors are working in mining industry where the government works on regulation and policy making rather than investing in mining projects. Mining sector is amongst the key priorities for economic growth in Rwanda.

Mining is adversary- significantly causing environmental degradation in terms of water pollution, resources depletion etc. This activity carried out in several parts of the country has consequently affected the soils of hill and marshes, where erosion rate has been increased to overload the marches and rivers (OAGSF, 2015).

Office of the General Auditor General of the State Finances has done audit on mining activities in 2015 because of different environmental reasons mainly, here below there are some of them such as:

a. Increase in mines production means increase in environmental destruction, the projected income was estimated to triple by 2017 from 2012.
b. Present severe environmental problem regarding some mining activities like: disposal of soil and sand into water while separating impurities from minerals, loss of forests cover, use of inadequate methods in minerals extraction and illegal mining activities, a considerable number of open pits abandoned or still under exploitation which are responsible to high soil loss during rainy season.

Moreover, environmental concern lack of management of the top soil from mining operation, erosion control plan of mine sites, deterioration of Gishwati and Mukura forest because of illegal mining activities, operation of mining activities in rivers, lack of facilities to capture waste water and tailing from minerals washing sites (OAGSF, 2015).

Sebeya is one of the rivers that are vulnerable to pollution because of the mining activities, the table 3.1 highlights the status of the pollution from Ngororero District only.

Table 3.1 Mining companies from Ngororerro District and their contribution to water pollution of Sebeya river

No	**River**		**Destination**	**Mining operators**	**Observation**
1	Bikoneko	Muhanda	Sebeya	NRD and SFX	Washing, dumping tailing and soil
2	Gaseke	Muhanda	Sebeya	NRD and SFX	Washing, dumping tailing and soil
3	Gugano	Muhanda	Sebeya	NRD and SFX	Washing, dumping tailing and soil
4	Humiro	Muhanda	Sebeya	NRD and SFX	Washing, dumping tailing and soil
5	Rongero	Muhanda	Sebeya	NRD and SFX	Washing, dumping tailing and soil
6	Humiro	Muhanda	Sebeya	NRD and SFX	Washing, dumping tailing and soil
7	Sebeya	Muhanda	Sebeya	BECHA, NRD and SFX	Washing, dumping tailing and soil

Source: OAGSF (2015)

The audit carried out by Office of the Auditor General of State Finances (2015), has listed the mining operators without license and environmental impact assessment, see table 3.2.

Table 3.2 Status of mining companies is Sebeya catchment

No	Company/cooperative /individual name	Perimeter	District	License number	Expiry date
1	BOCCA 1207 Ltd.	Gatyazo	Rubavu	0259/16.01/MINIRENA/2012	28/08/2016
2	Cooperative de Development et d'Exploitation Miniere de Musasa (CODEMM)	Rundoyi	Rutsiro	0337/MINIRENA/2011	18/01/2015
3	FUTURE PROMOTION COMPANY Ltd	Rusumo	Rutsiro	0197/MINIRENA/2014	23/06/2018
5	MUPENZI MINING COMPANY	Rugamba	Nyabihu	0076/MINIRENA/2014	17/01/2018
6	MUYIRA MINING COMPANY Ltd	Nyamibombwe	Rutsiro	0182/M.INIRENA/2014	24/06/2018
7	SOCIETE MINIERE DE KANAMA (SOMIKA) ltd	yungwe-murambi	Rubavu	0110/MINIRENA/2012	03/01/2016
8	CEMIR	Gaseke	Ngororero	0308/MINIRENA/2012	10/02/2016

Source: OAGSF (2015)

Land use practices in Sebeya catchment has imparted on water quality at critical point, the table 3.3 shows part of the results of the research carried by NUR (2012) on water quality monitoring in 2012. Water quality parameters have been measured; the researchers have selected different points of Sebeya River and some of its tributaries.

Most of the values were very high compared to the standards. Even if the Government of Rwanda has started to conserve Gishwati forest from 2002 through different programs, the studies have showed more concerns regarding water resources management in Sebeya catchment, especially Sebeya river (NUR, 2012).

Table 3.3 Water quality parameters monitored in Sebeya river and its tributaries between October and November 2011

Parameter	Unit	Sebeya River before entering Kivu Lake	Sebeya River at Nyundo bridge	Karambo River before discharging into Sebeya	Sebeya River at Musabike Sector	Standards for surface water
Temperature	°c	17.80	17.6	15.7	17.2	Ambient
Ph	_	7.53	7.58	6.57	6.55	6.5 - 8.5
Turbidity	NTU	675	644	44700	6310	5
Conductivity	µS/cm	134	148	140	17.7	< 1000
Total suspended solids	mg/l	397	530	8520	450	< 30
Total Nitrogen	mg/l	Na	Na	Na	Na	< 3
Total Phosphorus	mg/l	0.34	0.48	1.66	0.47	< 5
COD	mg/l	32.1	28.7	567	81.2	< 50
BOD	mg/l	10.05	13.4	44.9	20.13	< 30
Dissolved oxygen	mg/l	7.29	6.7	6.91	5.7	5
Copper	mg/l	Nd	0.05	0.02	Nd	0.1
Zinc	mg/l	0	0	0.02	Nd	3
Iron	mg/l	2.8	2.05	0.84	6.89	0.3
Manganese	mg/l	0.112	0.08	Nd	0.491	0.1
total hardness	mg/l $CaCO_3$	52	98	Na	110	250
faecal coliform	Cfu/ 100 ml	816	206	212	210	4×10^2
e-coli	Cfu/ 100 ml	8×10^2	510	212	520	4×10^0

Source: NUR (2012)

3.2 Determining the perception of the local people and administration on the existence of erosion and its impacts on the population and the surrounding environment

The perception of the local people in Sebeya catchment and staff of the institutions dealing with water resources and environmental management was studied. Questionnaire was used to sort for their perceptions. Some 30 people were interviewed because of limited time; these include local people, people working at the Gisenyi HPP and Gihira WTP. The interview focused in determining the followings: Biodata of the interviewees, existence of erosion in the catchment, and the impacts of erosion both onsite and offsite within the catchment. The results of the interviews were presented in tabular forms and details explain.

Data obtained from questionnaires were analyzed basing on biodata of respondents like age, education level, field of studies and experience. The second aspect of interest that was tackled on was regarding existence of soil erosion, the most elements of concern were: magnitude, factors (such as deforestation, slope, rainfall, farming methods, mining activities, informal settlement, type soil), effort put in place to control, contributors in control of soil erosion, the role of WASAC Ltd and Prime Energy Ltd in awareness of soil erosion in the catchment considering that they own some of the plants in the locality. The third referred to the impacts of soil erosion, generally on: decrease in land productivity, soil loss, water pollution, death, house destruction, others; moreover, specific impacts were addressed on Gihira WTP and Gisenyi HPP. At Gihira WTP, questionnaire focused on: increase in cost of water treatment, increase of maintenance cost, damage of physical components like conveyance structures, and intake, reducing the amount of water purified, intermittent water supply. At Gisenyi HPP, more interest was on: increase of maintenance cost, damage of physical components of the plant like conveyance structures, and intake, turbines, reduction in amount of electricity generation.

3.3 Characterization of the catchment in terms of parameters influencing erosion

The Sebeya catchment was characterization based on parameters that determine the erosion potential. These include that parameter that made up the modified Universal Soil Loss Equation they include intensity of rainfall, soil type, land cover and management practices, and slope (K. Fidele et al., 2016). Others are elevation, and slope.

Digital Elevation Model (DEM) was use in ArcGIS environment to delineate the catchment (see Figure 3.4 for the flow chart of the procedure). Digitize layers of the parameters were clipped to create several maps that were used to characterized the erosion potential of the catchment. considered the factors of erosion appeared in Universal Soil Loss Equation (USLE) which characterize Sebeya Catchment to account the determinants of potential of soil erosion. Different maps were generated and /or collected as secondary data collected such as topographical map (from digital elevation model), soil map (capture soil type in the area), land use map, precipitation, distribution of the population in terms of density throughout the catchment. All of these were necessary for analysis of rainfall erosivity factor, Soil erodibility factor, Slope factor, Slope length factor and cover management factor (K. Fidele et al., 2016). The combinations of these factors produce work to generate the removal of the soil and these results in a given type of erosion (rill, shit, gully). Soil erodibility factor was taken into consideration for soil characteristics on soil erosion process for a given rainfall; slope and slope length factor depends on the nature of the slope of the terrain; cover management factor is function of land use and management principles; rainfall erosivity is of rainfall intensity and more of type of climate elements (Clay & Lewis, 1990). From all mentioned above that govern erosion, the perception on soil erosion in Sebeya catchment was better understood by interpretation of the map showing erosion rate in different areas of Rwanda modelled using GIS (REMA, 2010).

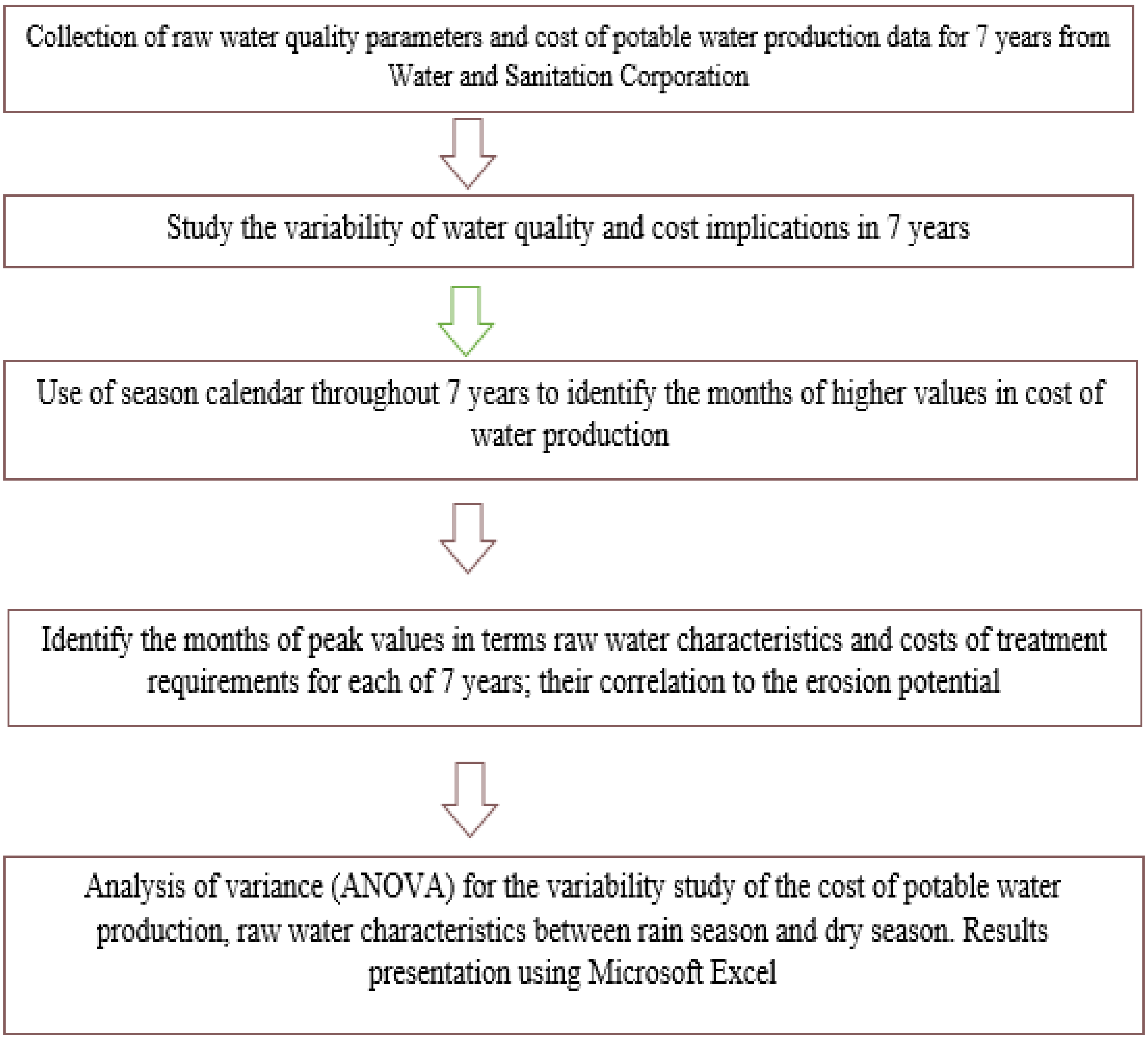
3.4 Assessment of impacts of sediments transport on the power production of Gisenyi HPP

Sediments transported by water affect the performance of hydropower stations in the areas where their content is high (H. N. Patel et al., 2013). Usually the amount of sediments transported by a river is high during the raining season. The impact of sediment transport on power production was accessed. It is well known that the amount of electricity generated at a hydropower is directly proportional to the product of available discharge and head. This product is expected to be high during the raining season and therefore it is expected that more electricity can be generated during raining season, anything contrary to this might be as a result of not being able to use the available water for power generation and this could be as a result of excessive sediment that affect the working

3.5 Assessment of impacts of sediments transports on potable water production at Gihira WTP

Management of natural resources in sustainable manner is one of the critical issues that every country is obliged to address effectively looking at historical events, having clear information of change in land use is very important in land management and management of water resources in the country (FAO, 2013). In Rwanda during raining seasons some water treatment are oblige to stop working temporarily because of high amount of sediment transported by the water. Assessment cost of water treatment as compared by the amount of the sediment transportation by Sebeya River was conducted to access the impact of sediment transport on the water amount of water produced. The variables considered were characteristics of raw water, cost of potable water production, raining and dry seasons.

Impact of soil erosion are felt even by water quality, the movement of pollutants from the land ends up to transport sediments into rivers, streams, lakes, marshlands on daily basis (B.Tilahun, 2013). The impacts of Sebeya river sedimentation on water treatment at Gihira WTP was studied by consideration of season calendar, cost of portable water production, raw water characteristics and rainfall. The changes in all considered data in their respective seasons was compared and correlated. To produce the part of assessment results; the mentioned steps here below was fallowed.



Tukey Test was used as post processing of ANOVA to know which pairs of means are statistically- significantly different from one another go get the final conclusion

Chapter four

RESULTS AND DISCUSSIONS

4.1 Perception of the local people and administration on the existence of erosion and its impacts on the population and the surrounding environment

4.1.1 Biodata of respondents

The analysis of questionnaires data shows that the biodata of respondents is good enough to provide reliable information about perception on erosion. More than 80 % of the respondents are at least 21 years or more; more than 60 % have secondary school education including more than 40% with bachelor degree; more than 22 % had experience of about 1 year to 20 years in the field of in water and environmental sciences or hydroelectricity (see table 6.4). About 23.33 % of respondents were female.

Table 4.1 Biodata of respondents

Sex								
Male	23							
%	76.67							
Female	7							
%	23.33							
Age	20 years	21-35 years	36-40 years	40 – 50years	above 50 years			
	4	16	8	1	1			
%	13.33	53.33	26.67	3.33	3.33			
Education	Primary school	Secondary school	A_1	A_0	Masters			
	7	6	3	10	0			
%	23.33	20.00	10.00	33.33	0.00			
Studies in Water and Environmental Sciences:								
	3							
%	10							
Studies in hydroelectricity and water supply								
	5							
%	16.67							
Experience in Domain	1	2	3	4	5	5-10	10-20	> 20
	2	2	1		1	0	2	1
%	**6.67**	**6.67**	**3.33**	**0.00**	**3.33**	**0.00**	**6.67**	**3.33**

4.1.2 Existence of soil erosion

Unilaterally all respondent both the local people and administration agreed that there the problem of erosion in Sebeya. However, they varied in their perception of its magnitude, where 10% of the respondant think it is law, while 50% and 37% said it moderate and severe respectably. Majority of the respondent agree that the main factors contributing to erosion in the catchments are deforestation, slope, rainfall, farming methods, mining activities, informal settlement and type of soils Table 4.2.

About 46.67% perceived that erosion is increasing while 53.33 % consider it decreasing. This might be because of the location of the respondents as various erosion control activities are taking place at various locations in the catchment. The result shows that central and local governments contribute to erosion control. Majority of the respondent do not know whether or not WASAC and Prime Energy Ltd contribute in erosion control, however they agree that the two companies contribute in afforestation to protect buffer zones, sensitization of the community and stabilization of slopes by using gabions (see table 4.3).

Table 4.2 Existence of soil erosion

		Total	Percentage (%)
Do you think there is erosion in Sebeya catchment?	Yes	30	100.00
	No	0	0.00
If yes, how do you quantify it magnitude?	Low	3	10.00
	Moderate	15	50.00
	Severe	11	36.67
If yes, what does cause it?	Deforestation	26	86.67
	Slope	27	90.00
	Rainfall	26	86.67
	Farming methods	25	83.33
	Mining activities	13	43.33
	Informal human settlement	19	63.33
	Soil type	22	73.33
Does it increase with the time (rate)?	Yes	14	46.67
	No	16	53.33
Is there any effort put in place to control (reduce) erosion?	Yes	28	93.33
	No	2	6.67
If yes by whom?	Government	25	83.33
	NGOs	0	0.00
	Development Partners	0	0.00
	Local People	26	86.67
	Others	0	0.00
Is WASAC contributing in erosion control the Sebeya Catchment?	Yes	7	23.33
	No	4	13.33
	I don't know	19	63.33
If yes how	Afforestation	3	10.00
	Construction of channel by gabions	2	6.67
	Sensitization	4	13.33
Is Prime Energy Ltd contributing in erosion control the Sebeya Catchment?	Yes	4	13.33
	No	4	13.33
	I don't know	22	73.33
If yes how?	Afforestation	1	3.33
	Construction of channel by gabions	1	3.33
	Sensitization	3	10.00

4.1.3 Impacts of soil erosion

Local people and the administration aware of the impacts of soil erosion on environment and the water resources development in Sebeya catchment. All the respondents have agreed that erosion is source of more than one issue that environment and infrastructures are facing. For example, the responses showed that soil erosion is responsible of decrease in land productivity, soil loss, water pollution, deaths, house destruction etc. (see Table 4.3).

The vulnerability of Gihira water treatment plant from erosion was found high, more than 80% of the respondents agreed that the challenges to that infrastructure are composed of increase in cost of water treatment, increase in maintenance cost, damage of physical components like conveyance structures, and intake, reduction in amount of water purified, intermittent water supply. Furthermore, 6.7 % don't know which kind of impact that the water treatment plant is subjected to. This may be due to the fact that they are not aware of the process of water treatment including how raw water are obtained.

Gisenyi HPP was also found to be affected by sediment transport as a result of soil erosion. About 70% of the respondents knew some of the problem HPP is facing as a result of erosion, these include: increase in maintenance cost, damage of physical components of the plant like conveyance structures, intake, turbines, and reduction in amount of electricity generation. About 96.7 % of respondents appreciated the contribution of the Government in cooperation with local people in control of soil erosion in the catchment; but the local community and owners of infrastructures call upon the governmental (at high percentage, more than 86 % of the respondents) institutions in charge of environment to increase their level of intervention with the focus on financial support, capacity building and others (protection of buffer zones, provision of waste disposal sites, and ensuring proper cooperation WASAC and Prime Energy Ltd in the protection Sebeye river, etc.) (see table 4.3).

Table 4.3 Impacts of soil erosion

		Total	Percentage (%)
Do you think there are issues from soil erosion?	Yes	30	100.0
	No	0	0.0
If yes, what are they	Decrease in land productivity	20	66.7
	Soil loss	19	63.3
	water pollution	30	100.0
	Death	28	93.3
	House destruction	27	90.0
	Others	1	3.3
Do you think Gihira water treatment plant is affected by erosion	Yes	25	83.3
	No		0.0
	I don’t know	5	16.7
If yes what are the effects?	Increase in cost of water treatment	25	83.3
	Increase of maintenance cost	24	80.0
	Damage of physical components like conveyance structures, and intake	25	83.3
	Reducing the amount of water purified	25	83.3
	Intermittent water supply	25	83.3
	I don’t know	2	6.7
Do you think Gisenyi hydropower plant is affected by erosion?	Yes	21	70.0
	No	0	0.0
	I don’t know	9	30.0
If yes what are the effects?	Increase of maintenance cost	19	63.3
	Damage of physical components of the plant like conveyance structures, and intake, turbines	21	70.0
	Reduction in amount of electricity generation	20	66.7
	I don’t know	0	0.0
Do you think there is need for protection against erosion in Sebeya catchment?	Yes	29	96.7
	No	1	3.3
If yes, what do you think is needed to support erosion protection in Sebeya Catchment?	Financial assistance	26	86.7
	Capacity building	28	93.3
	Others (state it)	5	16.7

4.2 Characteristics of Sebeya catchment in terms of parameters influencing erosion

4.2.1 Contribution of Rainfall to Erosion in Sebeya Catchment

Rwanda enjoys bimodal rainfall with two raining seasons in a year. The mean annual rainfall is about 1200 mm/year and varies across the country from west to east. The altitude of the country ranges from 900 to 4500m and it is responsible for moderate tropical climate with annual average temperature of about 20^0 C. Western province of the country, where Sebeya catchment is located, has the highest annual precipitation compared to other four provinces. These raises the erosion potential of the catchment as rainfall is one of the major contributing factor to erosion. Sebeya catchment annual average temperature ranges between 15^0c and 17^0 C. (REMA, 2015).

Seasons in Sebeya catchment and Rwanda

There are four seasons in Rwanda two raining seasons and two dry seasons. Though there is rainfall throughout the year in the west of the country two obvious raining seasons that are *long raining season* that extent from February - May and *short raining season* that extend from October to November. The *long dry season* stands for the period June to September and *short dry season* from December to January (REMA, 2015). The variability of rainfall is show in Figure 4.1, Figure 4.2 and Figure 4.3.

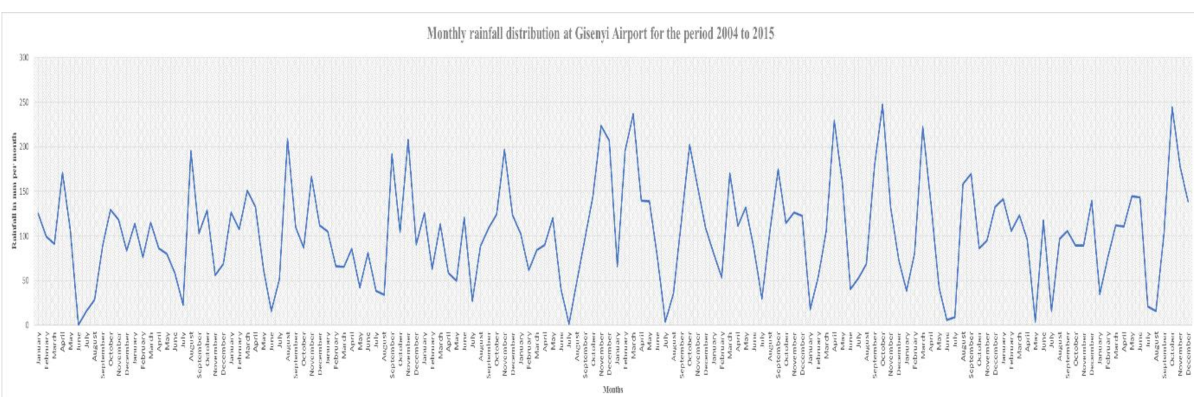


Figure 4.1 Monthly rainfall at Gisenyi from 2004-2015

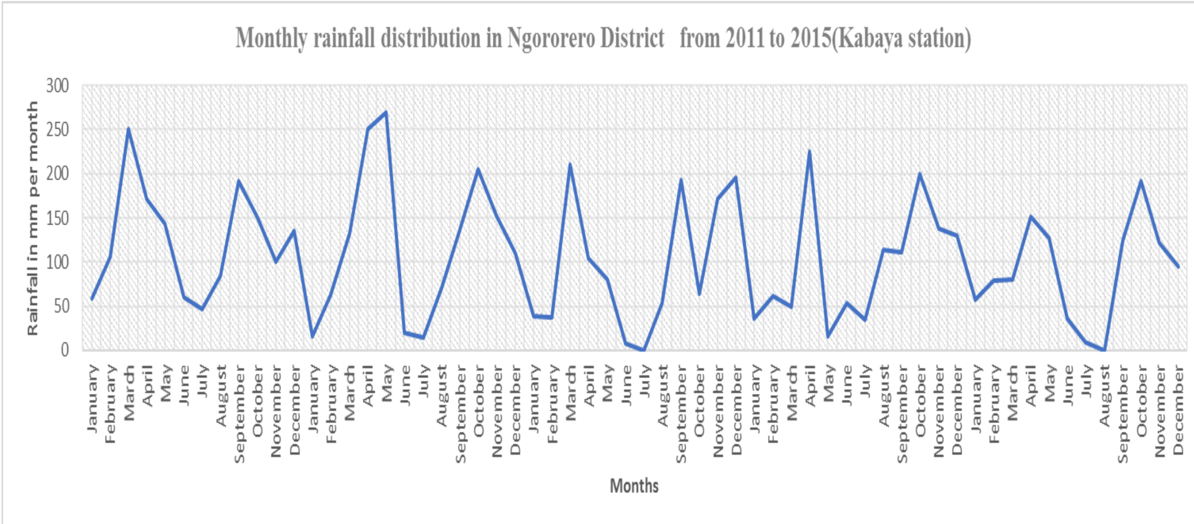


Figure 4.2 Monthly rainfall at Kabaya station

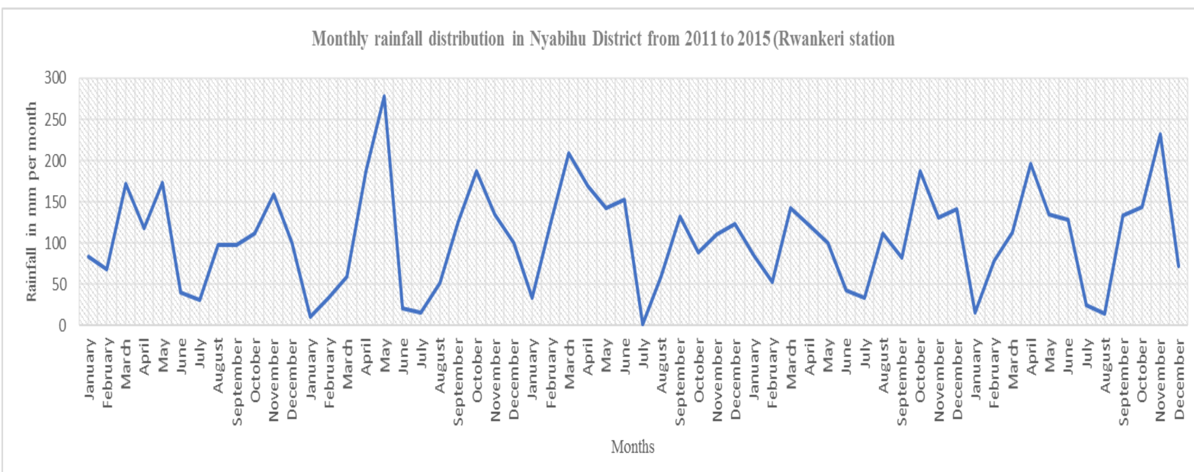


Figure 4.3 Monthly rainfall at Nyabihu station

Generally, there are two peaks that are normally observed in between May to April and October to November, though these peaks keep changing in the resent years which might be due to climate change. The variability can was observed in Sebeya catchment between 2011 to 2015, and itaffected the rainfall distribution pattern in the long run, the total months of the period that could produce higher or lower intensity experienced the fluctuation. In addition, the amount was higher generally except in the month of July which kept on producing the smallest quantity of annual rainfall.

Descriptive analysis of rainfall: Rubavu district (2010 to 2015)

Rubavu metrological station (Gisenye Airport) is is located at longitude 29.25, latitude of - 1.66 at an elevation of 1554 m. Based on the analysis of the rainfall data from Gisenyi Airport metrological station it was found that there was fluctuation in either mean values of monthly rainfall or total annual rainfall between 2010 and 2015. There was either increase or decrease in monthly rainfall, exception was found in the month of July where the rainfall intensity has been increasing from 2010 to 2012 and decreasing in 2013 keep on increasing up to 2015. Referring to the table 4.4; there is higher difference between the monthly rainfall and their corresponding mean in every year, the computed standard deviation values were found to be higher which means that instability was very high. The worst case was in 2012 with standard deviation of 75.9and best case was found in 2011 with the standard deviation of 42.504.

Table 4.4 Monthly rainfall in mm, mean and standard deviation at station of Gisenyi Airport from 2010 to 2015

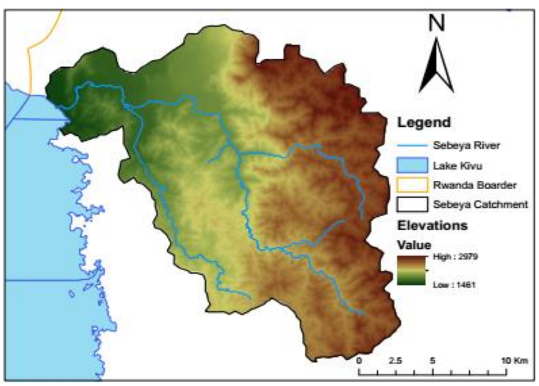
	JAN	FEB	MAR	APR	MA	JUN	JUL	AU	SEPT	OCT	NOV	DEC	MEAN	STDEV
2010	66.2	195.2	237.1	139.6	139.2	75.1	3.8	35.6	118	202.2	154.8	109.4	123.02	69.825
2011	80.4	53.4	170.6	111.1	132	86	29.7	107.2	174.6	114.4	126.3	122.5	109.02	42.504
2012	17.5	54.7	104.8	229.1	159.4	40.4	53.2	68.9	178.7	247.7	131.9	73	113.28	75.935
2013	38.5	81.2	222.6	136.8	42.6	5.9	9.2	158.3	169.8	86.5		132.9	98.57	71.013
2014	141.4	105.9	123.4	96.1	3.7	117.7	15.8	97	105.5	129.1	151.8	139.8	102.27	46.788
2015	34.7	74.7	111.7	110.7	144.4	143.2	20.9	15.8	103.7	244.6	177.4	138.8	110.05	67.114

The runoff depends on rainfall intensity, the energy of raindrops breaks the soil surface to produce and disperse soil particles. The greatest erosion is observed during short-duration with high intensity rainfall, the significant amount of soil loss is noticeable when these events are cumulated over time (Telles et al., 2013). Annual rainfall in

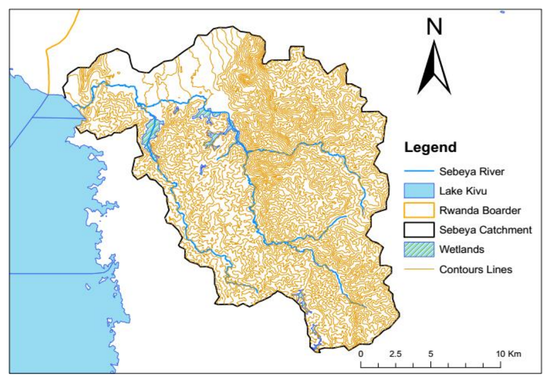
Sebeya catchment is equal or above to 1200 mm and agriculture activity is practiced during rainy seasons where the tillage of land exposes and facilitates soil erosion in the area.

4.2.2 Variation in elevation and its contribution to erosion in Sebeya Catchment

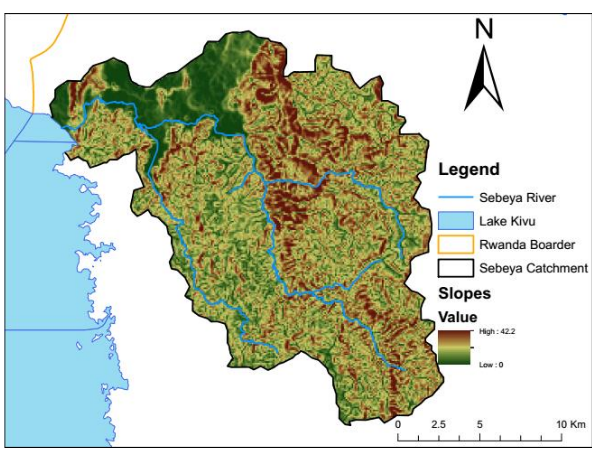
Length of Sebeya River is about 48.38 km and runs in the direction of north-western from 2660 m above mean sea level into Lake Kivu at 470 meters above mean sea level in Congo basin. About 80 percent of this land is on high altitude which is above 2000 meter above sea level (msal) with the maximum valueof 2950 masl. The distribution of elevation in the catchment is presented in Figure 4.4. term of (a) elevations, (b) contours and (c) slopes distribution.



a. Elevation distribution



b. View of contours



c. Slopes distribution

Figure 4.4 Topographical map of Sebeya catchment

Erosion is also severe depending on the nature of the slopes; naturally, the steeper the slope of the ground is, the more the amount of the soil is lost by water erosion. Moreover, the length of the slope also affect the erosion process, if short lengths are put together can increase the amount of oil loss due to accumulation of runoff (Telles et al., 2013).

The elevation of the catchment ranges from about 1460 m.a.s.l. to about 2980 m.a.s.l. (Figure 4.4) compared to the altitude of the country which varies from 900 m to 4500 m (REMA, 2015). The slope in the catchment ranges between 0 % to 42 % where the most part of the catchment is characterized the slope fluctuating between 6% and 42 %. Its nature in topography and slope exposes the catchment to soil erosion; in addition, the four districts of contributing flow Sebeya catchment area are among the 11 districts that are very highly susceptible to land slide hazards at national level due to slope and slope length responsible for velocity and scouring of soil particles (MIDMAR, 2015). This makes the potential of erosion and mass movement very high in the catchment.

4.2.3 Soil types and its contribution to erosion in Seveya Catchment

Except for the northern part of the catchment which is located in the lava region, the catchment features a dense drainage network with steep slopes draining predominantly mature, deeply weathered soils with high infiltration rates. The catchment watershed is dominated by a granite basement aquifer with a highly permeable volcanic and basalt layer in the north. The granite aquifer has low storage capacity. The volcanic and basalt layer on the contrary has excellent infiltration, storage and transmission characteristics to the extent that permanent surface water courses are almost absent. Also, the soil characteristics in the Sebeya catchment show high infiltration rate, the soil characteristics are dominated by deeply weathered, well drained, erodible tropical soils and dark surface layer soils originating from volcanic materials with high infiltration capacity during rainfall. Map of soil characteristics are provided in Figure 4.5.

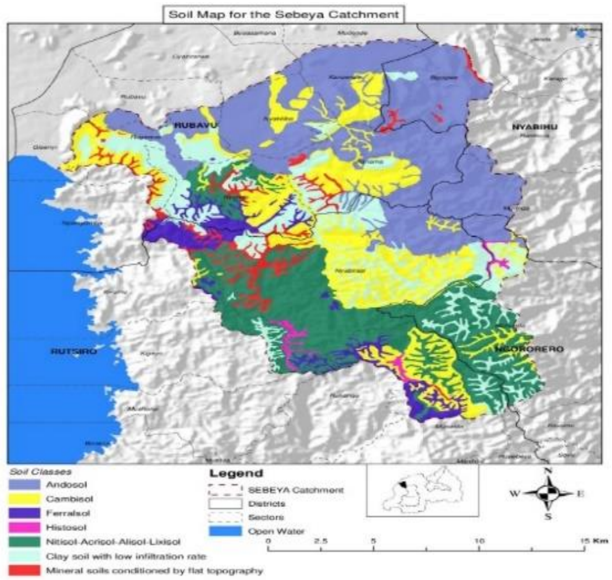


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Figure 4.5 Soil map of Sebeya catchment

Referring to Rwanda soil map produced in 1981 at scale of 1/250000, there are four types of soil based on the percentage of material concentration: gravel, sand, silt and clay (MIDMAR, 2015), area laying in Sebeya catchment is characterized by mostly gravely, a certain portion sand and silt and very small part by clay. By consideration of Figure 4.5, several types of soil appear such Andosol, combisol, ferralsol, histosol, nitisol, acrisol, arisol, lixisol, clay with low infiltration rate, mineral soils conditioned by flat topography.

The ability of the soil to resist to erosion depends on soil erodibility factor, the latter depends on type and texture of the soil. The faster infiltration is, the higher the organic matter content is, and the more soil structure is improved, the less the soil is vulnerable to erosion. Sand, sandy loam and loam-textured soils tend to be less vulnerable than silt, very fine sand, and certain clay textured soils (Phuong, Shrestha, & Chuong, 2017). The susceptibility of soil to erosion was found to be less in terms soil characteristics for Sebeya catchment, that helps in reducing the erosion potential in the catchment.

4.2.4 Land use variation and contribution to erosion in Sebeya catchment

The main components of land use in the catchment are agriculture, mining and livestock grazing land. Agriculture is rain fed and it occupies 62 percent of the total catchment area; most part of Gishwati forest has been transformed into grazing land. Different mining sites are also within the area, these activities have accelerated erosion process. The forests cover 11 percent of the total area and artificial irrigation (wetland irrigation) is not very important with no part of land from wetland is in use. Population derive livelihood from agriculture, mining and livestock (Mumyaneza, 2014). Different features of landuse on Figure 4.6 in different proportion of occupied area, include natural forest, forest plantation, natural open land, irrigated/agriculture in wetland, rainfed agriculture, built-up area, open water, livestock area.

The land use reflects the land cover (type, quantity and extent), the disturbance of soil structure and erosion potential (Phuong et al., 2017), the better is the land cover the more resistance of the soil is because there is high reduction in rain-drop energy imparting on the soil and velocity of the runoff (B.Tilahun, 2013). Effectiveness of vegetation cover depends on management method, the level of its availability throughout the year and season type (Telles et al., 2013).

It was found that there is high disturbance of the vegetation cover in the most part of Sebeya catchment that happens during or closer to rainy season due agriculture activities taking places, its combination with rainfall contribute to high rate of erosion in the catchment.

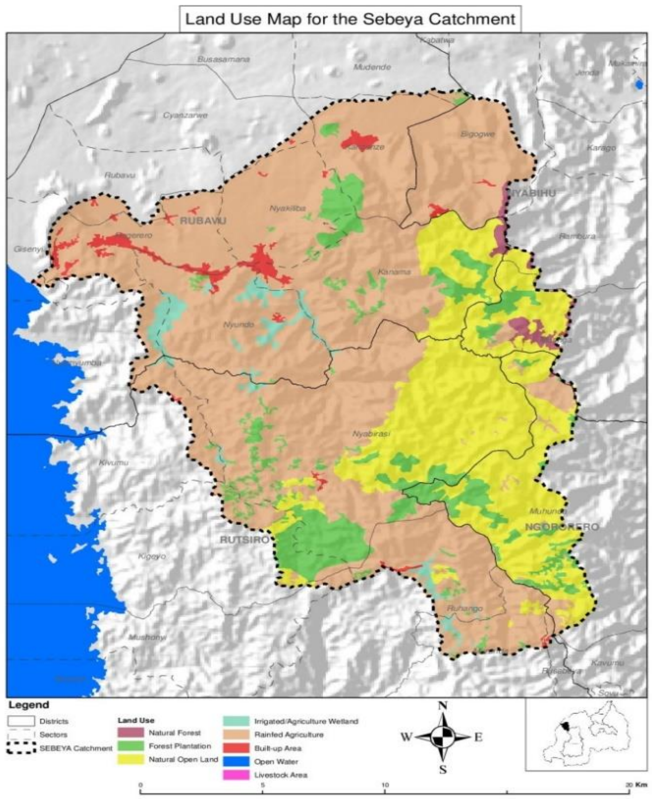

Figure 4.6 Land use map of Sebeya catchment

4.2.5 Population distribution and it contribution to erosion in Sebeya catchment

As mentioned earlier Rwanda is the densest populated country in Africa and Sebeya catchment is one of the highest populated catchment in the country (Figure 4.7),. There is a significant urban population part (a quarter of the population) located in the northern part of the catchment (sectors Rubavu, Nyakiliba, Rugerero and Gisenyi). The sectors along the shores of Lake Kivu and along the main road from Rubavu to Musanze are very densely populated with more than 1000 hab/km² while the sectors in the highlands of the south-east show lowest population density in the bracket of 250 to 500 hab./km². The population is young with over 40% of the population younger than 15 and almost 55 % of the population is below 20. The total female population exceeds the male population by about 9 %. The population is predominantly rural (74% pop.). Although there was a significant reduction of the percentage of the extreme poverty especially over the last 10 years, still 47% of the population is living in Umudugudu (Cell) or dispersed housing is about 30% HH.

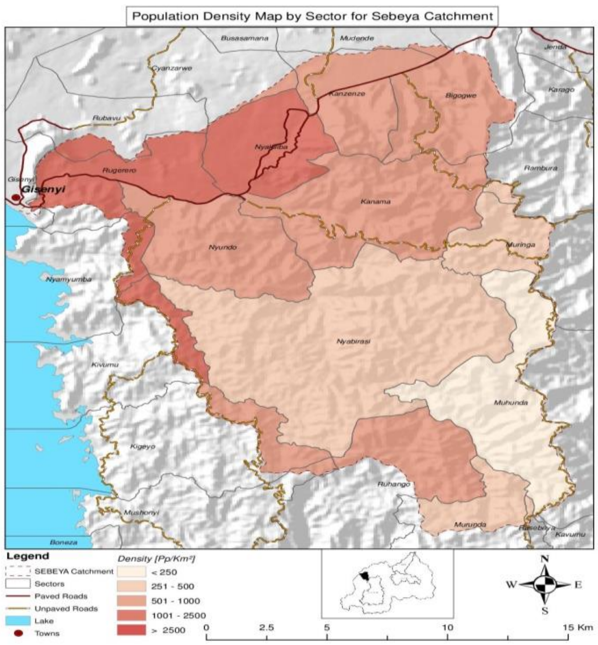

Figure 4.7 Map of population density in Sebeya catchment

Poverty levels among the population in the four districts that have part of their territory in the catchments, are high, particularly in the predominantly agricultural districts of Ngororero and Rutsiro. Access to the national road network is very limited in these districts.

Table 4.5 Status in the poverty level of the population in Sebeya catchment

District	District population	
	Poor (%)	extreme poor (%)
Ngororero	51.9	29.5
Rutsiro	53.0	26.1
Nyabihu	28.6	11.9
Rubavu	35.8	19.0

MIDMAR (2015) studies the most impacting five hazards on the country of Rwanda (droughts, floods, landslides, earthquakes and windstorms) based on their negative effects on economic and social impact. The Western Province and Sebeya catchment in particular is vulnerable to the above-mentioned disasters except drought due to its characteristics including land use. Majority of the population of Sebeya catchment drives their livelihoods from agricultural activities, which in turn increases the exposure of the of the catchment to erosion.

4.3 Impacts of sediments transport on the power production of Gisenyi HPP

4.3.1 Hydropower production at Gsenyi HPP

Interview conducted with Technician in charge of mechanical maintenance of the plant and electrical supervisor of the plant on 26 May 2017 resulted in preliminary information about the situation at Gisenyi HPP. Gisenyi HPP is located in western province of Rwanda in Rubavu District at the downstream part of Sebeya river, the plant has started to operate in 1956, with the turbine of Francis horizontal type. This infrastructure has two turbines able to produce 1200 kw of maximum theoretical hydropower. The main challenges of the plant are composed of pollution and shortage of water. Pollution of water is adversary affecting hydropower production at Gisenyi HPP in two ways, the first was found in terms of hydropower production and the second refers in term of damage of physical elements of the plant like blades of the turbine, penstock, intake structures, etc. We discovered that at Gisenyi HPP the turbines are turned off for two reasons, the first is water shortage in sunny season when the discharge is not sufficient to supply the both machines in this case one of the turbines is stopped, the second is the river sediment transport observed in rainy season which is the most dangerous for the plant and it is due the presence of high concentration of the sediments in water reaching the turbine where both turbines are stopped for sediments removal or waiting the sediments to cease coming or their reduce in concentration. At a certain time, the level of sediments concentration is very high, this prevent the rotation of the turbines machines at the Gisenyi HPP, as a result there is water needed to produce for electricity but could not be used because of sediment, just reducing the electricity generation of the HPP. Table 4.6 present the details of monthly electricity generation from 2004 to 2013.

Table 4.6 Power production at Gisenyi HPP in kw

	2004	2005	2006	2007	2008	2009	2013
January	889.4	492	963	957.6	801	0	435
February	881	488.9	961	785.2	836.7	511	437
March	896	498	896.8	975.7	878	513	421
April	890.41	937.7	678	779.8	857	508	420
May	870.4	844.4	893	764.5	851	453	436
June	985	864.4	992.5	820	852	0	416
July	944.3	459.3	868.2	830	812	0	783
August	776.9	739.2	880	820.2	818.8	431	979
September	820.1	858.1	866.6	770.2	805	836	896
October	Nd	1111.3	1036	841.9	825	944.6	909
November	489.1	873.3	1016.6	826.7	848	835	956
December	492.9	888	494.2	804.5	858	852.8	979

4.3.2 Analysis overall efficiency of turbines in hydropower production at Gisenyi HPP

Efficiency analysis consisted of comparison of average monthly power production and theoretical capacity of the HPP. Comparison of actual production (see table 4.6) and theoretical production (1200 kw) resulted in overview of how the hydropower plant was efficient in the considered period, was estimated as the ratio of actual electricity generation to theoretical potential at the given head and discharge. For the seven (7) years in consideration, the electricity generation has never reached its maximum theoretical power, see table 4.7.

From 2004 up to 2013, the maximum monthly efficiency was found to be 0.9262 in October 2005. Overall average annual mean was found to be small in every year under consideration in this study. In the normal operating conditions of the plant and in function of water availability, the plant must be more efficient in rain season than in dry season; referring to the monthly mean for seven years in the table 4.6, it was found that for some months the plant was more efficient in dry season than in the rain season but where it was not the case the difference was found to be small. The variability in the annual average mean is high, and in the last years the plant was less efficient than in the previous ones. Due data availability, the period considered for the hydropower in terms of rainfall data ranges 2004 to 2013. The monthly efficiencies of the plant for the period 2004 to 2009 and 2013 are presented in table 4.7.

Table 4.7 Efficiency analysis of hydropower production at Gisenyi Gisenyi HPP

	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2013**	Total	Mean
January	0.7412	0.4100	0.8025	0.7980	0.6675	0.0000	0.3625	3.7817	0.5402
February	0.7342	0.4074	0.8008	0.6543	0.6973	0.4258	0.3642	4.0840	0.5834
March	0.7467	0.4150	0.7473	0.8131	0.7317	0.4275	0.3508	4.2321	0.6046
April	0.7420	0.7814	0.5650	0.6498	0.7142	0.4233	0.3500	4.2258	0.6037
May	0.7253	0.7037	0.7442	0.6371	0.7092	0.3775	0.3633	4.2603	0.6086
June	0.8208	0.7203	0.8271	0.6833	0.7100	0.0000	0.3467	4.1083	0.5869
July	0.7869	0.3828	0.7235	0.6917	0.6767	0.0000	0.6525	3.9140	0.5591
August	0.6474	0.6160	0.7333	0.6835	0.6823	0.3592	0.8158	4.5376	0.6482
September	0.6834	0.7151	0.7222	0.6418	0.6708	0.0000	0.7467	4.1800	0.6967
October	#VALUE!	0.9261	0.8633	0.7016	0.6875	0.0000	0.7575	#VALUE	#VALUE
November	0.4076	0.7278	0.8472	0.6889	0.7067	0.0000	0.7967	4.1748	0.6958
December	0.4108	0.7400	0.4118	0.6704	0.7150	0.0000	0.8158	3.7638	0.6273
Total	7.4463	7.5455	8.7883	8.3136	8.3688	2.0133	6.7225		
Mean	0.6769	0.6288	0.7324	0.6928	0.6974	0.2517	0.5602		

4.3.3 Precipitation and hydropower analysis at Gisenyi HPP

The consistency in rainfall intensity was very low due variability of climate of Rwanda. By consideration of monthly mean in seven years (see table 4.8), some of the months that was expected to produce higher rainfall, in contrary there was some decreases in the amount of precipitation in the same months. For example, months of April and May, but the severe case was in May where the monthly mean of the precipitation was about 72 mm from 2004 to 2009 including the year 2013. The dry months also came in with high amount of rainfall that it could be in terms of seasonal calendar.

Table 4.8 Monthly rainfall and its mean at station of Gisenyi Airport from 2004 to 2009 and 2013

	JAN	**FEB**	**MAR**	**APRI**	**MAY**	**JUNE**	**JULY**	**AUG**	**SEPT**	**OCT**	**NOV**	**DEC**	**Mean**
2004	124.9	99.1	91.3	170.9	106.9	0	15.9	28.6	89.6	129.8	118	83.4	88.20
2005	113.9	75.9	114.8	85.9	79.7	57.7	22.9	195.2	102.9	128.7	56.2	68.8	91.88
2006	126.3	107.5	150.7	132.9	62.1	15.7	51.4	208.9	110	86.7	166.7	112.1	110.92
2007	105.3	65.9	65.2	85.6	42.2	81.3	38.6	34.4	191.8	104.4	207.8	90.4	92.74
2008	126	63	113.1	58.5	50	120.5	27.5	88.9	109.1	124.6	196.6	123.4	100.10
2009	102.2	61.7	84.1	89.7	120.1	40.8	1.5	50.6	96.7	145.3	223.8	207.1	101.97
2013	38.5	81.2	222.6	136.8	42.6	5.9	9.2	158.3	169.8	86.5		132.9	98.57
Mean	105.3	79.186	120.25	108.61	71.943	45.986	23.857	109.27	124.27	115.14	161.51	116.87	

By using histogram representation, mean of hydropower production was compared by grouping the months in two main classes (rain and dry seasons), the first class starts from February to November and the second from January on the figure 4.8. The means were calculated by averaging different values in their respective months in the same period. The means of the hydropower produced in rainy months were not very different from the ones produced in dry months. Apart from rainfall, that clearly proved that there was another factor to influence the amount of power production at Gisenyi HPP and this is the erosion. see Figure 4.8, on this graph from January to November constitute rain season and from January to December are part of dry season.

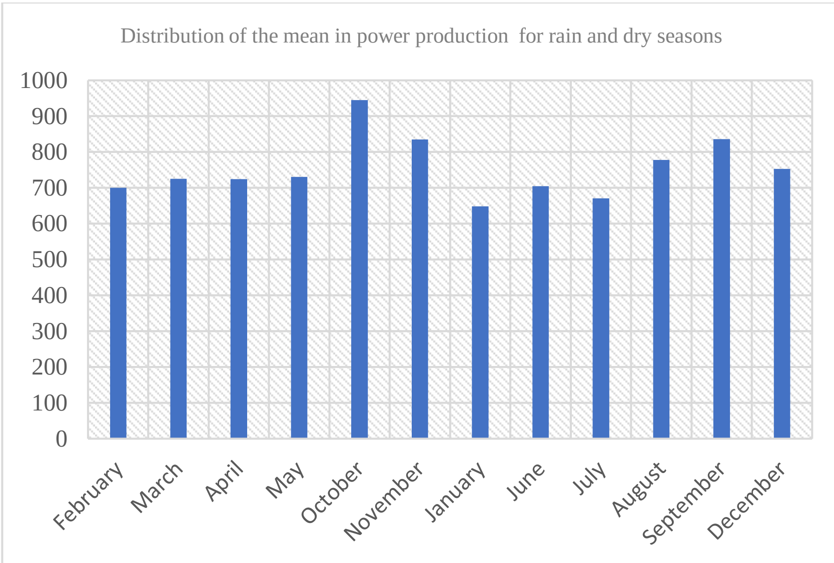

Figure 4.8 Comparison in the means of hydropower in Rain and Dry seasons

4.3.4 T-test for average of monthly power production in rain season and dry season

T-test was used to test the diffirence in electricity between the mean of raining seasons and that of the dry seasons. The hypothesis was that electricity generation is high during the raining season and it's the null hypothesis is then consider as the electricity generation during the dry season is the same as during the raining season; the t-test is based on standard error of the difference between two means and it not suitable when comparing more than two means.

The confidence interval was considered to be 95% and the significant α-0.05. The results of the finding are interpreted as follows: if t-value is less than or equal to α>0.05 then Reject Null Hypothesis (there is enough evidence to support that the claim thatelectricity generation during the raining season is equal electricity generation during the dry season), and if α<=0.05 Fail to Reject Null Hypothesis (there is not enough evidence to support that the claim that electricity generation during the raining season is equal electricity generation during the dry season).

Table 4.9 Average of monthly power production in rain season and dry season

SEASON							**SD**	**MEAN**
RAIN	700.1	725.5	724.4	730.3	944.6	835.0	94.8	776.7
DRY	648.3	704.3	671.0	777.9	836.0	752.8	70.5	731.7

The two population are average monthly power production in kw in rain season and dry season. Their corresponding mean are 776.7 kw and 731.7 kw in both seasons; standard deviation one (SD1) and standard deviation two (SD2) are 94.8 and 70.5. sample sizes N1= 6*7 = 42 and N2 = 6*7 = 42 where degrees of freedom (df) equal N -1 = 42 -1 = 41

Mathematically, t-value is calculated by:

$$t = \frac{m1 - m2}{\sqrt{\frac{SD_1^2}{N1} + \frac{SD_2^2}{N2}}}$$

$$= \frac{776.7 - 731.7}{\sqrt{\frac{sqrd(94.8)}{41} + \frac{sqrd(70.5)}{41}}} = \frac{45}{18.45} =$$

2.439

T = 2.439

It was concluded that the average monthly power production in rain season was different from that of dry season; the average power in rain season was significantly higher than that of dry season. The plant power production in rain season was high compared to that that of dry season.

4.3.5 Application of ANOVA in monthly hydropower production

Analysis of variances tool was used for F-tests to see if in hydropower production values in seven years and for different months are statistically different. The error type I with α=0.05 was adopted, which means that once you run two-sample tests 100 times, 5 out of 100 have high probability of resulting the long values (Eleisa.H, 2009).

The aim of AVONA is to test null hypothesis expressed as $H_{o:}\ \mu_1 = \mu_2 = \mu_3 \ldots\ldots\ldots\ldots\ldots = \mu_k$. if the null hypothesis is true all y_{ij} are produced from same population, and we can estimate easily two values of σ^2. The first is the calculated from sample variances (S_1^2, S_2^2 .... S_k^2) the population of the group (sample), in other words it means within the groups, the second is computed from all sample (group) means ($\bar{y}_{1.}$, $\bar{y}_{2.}$ .... $\bar{y}_{k.}$), σ^2 is calculated as:

$$S_e^2 = \frac{1}{k}\sum_{i=1}^{k} S_i^2 \quad \text{and} \quad s_{\bar{y}}^2 = \frac{\sum_{i=1}^{k}(\bar{y}i. - \bar{y}..)^2}{k-1} \qquad F = \frac{n s_{\bar{y}}^2}{S_e^2}$$

Where n is number of population in each group and k represents the number of groups in dataset. F is compared to Fc, values are statistically different when F is greater than Fc and F ratio is likely to occur at $\alpha < 0.05$ (Eleisa.H, 2009). The degrees of freedom (df) ware calculated within group and between groups and they are useful in Fc determination.

- Degree of freedom between groups = k -1
- Degree of freedom within groups = k (n-1)

The point (k (n-1), k -1) was used to draw the Fc from the table of critical values for the F distribution with 0.05 significance level. After computation, the point was (6, 66).

From September to December 2009, Gisenyi HPP was under rehabilitation, to bridge the gap in data of four months year 2009 the mathematical mean was used from the same months of other 6 remaining years

Table 4.10 ANOVA for hydropower production at Gisenyi HPP

	January	889.4	492	963	957.6	801	0	435	
	February	881	488.9	961	785.2	836.7	511	437	
	March	896	498	896.8	975.7	878	513	421	
	April	890.41	937.7	678	779.8	857	508	420	
	May	870.4	844.4	893	764.5	851	453	436	
	June	985	864.4	992.5	820	852	0	416	
	July	944.3	459.3	868.2	830	812	0	783	
	August	776.9	739.2	880	820.2	818.8	431	979	
	Septembe	820.1	858.1	866.6	770.2	805	836.0	896	
	October	944.6	1111.3	1036	841.9	825	944.6	909	
	Novembe	489.1	873.3	1016.6	826.7	848	835.0	956	
	December	492.9	888	494.2	804.5	858	752.8	979	
Total $y_{1.}$		**9880.11**	**9054.6**	**10545.9**	**9976.3**	**10042.5**	**5784.35**	**8067**	
Mean $\bar{y}_{1.}$		**823.343**	**754.55**	**878.825**	**831.358**	**836.875**	**482.029**	**672.25**	
Variance S_1^2		**27111.3**	**46937.8**	**23591**	**4625.48**	**589.468**	**112739**	**67904.6**	**283498**
s_e^2									**40499.8**
$\bar{y}_{..}$									**754.176**
$\sum_{i=1}^{k}(\bar{y}_{i.}-\bar{y}_{..})^2$		4784.04	0.14009	15537.4	5957.16	6839.17	74063.7	6711.82	**113894**
$s_{\bar{y}}^2$									**18982.3**
$ns_{\bar{y}}^2$									**227787**
F									**5.6244**

The F ratio in table 12.4 was found to be 5.62 and the value was compared to the Fc (Fc = 2.24) drawn in the table of critical values for the F distribution with 0.05 significance level. the values of the different populations in different groups are statistically different due to the value of F that is greater than Fc. Meaning that monthly power production was subjected under variation as a consequence of soil erosion taking place in the upstream part of the Gisenyi hydropower plant.

Assessment of sediment transport on hydropower production at Gisenyi HPP found that the monthly power in 7 years was statistically different and within seasons the overall average was not statistically different. In addition, hydropower plant was more efficient for some dry months than other rain months (see table 4.7). As implication to that, in the period considered by the research, the soil particles detached and transported from the land in the catchment to Sebeya river have caused the reduction in hydropower production in rainy season.

Charles (2010) presented some issues that hydropower plants faces in Sebeya catchment; for example, at Gihira HPP sediments has damaged the whole system of the turbine which resulted in its replacement as consequence of erosion from deforestation of Gishwati forest.

4.3.6 Tukey Test in average monthly power production

The post processing was the next step after ANOVA because analysis of variances found that average monthly power production was significantly- statistically different. As principles of ANOVA don't take interest in knowing which means are different from each other, Tukey Test was used to get the final conclusion on this.

Overall annual mean from each of the whole population of each treatment (sample) was computed and arrangement fallowed in column and row in their respective years to calculate the difference in each pair of mean and Q.

$Q = \frac{Mean\ X - Mean\ Y}{\sqrt{s_e^2/n}}$ mean X represents large mean and mean Y small mean in pair of means under consideration and Qcv is obtained from its distribution table. This table use number of means and degree of freedom within groups to be able to draw Qcv.

$Q = \sqrt{s_e^2}/n = \sqrt{40499.77/12}$ = 58.095

Table 4.11 Difference in mean between treatments of power production

	823.34	**754.55**	**878.83**	**831.36**	**836.88**	**482.03**	**672.25**
823.34							
754.55	68.79						
878.83	55.48	124.28					
831.36	8.02	76.81	47.47				
836.88	13.53	82.32	41.95	5.52			
482.03	341.31	272.52	396.80	349.33	354.85		
672.25	151.09	82.30	206.58	159.11	164.63	190.22	

Table 4.12 Q for each pairwise comparison of power production

	823.34	**754.55**	**878.83**	**831.36**	**836.88**	**482.03**	**672.25**
823.34							
754.55	1.184						
878.83	0.955	2.139					
831.36	0.138	1.322	0.817				
836.88	0.233	1.417	0.722	0.095			
482.03	**5.875**	**4.691**	**6.013**	**6.013**	**6.108**		
672.25	2.601	1.417	3.556	2.739	3.274	3.274	

The degree of freedom (df) within groups was 66 and the number of means was 7, the Qcv was calculated using the table of Critical Values for the Tukey Q Test (see annex 3).

By interpolation, Qcv = 4.3. The value of Qcv is less than the Q by testing the pair of mean of 2009 and that of 2004, 2005, 2006, 2007,2008; only these pairs are significantly different from one other.

4.4 Impacts of sediments transports on potable water production at Gihira WTP

Gihira water treatment is located in Rubavu District of western province of Rwanda from 1960's. It is used to supply drinking water in Rubavu town and neighboring area centers. At Gihira WTP, the study using descriptive statistical analysis proved the monthly cost of water treatment has increased from 65000 Rwf 1971's to 2 million in 2009 (Charles, 2010). WTP is fed by Sebeya River, the latter originates from the high land of Gishwati Forest, this river is the source of the floods in the surrounding areas during heavy rainfall and sediments transport with other types of pollutants in Kivu Lake through Sebeya river (NUR, 2012).

4.4.1 Quality of water source

The quality of raw water at the intake structure of Gihira water treatment plant was found changing over considered period. Water resources in Rwanda are polluted by Anthropogenic activities which is the same situation on water of Sebeya River. The change in land use and climate elements caused the variation in erosion rate, this was understood by the analysis of characteristics of raw water before its treatment between years 2010 and 2016. A set of tables gave the values of several characteristics of raw water (see from table 15.4 to 21.4).

Table 4.13 Raw Water quality at Gihira WTP, 2010

PARAMETERS -UNITY	Guiding values from WHO	January	February	March	April	May	June	July	August	September	October	November	December
Bacteriological													
Total coliforms cfu/100ml	0 cfu/100 ml	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100
Fecal Coliforms cfu/100ml	0 cfu/100 ml	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100
Physicochemical													
Turbidity NTU	< 5 NTU	226-44150	348-33660	325-40572	222-16280	290-63840	254-17864	157 - 1670	169 - 2079	214-14100	335-16680	305-17600	334 - 17208
Ph	6,5<pH<8,5	5,0-7,5	5.5-7.5	5.0-7.5	7.5	5,0-7,5	6.0 - 7.5	7.5	7.5	7.5	7.0-7.5	4.0-7.5	6.0 - 7.5
Chlorides mg/l		43.8	78	11.2									
Sulfates mg/l	250	16.5	16	23.5	12	5	12	< 2	12.5	-1	3.7	3.7	< 2
Calcium mg/l	100	34.4	14.78						16.64	9.64	40.64		
Iodine mg/l													
Aluminum mg/l		0.328			0.565	0.433		0.486	< 0,008	<0.008	0.561	0.4355	
TH °F	60	11.46	5.92						6.95	5.92	14.94		
TA °F	ND	0	0	0	0	0	0	0	0	0	0		
TAC °F	ND	2.5	2.7	3					2.6	2.4	3		
Tca °F	100	8.6	3.68						4.16	2.41	10.16		
TMg °F	50	2.86	2.24										
Brome mg/l													
Nitrates mg/l	50	11.8	44.2	7.6	24.4	12.2	24.4	13.6	9.1	<0.3	10.95	<0.3	45
Nitrites mg/l	0,1	0.01	<0.002	<0.002	<0.002	<0.002	<0.002	<0,002	0.01	<0.002	<0.002	<0.002	<0.002
Azote Ammoniacal. mg/l		0.575	0.96	0.26	0.84	0.465	0.84	0.405	0.41	0.245	0.945	0.235	
Ammonium mg/l	0,5												
Organic matters mg/l	2							10.6					
Suspended solids mg/l	Absence												
Iron mg/l	0,2	15.1	13.18		4.775	43.81	4.775	-			12.07		
Manganese mg/l	0,05												
Copper mg/l	0,1	< 0,04	<0.04	< 0.04	< 0.04	< 0.04	< 0.04	0.02	<0,04		<0.04		
Zinc mg/l	0,1	0.06	0.25	0.2	0.43		0.43	0.38	<0,01	<0.01	0.135	<0.01	
Phosphates mg/l	5				1.92	1.04	1.92	0.265	0.74	0.725	1.69	<0.02	0.53
Cyanide		0.0075	<0.001	0.001		<0,001		<0,001	0.021	0.001			
Barium mg/l	0,7	< 1,0	<1.0	<1.0	< 1.0	< 1.0	< 1.0	<1,0	1	<1.0		<1.0	<1.0
Chromium VI mg/l	0,05	< 0,01	<0.01	<0.01	<0,01	<0,01	<0,01	<0,01	<0,01	<0.01	<0.01	<0.01	<0.01
Nickel mg/l		0.128	78		0.204	0.169	0.204		0.049	0.0965	0.6	0.6	0.0775
Cobalt		1.33	4.56	1.64	3.44	0.53	3.44	<0,01	0,01	<0.01	< 0.01	0	1.93

Table 4.14 Raw Water quality at Gihira WTP, 2011

Parameters 2011	**Unit**	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
Color	APHA	-	-	-	-	-	-	132	-	-	-	-	-
Turbidity	NTU	1532	1228	886	1630	902	1178	936	1325	735	895	1450	1835
pH		7.2	7	7.3	7	6.8	6.9	7	7.2	7.3	7.1	7	7
Suspended solids	mg/l	-	-	-	-	-	-	-	-	-	-	-	-
Organic matter	mg/l	-	-	-	-	-	-	-	-	-	-	-	-
Free CO_2	mg/l	-	-	-	-	-	-	-	-	-	-	-	-
Dissolved Oxygen	mg/l	-	-	-	-	-	-	-	-	-	-	-	-
Silica	mg/l	7	< 1.0	-	-	-	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	
Ammoniacal Nitrogen	mg/l	-	-	-	-	-	0.02	0.76	0.84	0.86	0.03	0.05	< 0.01
Nitrite NO_2^-	mg/l	< 0.002	< 0.002	-	-	-	0.015	0.014	< 0.002	0.016	< 0.002	< 0.002	< 0.002
Nitrate NO_3^-	mg/l	36.2	36.4	-	-	-	17	40.2	1.2	2.6	< 0.3	< 0.3	23.3
Cyanide CN^-	mg/l							0.004	0.005	0.006	< 0.001	< 0.001	0.002
Iodide I^-	mg/l	-	-	-	-	-	-	< 0.07	0.43	1.02	< 0.07	< 0.07	0.06
Fluoride F^-	mg/l	-	-	-	-	-	-	-	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Sulfate SO_4^{2-}	mg/l	< 2	< 2	-	-	-	< 2	< 2	< 2	<2	-	-	-
Phosphate PO_4^{3-}	mg/l	12.6	16.4	-	-	-	0.48	0.08	0.54	0.45	0.06	0.08	0.05
Manganese Mn^{2+}	mg/l	-	-	-	-	-	-	-	-	-	< 0.007	< 0.007	0.118
Iron Fe^{3+}	mg/l	-	-	-	-	-	-	-	-	-	< 0.02	< 0.02	1.69
copper Cu^{2+}	mg/l	-	-	-	-	-	-	-	-	-	-	-	-
Zinc Zn^{2+}	mg/l	-	-	-	-	-	< 0.01	0.03	0.02	0.04	0.06	0.04	< 0.01
Barium Ba^{2+}	mg/l	< 1	< 1	< 1	-	-	-	< 1	< 1	< 1	< 1	< 1	< 1
Bromide Br^-	mg/l	-	-	-	-	-	-	< 0.05	0.94	1.33	< 0.05	< 0.05	0.37
Chromium Cr^{6+}	mg/l	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Lead Pb^{2+}	µg/l	-	-	-	-	-	-	-	-	-	-	-	-
Cadmium Cd^{2+}	µg/l	-	-	-	-	-	-	-	-	-	-	-	-
Aluminum Al^{3+}	Mg/l	-	-	-	-	-	0.221	0.341	0.294	0.287	0.546	0.385	0.284

Table 4.15 Raw Water quality at Gihira WTP, 2012

Parameters	**Unit**	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
Color	APHA	-	-	-	-	-	-	-	-	-	-	-	-
Turbidity	NTU	1025	1005.5	1770.6	1615.6	1330.3	962.5	813.6	914.8	1172.6	861.7	905.2	968.4
pH		7	7	6.9	7.4	7	7	7	7	7	7	7	7
Suspended solids	mg/l	-	-	-	-	-	-	-	-	-	-	-	-
Organic matter	mg/l	-	-	-	-	-	-	-	-	-	-	-	-
Free CO_2	mg/l	-	-	-	-	-	-	-	-	-	-	-	-
Dissolved Oxygen	mg/l	-	-	-	-	-	-	-	-	-	-	-	-
Silica	mg/l	<1.0	<1.0		<1.0	<1.0			<1.0				
Ammoniacal Nitrogen	mg/l	-	-	-	-	-	-	-	-	-	-	-	-
Nitrite NO_2^-	mg/l	<0.002	<0.002		<0.002	0.064	<0.002		2.6	<0.002		<0.002	<0.002
Nitrate NO_3^-	mg/l	<0.3	<0.3		2.8	<0.1	<0.3		<0.04	12.6		9.9	4.6
Cyanide CN^-	mg/l	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		0.005	<0.001			
Iodide I^-	mg/l								0.8	<0.05	<0.07	<0.07	<0.07
Fluoride F^-	mg/l	<0.02	0.29		<0.02	<0.03	<0.02		1.31	<0.02		<0.02	<0.02
Sulfate SO_4^{2-}	mg/l	-	-	-	-	-	15		-	-8		-8	-8
Phosphate PO_4^{3-}	mg/l	0.04	<0.02		0.36	0.36	0.56		0.48	0.14		0.26	0.06
Manganese Mn^{2+}	mg/l	0.413	0.63		0.121	0.121	0.03		0.65				
Iron Fe^{3+}	mg/l	-	0.88	-	-	-	-	-	-				
copper Cu^{2+}	mg/l	-	-	-	-	-	-						
Zinc Zn^{2+}	mg/l	0.05	<0.01		<0.01	<0.01	0.57		0.54	0.17		0.17	<0.01
Barium Ba^{2+}	mg/l	<1.00	<1.00		<1.00	<1.00	-		<1.00	<1.00			
Bromide Br^-	mg/l	<0.05	<0.05				<0.05		0.32	0.13		<0.05	<0.05
Chromium Cr^{6+}	mg/l	<0.01	<0.01		-	-	-		-	-			
Lead Pb^{2+}	µg/l	-	-	-	-	-	-	--	-	-	-	-	-
Cadmium Cd^{2+}	µg/l	-	-	-	-	-	-	-	-	-	-	-	-
Aluminium Al^{3+}	Mg/l	-	-	-	-	-	-	-	0.62	0.268	-	0.322	0.342

Table 4.16 Raw Water quality at Gihira WTP, 2013

Parameters	**Unit**	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
Color	APHA	-	-	-	-	-	-	-	-	-	-	-	-
Turbidity	NTU	889.3	736	999.3	768.6	201.8	201	185	158	213	249	315	1460
pH		7	7	7	7	7	7	7	7	7	7	7	7
Residual Chlorine	mg/l				<0.0016	0.0061							
Total Chlorine	mg/l	<0.02	0.11	0.14	<0.026	<0.0016		0.03	0.11	<0.02	<0.02	0.14	<0.02
Total Iron	mg/l	1.19	2.51	1.87	1.34	1.64	1.36	2.11	2.08	<0.02	0.86	>3.00	5.2
Ammoniacal Nitrogen	mg/l	<0.01	0.07	0.06	0.061	0.074	0.07	-0.04	0.14	0.31	0.08	0.22	0.45
Nitrite NO_2^-	mg/l	<0.002	0.001	0.001	0.001	1.96	-0.008	-0.001	<0.002	<0.002	-0.006	<0.002	0.002
Nitrate NO_3^-	mg/l	<0.3	<0.3	<0.6	<0.4	3.16	<0.3	0.8	0.2	8.7	<0.1	<0.3	27
Cyanide CN^-	mg/l	<0.001	0.008	0.024	0.004	0.016	<0.001	0.011	0.012	0	0.011	0.012	0.008
Iodide I^-	mg/l	-0.07	0.89	0.81	<0.001	0.006	<0.07	0.18	0.55	1.26	<0.07	0.08	
Fluoride F^-	mg/l	<0.02	0.94	0.75	0.68	0.836	0.13	0.13	-0.01	0.11	0.1	0.09	<0.02
Sulfate SO_4^{2-}	mg/l			-	0.074	0.087	11	11	14	11	17	21	10
Phosphate PO_4^{3-}	mg/l	<0.02	0.29	0.19	0.21	0.96	0.12						
Manganese Mn^{2+}	mg/l	0.415	0.305	0.275	0.461	0.676	0.203	0.301	0.156	0.21	0.45	0.13	1.14
Silver	mg/l					0.967							
Potassium	mg/l	1.2	0.8	0.6	1.34	1.46		2.8	4.1	3.3	3.6	3.6	4.2
Chloride	mg/l	0.27	0.14	0.2	0.12	0.28	4	3.7	15.2	2	0.28		
Sulfide	mg/l					0.0165	30	41	40	36	40	25	32
Cobalt	mg/l	2.06	<0.01	0.3	1.34	1.23	0.17		0.47	0.17	<0.01	0.74	1.2
Nickel	mg/l	0.135	0.112	0.122	0.16	0.189	0.01	0.23	0.012	0.011	-0.005	0.043	0.098
Copper Cu^{2+}	mg/l			-		1.19	0.38						
Zinc Zn^{2+}	mg/l							0.07	0.97	0.05	0.07	0.15	0.08
Bromide Br^-	mg/l	-0.09	0.67	0.58	0.62	0.067	<0.05	0.37	2.04	0.66	<0.05	0.16	
Aluminum Al^{3+}	Mg/l	0.615	0.023	0.018	0.018	0.071		0.097	0.246	0.077	0.079	0.126	0.268

Table 4.17 Raw Water quality at Gihira WTP, 2014

Parameters 2014	**Unit**	**Limits**	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
Total Coliforms	Cfu/100ml	0 cfu/100 ml	-	>100	>100	>100	39	49	44	40	59	38	46	42
Fecal coliforms	Cfu/100ml	0 cfu/100 ml	-	50	80	75	-	-	-	-	-	-	-	-
E. Coli	Cfu/100ml	0 cfu/100 ml	-	10	48	30	-	-	-	-	-	-	-	-
Fecal Streptococcus	Cfu/100ml	0 cfu/100 ml	-	0	-	-	-	-	-	-	-	-	-	-
pH		6.5<pH<8.5	7	7	7	7	7	7	7	7	7	7	7	7
Color	APHA	15 APHA												
Turbidity	NTU	< 5 NTU	222	65	115	102	107.8	480	1238.5	956.4	856	577.5	330.9	1929.8
Suspended matter	mg/l	0 mg/l	-	-	-	-	-	-	-	-	-	-	-	-
Residual free Chlorine	mg/l	0.2 - 0.5mg/l	-	-	<0.02	<0.02	-	-	-	-	-	-	-	-
TA	mg/l	0	0	0	0	0	0	0	0	0	0	0	0	0
TAC	mg/l	3	2.4	2.6	1.9	2	2	2.2	2.2	2.5	2.4	1.9	2	2.2
TH	mg/l	3.2	3.6	3.6	4	4	3.8	4.2	-	-	-	-	-	-
Tca	mg/l	1.6	1.8	2	1.6	2	2	2.1	-	-	-	-	-	-
TMg	mg/l	1.6	1.8	1.6	2.4	2	1.8	1.8	-	-	-	-	-	-
Calcium	mg/l	80mg/L	7.2	8	6.4	8	7.9	8.6	-	-	-	-	-	-
Magnesium	mg/l	100mg/l	4.32	3.84	5.8	4.8	4.6	4.5	-	-	-	-	-	-
Dissolved Oxygen	mg/l		-	-	-	-	-	-	-	-	-	-	-	-
Organic matter	mg/l	2 mg/l	-	-	-	-	-	-	-	-	-	-	-	-
Iron	mg/l	0.3 mg/l	3.5	1.8	2.5	2.2	2.4	3.7	8.4		4.8	4.2	-	9.2
Manganese	mg/l	0.1 mg/l	0.2	0.5	0.3	0.2	0.2	0.7	1.5	1.6	1.1	1	1	1.6
Nitrites	mg/l	0.05 mg/l	0	<0.002	0	<0.007	0.01	0.01	0.01	0.01	-	-	-	-
Nitrates	mg/l	15 mg/l												
Ammoniacal Nitrogen	mg/l	0.05 mg/l	0.3	0.4	-	0.1	-	-	-	-	-	-	-	-
Phosphates	mg/l	5 mg/l	0.22	0.26	1.1	0.1	0.2	0.4						
Copper	mg/l	1mg/l	-	-	-	-	-	-	-		-	-	-	
Zinc	mg/l	3 mg/l	-	-	-	-	-	-	-	-	-	-	-	-
Silica	mg/l	IND	-	-	-	-	-	-	-	-	-	-	-	-
Fluoride	mg/l	1.5mg/l	<0.02	0.19	<0.02	0.24	-	-	-	-	-	-	-	-
Cyanide	mg/l	0.05 mg/l	0.01	<0.001	0.003	<0.001	0.002	-	-	-		-	-	-
Nickel	mg/l	0.02mg/l	-	-	-		-	-	-	-		-	-	-
Conductivity	μs/cm		-	-	-		-	-	-	-		-	-	-
T.D.S	mg/l		-	-	-		-	-	-	-		-	-	-
Salinity	‰		-	-	-		-	-	-	-		-	-	-
Iodine	mg/l	ND	<0.07	<0.07	0.47	<0.07	0.54	1.02	0.6	0.2	0.9	0.4	0.55	4.3
Chromium	mg/l	0 mg/l												
Bromide	mg/l	5mg/l	<0.05	<0.05	0.24	<0.05	0.22	0.6	0.5	0.44	0.4	0.3	0.22	0.48
Sulphates	mg/l	250 mg/l							-	-	-		-	-
Chlorides	mg/l	250 mg/l	36	24	11.5	32	10.15	10.2	-	-	-		-	-
Aluminium	mg/l	0.2 mg/l	-	-	-		-	-	-	-	-		-	-
Temperature	°C	25°C	-	-	-		-	-	-	-	-		-	-

Table 4.18 Raw Water quality at Gihira WTP, 2015

Parameters 2015	Unit	Limits	January	February	March	April	May	June	July	August	September	October	November	December
Total Coliforms	Cfu/100ml	0 cfu/100 ml	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100
Fecal coliforms	Cfu/100ml	0 cfu/100 ml	48	37	63	58	38	48	48	52	44	42	60	48
E. Coli	Cfu/100ml	0 cfu/100 ml	12	23	23	21	19	12	12	10	8	12	18	14
Fecal Streptococcus	Cfu/100ml	0 cfu/100 ml	4	9	7	8	2	4	4					
pH		6.5<pH<8.5	7	7	7	7	7	7	7	7	7	7	7	7
Color	APHA	15 APHA												
Turbidity	NTU	< 5 NTU	850	1030.5	414.7	412.3	528.5	850	295.964	587.826	760.5	722.62	773.6	1107
Suspended matter	mg/l	0 mg/l	-	-	-	-	-	-	-	-	-	-	-	-
Residual free Chlorine	mg/l	0.2 - 0.5mg/l	-	-	-	-	-	-	-	-	-	-	-	-
TA	mg/l	0	0	0	0	0	0	0	0	0	0	0	0	0.22
TAC	mg/l	3	2.5	2.4	2.1	2.1	2	2	2.5	2.5	2.2	2.9		4.6
TH	mg/l	3.2	-	-	-	-	-	-	4	4.4	4.2	5.3	8.7	-
Tca	mg/l	1.6	-	-	-	-	-	-	1	2	1.5	2	2.2	3.9
TMg	mg/l	1.6	-	--	-	-	-	-	3	2.4	2.9	3.3	2.4	1.6
Calcium	mg/l	80mg/L	4	-	-	-	-	-	4	8	4	8	8.4	8
Magnesium	mg/l	100mg/l	7.2	-	-	-	-	-	7.2	5.76	6.96	7.92	6	2.72
Dissolved Oxygen	mg/l		-	-	-	-	-	-	-	-	-	-	-	-
Organic matter	mg/l	2 mg/l	-	-	-	-	-	-	-	-	-	-	-	-
Iron	mg/l	0.3 mg/l	4.88	2.56	2.41	4.27	4.91	4.48	4.88	6.42	7.42	7.092	7.58	7.92
Manganese	mg/l	0.1 mg/l	0.98	1.1645	0.806	0.552	0.003	1.25	0.98	3.64	1.081	1.2	1.022	2.47
Nitrites	mg/l	0.05 mg/l	-	-	-	-	-	-	-	-	-	-	-	0.025
Nitrates	mg/l	15 mg/l	5.6	<0.3	<0.1	0.52	0.85	-	5.6	6.4	5.1	5.3	4.8	0.095
Ammoniacal Nitrogen	mg/l	0.05 mg/l	0.62	0.715	0.24	0.31	0.165	-	0.62	0.8	0.83	0.52	0.48	95
Phosphates	mg/l	5 mg/l	<0.02	0.06	0.208	0.63	0.14	-	<0.02	<0.02	<0.2	<0.02	<0.02	0.86
Copper	mg/l	1mg/l	-	-	-	-	-	-	0.12	0.15	0.36	0.24	0.16	0.16
Zinc	mg/l	3 mg/l	0.5	0.07	<0.01	0.107	0.065	-	0.5	0.62	0.25	0.345	0.42	0.45
Silica	mg/l	IND	0.15	<1	4.866	13.24	8	-	0.15	0.2	0.35	0.5	0.13	2.455
Fluoride	mg/l	1.5mg/l	-	-	-	-	-	-	<0.02	<0.02	1.05	0.28	<0.02	2.8
Cyanide	mg/l	0.05 mg/l	-	-	-	-	-	-	-	-	-	-	-	0.038
Nickel	mg/l	0.02mg/l	-	-	-	-	-	-	-	-	-	-	-	-
conductivity	μs/cm		-	-	-	-	-	-	-	-	-	-	-	-
T.D.S	mg/l		-	-	-	-	-	-	-	-	-	-	-	-
Salinity	‰		-	-	-	-	-	-	-	-	-	-	-	-
Iodine	mg/l	ND	<0.07		0.256	0.48	2.745	<0.06	<0.07	0.48	0.27			
Chromium	mg/l	0 mg/l	-	-	-	-	-	-	-	-	-	-	-	-0.01
Bromide	mg/l	5mg/l	<0.05		0.1966	0.173	1.86	-	<0.05	0.2	0.11			2.255
Sulphates	mg/l	250 mg/l	-	-	-	-	-	-	-	-	-	-	-	4.5
Chlorides	mg/l	250 mg/l	-	-	-	-	-	-	-	-	-	-	-	94.35
Aluminium	mg/l	0.2 mg/l	0.284	0.001	0.065	0.051	0.0045		0.284	0.334	0.132	0.314	0.324	0.745
Temperature	°C	25°C	-	-	-	-	-	-	-	-	-	-	-	

Table 4.19 Raw Water quality at Gihira WTP, 2016

Parameters 2016	**Unit**	**Limits**	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
Total Coliforms	Cfu/100ml	0 cfu/100 ml	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞
Fecal coliforms	Cfu/100ml	0 cfu/100 ml	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞
E. Coli	Cfu/100ml	0 cfu/100 ml	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞
Fecal Streptococcus	Cfu/100ml	0 cfu/100 ml	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞
Ph		6.5<pH<8.5	7	7	7	7	7	7	7	7	7	7	7	7
Color	APHA	15 APHA												
Turbidity	NTU	< 5 NTU	910.9	599.61	870.2	1584.2	1680	1198.5	1014.1	1107	850	1126	960	1250
Suspended matter	mg/l	0 mg/l											745	
Residual free Chlorine	mg/l	0.2 - 0.5mg/l									_			
TA	mg/l	0	0	0	0	0	0		0.22	0.22				0
TAC	mg/l	3	4	1.9		4.8	3.7		4.6	4.6				0.8
TH	mg/l	3.2	8.4	4.93		7.6	7.6		7.3	6.6				
Tca	mg/l	1.6	4.4	1.9		4.6	2.6		3.9	3.75				0.8
TMg	mg/l	1.6	4	3.07		4.1	5		1.6	1.55				
Calcium	mg/l	80mg/L	17.6	7.5		18.3	15.1		8	8.2				
Magnesium	mg/l	100mg/l	9.6	7.36	1.5	9.1	7.8		2.72	2.7				
Dissolved Oxygen	mg/l													
Organic matter	mg/l	2 mg/l		7.36										9.2
Iron	mg/l	0.3 mg/l	1.9	5.42	3.7	1.9	25.8	215	7.92	7.91	4.88	4.74		7.4
Manganese	mg/l	0.1 mg/l	1.9	1.09		2.2	0.768	1.038	2.47	2.6	0.98	0.76	0.87	1.001
Nitrites	mg/l	0.05 mg/l	0.748	0		0.711	0.14		0.025	0.02			0.98	0.019
Nitrates	mg/l	15 mg/l	46.8	7.9		45.2	8		0.095	0.089	5.6	6.3	8.7	50.8
Ammoniacal Nitrogen	mg/l	0.05 mg/l	0	0.17		0	0.75		95	92	0.62	0	0.66	0.64
Phosphates	mg/l	5 mg/l	0.46	1.3		0.51	1.48		0.86	0.88	<0.02			1.5
Copper	mg/l	1mg/l	0.82	0.14		0.93	1.38		0.16	0.18	2.6		-1.27	0.84
Zinc	mg/l	3 mg/l	0.15	0.04		0.16	0.13		0.45	0.48	0.5	0.46	0.04	0.02
Silica	mg/l	IND	9.9	3.17		8.9	0.08		2.455	2.41	0.15			11.2
Fluoride	mg/l	1.5mg/l	3.97	0		4.36	0.67		2.8	2.3	1.8	0.03		0.79
Cyanide	mg/l	0.05 mg/l	0.017	0.012		0.019	0.001		0.038	0.039	0.5		0.001	
Nickel	mg/l	0.02mg/l												
Conductivity	μs/cm													
T.D.S	mg/l													
Salinity	‰													
Iodine	mg/l	ND	0.24	0.66		0.22	1.88				<0.07			0.52
Chronium	mg/l	0 mg/l	0	0		0	0.024		-0.01	-0.02			-0.058	0.12
Bromide	mg/l	5mg/l	2.255	0.4		2.216	0.96		2.255	2.12	<0.05			0.44
Sulphates	mg/l	250 mg/l	19	14		18	19		4.5	4.3				678
Chlorides	mg/l	250 mg/l	0.02	57.4		0.03	22.5		94.35	99.31				174.5
Aluminium	mg/l	0.2 mg/l	0.745	0.2		0.762	0.516		0.745	0.61	0.284		0.198	0.395

The measured raw water characteristics in 2010 at intake of Gihira WTP include physicochemical and bacteriological parameters and was uncomplete, there was missing data in different months of year and parameters like iodine, brome etc. appeared just on the list with not even one measurement throughout year.

For comparison purpose, they were put together in the same table with WHO standards. The main factors of water pollution are the watershed managements practices that take place and the climate elements that influence the amount of the rainfall.

Starting from bacteriological characteristics, it was found that in all months from January to December, that the average monthly total coliforms and fecal coliforms were greater than the WHO standards (cfu/100ml) in 2010. The coliforms cause serious health hazards, considering that some people in the catchment are using untreated surface water from the river.

Most of the values in physicochemical characteristics were found to be lower than the standards value; among these parameters there: total calcium, total magnesium, sulfates, pH, copper, phosphorus, barium, chromium VI. In addition, some values of other parameters were higher compared to the standards; these are. turbidity, organic matter and iron (see table 4.13)

The season calendar was used, water quality characteristics values in turbidity, and iron was found to be the function of rainfall intensity. The worst case was observed on turbidity because its values in different months are very high compared to standard (5NTU), this shows that soil erosion potential was higher also in year 2010 in Sebeya river catchment.

The concentration of the organic maters 10mg/l in July, the only value appearing in table; iron concentration in January, February and October were 15.1mg/l, 13.181mg/l and 12.071mg/l respectively. apart from January, other both months are among the ones expected to produce the high rainfall.

Raw water quality drawn from the database of WASAC, showed that during year 2011 bacteriological parameters were not taken into consideration during analysis but only physicochemical parameters.

In dataset, the same challenge of missing data was persisting, which was worse compared to year 2010. Just few parameters with their corresponding values were available in some months of the whole year. In these, most of them respect the WHO standards like pH, nitrate, nitrite.

The concentration of Iron Fe^{3+} in December was 1.69 mg/l and this is higher than standard value of 0.2 mg/l where other values met the norms. The turbidity was continuing to be the parameter of higher values in all months, color and barium values were also found higher than the standard.

In the following years (2012, 2013, 2014, 2015, 2016), the bacteriological parameters have taken into consideration in years 2014 & 2015. For 2014, four kinds of bacteria were measured they are total coliforms, fecal coliforms, E-Coli and fecal Streptococcus. Concentration of total coliforms, fecal coliforms and E-Coli was found greater than 0cfu/100 ml (the standards) in all months where measurements were analyzed but for fecal Streptococcus analysis results met the standard concentration of 0cfu/100 ml. In months of February to April, the concentration of total coliforms reached more than 100 cfu/100 ml.

In 2015, results from bacteriological analysis on total coliforms, fecal coliforms, E-Coli and fecal Streptococcus showed that no one of them has met the drinking water standard in all months of measurements throughout the year. Taking an example of total coliforms, its concentration was greater than 100 cfu/100 ml where total coliforms concentration in the months of May to December year 2015 was ranging between 39 cfu/100 ml and 42 cfu/100 ml. Fecal coliforms and E-Coli was found higher in year 2014 than 2015 in February, March and April in addition concentration of fecal Streptococcus found high in 2015 than 2014.

Many of physicochemical characteristics met the standards of surface water quality provided by WHO like pH, sulfates, calcium, nitrates, nitrates, etc. Turbidity was found as exception in that its values was always more than its corresponding standards value in every month of the seven years.

In 2012, the concentration of nitrites was found as 2.6mg/l where the WHO standard is 0.1 mg/L; Manganese Mn^{2+} was 0.413, 0.63 mg/L, 0.121 mg/L, 0.121 mg/L, 0.65 mg/L in January, February, April, May, and July respectively this means that there were also big changes because its limits is 0.05 mg/L. Zinc concentration was 1mg/L in every month of analysis which was higher than 0.7 mg/L (standard value).

By 2013, iron concentration in Sebeya river also has been found higher than its standard limit as 1.19mg/L, 2.51 mg/L, 1.87 mg/L, 1.34 mg/L, 1.64 mg/L, 1.36 mg/L, 2.11 mg/L, 2.08, 0.86 mg/L, >3.00 mg/L, 5.2 mg/L in January, February, March, April, May, June, July, August, October, November and December where the standard is 0.2 mg/L. Copper was 1.19 mg/L in May and 0.38mg/L where its limit standard is 0.1 mg/L

Analysis carried out in 2014 resulted in concentration Iron, Copper Manganese were beyond their standard limits at least in one month. For example, Iron 3.5 mg/L, 1.8 mg/L, 2.5 mg/L, 2.2 mg/L, 2.4 mg/L, 3.7 mg/L, 8.4 mg/L, 4.8 mg/L, 4.2 mg/L, 9.2 mg/L in in January, February, March, April, May, June, July, September, October and December respectively. looking at Manganese concentration in the same year, it was resulted in higher values than the standard (0.05mg/L) from January to December.

The same situation was found in year 2015 & 2016, where apart from the bacteriological characteristics and turbidity other parameters were found to be part of those of high concentration. Some of them include iron, manganese, copper, zinc in 2015 and organic matters, iron, manganese, copper, zinc

Quality analysis of raw for the period 2010 to 2016 has given the results good enough to understand the effects of soil erosion on Sebeya river. Moreover, among them like bacteriological characteristics were found to be almost 100 percent beyond the standard limits that are responsible of health hazards when this water is untreated used. Physicochemical characteristics are represented by the turbidity to have extremely high value; others include iron, manganese, copper, zinc, etc. which also may be harmful.

The turbidity was considered because of its data availability in the dataset and it helps to capture the general image on the volume of the soil transported into the water body within the time; in addition, some water quality parameter like total dissolved solids and total suspended solids play the same role but the data set was poor in them to be considered.

Table 4.20 Turbidity of raw water at intake of Gihira water treatment plant

	JAN	FEB	MAR	APRI	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
2010	226-44150	348-33660	325-40572	222-16280	290-63840	254-17864	157 - 1670	169 – 2079	214-14100	335-16680	305-17600	334 - 17208
2011	1532	1228	886	1630	902	1178	936	1325	735	895	1450	1835
2012	1025	1005.5	1770.6	1615.6	1330.3	962.5	813.6	914.8	1172.6	861.7	905.2	968.4
2013	889.3	736	999.3	768.6	201.8	201	185	158	213	249	315	1460
2014	222	65	115	102	107.8	480	1238.5	956.4	856	577.5	330.9	1929.8
2015	850	1030.5	414.7	412.3	528.5	850	295.964	587.826	760.5	722.62	773.6	1107
2016	910.9	599.61	870.2	1584.2	1680	1198.5	1014.1	1107	850	1126	960	1250

According to the table 4.1, looking at the variability in values of turbidity it was observed that in 7 years (from 2010 to 2016) there was alternation of increase and decrease for the months of March, May, July, August, September, December. For the months of January, February, April, June, turbidity has been decreasing from 2010 to 2014 and increasing from 2014 to 2016. For November and October, the value of turbidity has been decreasing from 2010 to 2013 and increasing from 2013 to 2016. It was observed that, the values in the first years were almost higher compared to those of last years without considering the years of minimum values in different month.

Table 4.21 Turbidity of Raw water, mean, STDEV at Gihira WTP from 2011 to 2016

	JANS	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPT	OCT	NOV	DEC	MEAN	STDEV
2011	1532	1228	886	1630	902	1178	936	1325	735	895	1450	1835	1211.00	349.37
2012	1025	1005.5	1770.6	1615.6	1330.3	962.5	813.6	914.8	1172.6	861.7	905.2	968.4	1112.15	306.58
2013	889.3	736	999.3	768.6	201.8	201	185	158	213	249	315	1460	531.33	427.75
2014	222	65	115	102	107.8	480	1238.5	956.4	856	577.5	330.9	1929.8	581.74	572.60
2015	850	1030.5	414.7	412.3	528.5	850	295.964	587.826	760.5	722.62	773.6	1107	694.46	251.99
2016	910.9	599.61	870.2	1584.2	1680	1198.5	1014.1	1107	850	1126	960	1250	1095.88	306.30

The arithmetic mean and standard deviation in different years from 2011 to 2016 proved that there was high variation in the turbidity of raw water, and there was a big difference between average monthly turbidity and overall mean. Moreover, the values of standard deviation were found to be high which has a tremendous significance on how the monthly value are very different from their corresponding mean in every year of the six years.

The monthly mean turbidity was close to overall mean in 2015 with standard deviation of 251.99 but in 2014 the monthly turbidity was found to have highest variation due to its corresponding standard deviation of 572.60, this value is the highest compared to others.

4.4.2 ANOVA on turbidity of raw water at Gihira WTP

Analysis of variance was applied in the variability analysis of the turbidity of raw water for more concern on clarification for six years. The F- test was used where the computed F ratio was approximately 614; the error type I (α=0.05) was taken into consideration to get Fc and the degrees of freedom calculated by (k (n-1), k -1)

- Degree of freedom between groups = k -1 = 6-1 =5
- Degree of freedom within groups = 6 (12-1) = 66

The resulting point representing the couple of the degrees of freedom is (5, 66), consequently the Fc was found as 2.35.

Table 4.22 ANOVA in turbidity of raw water at Gihira WTP

	January	1532	1025	889.3	222	850	910.9	
	February	1228	1005.5	736	65	1030.5	599.61	
	March	886	1770.6	999.3	115	414.7	870.2	
	April	1630	1615.6	768.6	102	412.3	1584.2	
	May	902	1330.3	201.8	107.8	528.5	1680	
	June	1178	962.5	201	480	850	1198.5	
	July	936	813.6	185	1238.5	295.964	1014.1	
	August	1325	914.8	158	956.4	587.826	1107	
	September	735	1172.6	213	856	760.5	850	
	October	895	861.7	249	577.5	722.62	1126	
	November	1450	905.2	315	330.9	773.6	960	
	December	1835	968.4	1460	1929.8	1107	1250	
Total $y_{1.}$		14532	13345.8	6376	6980.9	8333.51	13150.51	
Mean $\bar{y}_{1.}$		1211	1112.15	531.3333	581.7417	694.4592	1095.876	
Variance S_1^2		122057.8	93993.01	182965.8	327866.1	63500.68	93818.96	**884202.34**
S_e^2								**147367.06**
$\bar{y}_{..}$								**871.09**
$\sum_{i=1}^{k}(\bar{y}_{i.} - \bar{y}_{..})^2$		115536.5	58108.32	115436.9	37329738	31199.63	50527.17	**37700546.02**
$s_{\bar{y}}^2$								**7540109.20**
$ns_{\bar{y}}^2$								**90481310.45**
F								613.99

The F ratio was found very high, meaning that the variation of mean monthly turbidity from 2011 to 2016 was high. The F was greater than Fc, which implied the statistical significance in the monthly values of turbidity for the period 2011 to 2016, which is the same situation found in rainfall and cost of producing potable water.

4.4.3 Tukey Test in average monthly turbidity

The post processing was the next step after ANOVA in turbidity because analysis of variances found that the values of average monthly turbidity were significantly-statistically different. As principles of ANOVA don't take interest in knowing which means are different from each other, Tukey Test was used to get the final conclusion on that aspect. Overall annual mean from each of the whole population of each treatment (sample) was computed and a set of them was sorted from the in column and row to calculate the difference in each pair of mean and Q. Mathematically,

$Q = \frac{Mean\ X - Mean\ Y}{\sqrt{s_e^2/n}}$ mean X represents large mean and mean Y small mean in pair of means under consideration and Qcv is obtained from its distribution table. This table use number of means and degree of freedom within groups to be able to draw Qcv.

$$Q = \sqrt{s_e^2}/n = \sqrt{147367.06/12} = 110.82$$

Table 4.23 Difference in mean between treatments of turbidity

	1211.00	**1112.15**	**531.33**	**581.74**	**694.46**	**1095.88**
1211.00						
1112.15	98.8					
531.33	679.7	580.8				
581.74	629.3	530.4	50.4			
694.46	516.5	417.7	163.1	112.7		
1095.88	115.1	16.3	564.5	514.1	401.4	

Table 4.24 Q for each pairwise comparison of turbidity

	1211.00	**1112.15**	**531.33**	**581.74**	**694.46**	**1095.88**
1211.00						
1112.15	0.892					
531.33	**6.133**	**5.241**				
581.74	**5.678**	**4.786**	0.455			
694.46	**4.661**	3.769	1.472	1.017		
1095.88	1.039	0.147	**5.094**	**4.639**	3.622	

The degree of freedom (df) within groups was 66 and the number of means was 6, the Qcv was calculated using the table of Critical Values for the Tukey Q Test (see annex 3).

By interpolation, Qcv = 4.15. The value of Qcv is less than the Q obtained by testing the pair of means for the period 2011 to 2016, only these pairs are significantly different from one other and include: (2011,2013); (2011,2014), (2011,2015); (2012,2013); (2012,2014); (2013,2016); (2014,2016).

4.4.4 Water production

Monthly water production at Gihira water treatment plant is expected to be the function of amount of rainfall in Sebeya River catchment and capacity of the water treatment plant. In wet season throughout the year the plant has to produce higher quantity of water than dry period in the normal or favorable environmental conditions. As earlier stated in Sebeya catchment, there is some amount of rainfall falling every month throughout the year, However, the followings are considered as the months of the raining season viz:February March, April, May, October, and November and the months of the dry season are June, July, August, September, December, January see fig 4.1. fig 4.2; fig 4.3.

Referring to table 4.25, the quantity of water produced monthly was found to be higher in dry months than in the raining season months almost all the cases; for example, water produced in July was 269720 m^{3}" where that of November was 219117 m^3 in 2012; 286910 m^3 in July and 254493 m^3 in November for 2015. Water produced monthly in January of 2015, 2016, 2017 expressed m^3 are 275506, 278043.5, 277060.5 respectively compared to water produced monthly in March of 2015, 2016, 2017 expressed m^3 which are 271851, 258009, 253739.5 respectively.

There was also increase in water production from year 2012 – 2013 up to date. This is very important situation for the treatment plant because it proves a kind of improvement in water resources management practices which of course requires the commitment and involvement of all stakeholders from national level to community level or they have incorporated of adequate methods in water treatments (see table 4.25).

Table 4.25 Monthly water production in m^3 from July 2012 to April 2017

	2012 – 2013	2013 – 2014	2014 -2015	2015 – 2016	2016 -2017
July	269720	283534	281433	286910	280175.8
August	262366	276991	268759	273615	287923.5
September	260609	233217	242319	276706.24	254574
October	247783	246142	245647	258432	261388.5
November	219117	189778	257703	254493	239202
December	241671	244805	244240	263368.5	277060.5
January	245841	257965	275506	278043.5	260925
February	231411	235117	236467	246930.5	225305
March	254371	266819	271851	258009	253739.5
April	233822	258637	257663	226754	246802
May	257836	278324	275103	256455	
June	266170	265566	254330	268323.2	
Total	**2,990,717**	**3,036,895**	**3,111,021**	**3,148,039.94**	

4.4.5 Cost of potable water production at Gihira WTP

The production of drinking water is influenced by several factors such as quality of raw water from the source, cost of chemicals, quality and quantity of water to be produced etc. Cost of water treatment (production) at Gihira WTP was found to be subjected to annual and monthly variation; annual cost has been increasing from year 2012-2013 up to date. Referring to the average cost of producing one m^3 in every month (see table 4.26), it was found inversely proportional to the intensity of rainfall in the catchment for most of the cases.

For example, the cost producing one m^3 in July of 2012, 2013, 2014, 2015 are 96.13rwf, 103.32 rwf, 108.65 rwf, 56.48 rwf and the monthly precipitation (Gisenyi station) in the same month in these respective years are 53.2mm, 9.2mm, 15.8mm, 20.9mm. In October, the respective costs per m^3 are 93.74 rwf, 120.29 rwf, 123.32 rwf, 119.50 rwf and monthly precipitation are 247.7mm, 86.5mm, 129.1mm, 244.6mm

It can be concluded that the main source of pollution that is transported be rainfall includes: landslides, eroded sediment, transportation of organic matter from agricultural lands and mining activities in the river catchment, improperly disposed waste. The disposed waste may be produced from neighboring infrastructures such as markets or domestic waste from population premises. Figure 4.9 shows the model that indicate the variation of cost of treatment of one cubic meter of water based on the amount of precipitation. The reason for poor correlation of the model might be due to other influencing factors such variation in chemical cost, labor efficiency of at the plant, state of the component of the plant such as filters, etc.

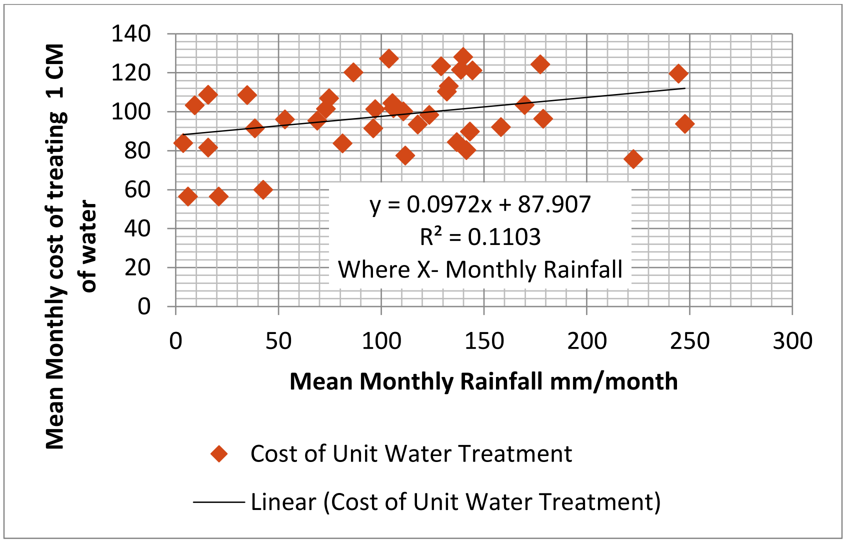

Figure 4.9 Regression model of rainfall to cost of producing one cubic meter of potable water

In general, the annual cost of producing one cubic meter of potable water has been increasing for the period 2012-2013 up to date. Year 2012-2013, around 85 rwf was sufficient to produce one cubic meter of water but this cost has increases to 119 rwf in 2015-2016. In contrast, referring to table 23.4 monthly average turbidity of raw water has been decreasing for the period 2012 to 2013 and increased for 2013 to 2016. This means in the same period other kind of parameters contributed to the production of water like cost of chemicals.

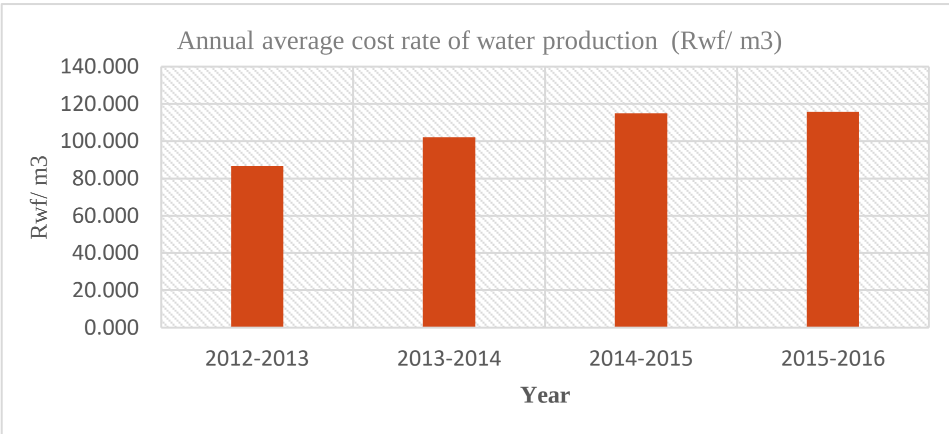

Figure 4.10 Changes in annual rate of producing drinking water at Gihira WTP

4.4.6 ANOVA of monthly rate of potable water production

The variation in the rate of producing one cubic meter of potable water at Gihira WTP plant from July 2012 to June 2016 was found not statistically significant at 0.05 level. Value obtained in F test is 2.7298, which is less than its corresponding Fc (critical F) of 2.82. see table 4.27.

Table 4.26 ANOVA on monthly rate of potable water production

		2012-2013	2013-2014	2014-2015	2015-2016	
	July	96.130	103.319	108.647	56.482	
	August	95.472	92.186	101.287	81.602	
	September	96.390	103.399	104.507	127.301	
	October	93.738	120.289	123.323	119.505	
	November	110.445	162.154	211.319	124.342	
	December	101.481	113.189	128.180	121.463	
	January	91.542	80.333	108.541	116.063	
	February	83.666	101.758	106.910	140.072	
	March	75.675	98.343	77.444	144.966	
	April	84.409	91.534	100.230	135.747	
	May	59.961	83.938	121.279	112.604	
	June	56.422	93.356	89.832	120.573	
Total y1.		**1045.331**	**1243.796**	**1381.499**	**1400.720**	
Mean $\bar{y}1.$		**87.111**	**103.650**	**115.125**	**116.727**	
Variance S_1^2		**261.887**	**467.177**	**1115.212**	**618.137**	**2462.4136**
s_e^2						**615.6034**
$\bar{y}_{..}$						**105.6531**
$\sum_{i=1}^{k}(\bar{y}_{i.} - \bar{y}_{..})^2$		343.8097709	4.013538401	89.71630162	122.6250782	**560.1647**
$s_{\bar{y}}^2$						**140.0412**
$ns_{\bar{y}}^2$						**1680.4941**
F						**2.7298**
Degrees of freedom						
Between groups		k -1 = 4 - 1 =3				
Within groups		k(n-1)	4(12-1) = 44		Point (3, 44)	

The findings show the difference in the cost of water production was almost the same between 2012 to 2016 statistically; Charles(2010) in his comparison of cost of production of potable water at Gihira WTP and Musanze WTP, using information from the plant he found big difference where Gihira used around 2 million and Musanze 200 thousands Rwandan francs monthly due to erosion taking place in the area (ten times higher) .

In addition, the erosion has been affecting the quality of water and several measures composed of best land management practices were implemented, but their impacts are not very appreciable to the reduction of cost of potable water production statistically based on the results.

Chapter five

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

5.1.1 The population of Sebeya catchment perceived the existence of erosion and vulnerability of infrastructures to its impacts in the catchment and agreed that the contributing main factors to erosion in the catchment are deforestation, slope, rainfall, farming methods, mining activities, informal settlement and type of soils

5.1.2 The characterization of the catchment indicates that there is high potential for erosion especially because of poor agricultural practices, deforestation, soil types and steep slopes at upstream end of the catchment.

5.1.3 It is concluded that the sediment transported in Sebeya River as a result of erosion is having high negative impact on electricity generation to the extend the amount of electricity generated in the raining season is almost the same as in the dry season.

5.1.4 The eroded sediments transported in Sebeya River is having negative impact on surface water purification for domestic use in the following ways: (1) increase the unit cost of water purification and (2) reduces the amount purified per month during the raining season.

5.2 Recommendations

It is important that the inhabitants of Sebeya catchment understand the existence of erosion and its impacts on livelihoods. Also, the corporations that are operating business that are influenced by erosion or sediment transport understand the losses they are incurring because of the erosion taking place in the catchments. To minimize these impacts, it is important that all stakeholders cooperate and contribute in controlling erosion in the Sebeya catchment. The contribution of stakeholders could be in the followings directions:

The Government:

a. Enlighten the population in terms of capacity building on the existing environmental Laws and enforced it to ensure proper control.
b. Invest in more projects toward minimizing erosion in the area example training local population in improved farming technics, forest conservations, organize human settlements, etc.

The Local Population:

a. Observed the existing environmental Laws and ensure wise use of natural resources as well as control erosion in their various activities such as farming, building houses, mining of construction and the minerals etc.
b. Corporates in learning and implementing new technologies that will contribute in erosion control

Investors:

a. The investors should contribute in implementing erosion control projects themselves and/or support the local population in doing that.

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ANNEX 1: Critical values of F in ANOVA for the 0.05 significance level

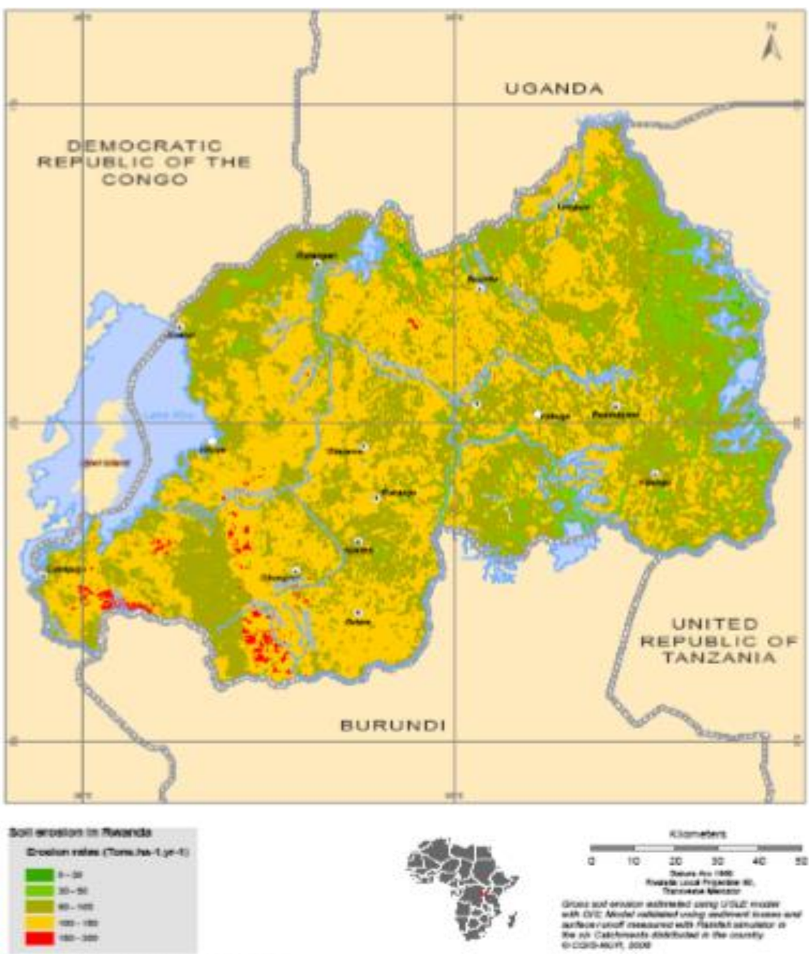
	1	2	3	4	5	6	7	8	9	10
1	161.45	199.50	215.71	224.58	230.16	233.99	236.77	238.88	240.54	241.88
2	18.51	19.00	19.16	19.25	19.30	19.33	19.35	19.37	19.39	19.40
3	10.13	9.55	9.28	9.12	9.01	8.94	8.89	8.85	8.81	8.79
4	7.71	6.94	6.59	6.39	6.26	6.16	6.09	6.04	6.00	5.96
5	6.61	5.79	5.41	5.19	5.05	4.95	4.88	4.82	4.77	4.74
6	5.99	5.14	4.76	4.53	4.39	4.28	4.21	4.15	4.10	4.06
7	5.59	4.74	4.35	4.12	3.97	3.87	3.79	3.73	3.68	3.64
8	5.32	4.46	4.07	3.84	3.69	3.58	3.50	3.44	3.39	3.35
9	5.12	4.26	3.86	3.63	3.48	3.37	3.29	3.23	3.18	3.14
10	4.97	4.10	3.71	3.48	3.33	3.22	3.14	3.07	3.02	2.98
11	4.84	3.98	3.59	3.36	3.20	3.10	3.01	2.95	2.90	2.85
12	4.75	3.89	3.49	3.26	3.11	3.00	2.91	2.85	2.80	2.75
13	4.67	3.81	3.41	3.18	3.03	2.92	2.83	2.77	2.71	2.67
14	4.60	3.74	3.34	3.11	2.96	2.85	2.76	2.70	2.65	2.60
15	4.54	3.68	3.29	3.06	2.90	2.79	2.71	2.64	2.59	2.54
16	4.49	3.63	3.24	3.01	2.85	2.74	2.66	2.59	2.54	2.49
17	4.45	3.59	3.20	2.97	2.81	2.70	2.61	2.55	2.49	2.45
18	4.41	3.56	3.16	2.93	2.77	2.66	2.58	2.51	2.46	2.41
19	4.38	3.52	3.13	2.90	2.74	2.63	2.54	2.48	2.42	2.38
20	4.35	3.49	3.10	2.87	2.71	2.60	2.51	2.45	2.39	2.35
21	4.33	3.47	3.07	2.84	2.69	2.57	2.49	2.42	2.37	2.32
22	4.30	3.44	3.05	2.82	2.66	2.55	2.46	2.40	2.34	2.30
23	4.28	3.42	3.03	2.80	2.64	2.53	2.44	2.38	2.32	2.28
24	4.26	3.40	3.01	2.78	2.62	2.51	2.42	2.36	2.30	2.26
25	4.24	3.39	2.99	2.76	2.60	2.49	2.41	2.34	2.28	2.24
26	4.23	3.37	2.98	2.74	2.59	2.47	2.39	2.32	2.27	2.22
27	4.21	3.35	2.96	2.73	2.57	2.46	2.37	2.31	2.25	2.20
28	4.20	3.34	2.95	2.71	2.56	2.45	2.36	2.29	2.24	2.19
29	4.18	3.33	2.93	2.70	2.55	2.43	2.35	2.28	2.22	2.18
30	4.17	3.32	2.92	2.69	2.53	2.42	2.33	2.27	2.21	2.17
31	4.16	3.31	2.91	2.68	2.52	2.41	2.32	2.26	2.20	2.15
32	4.15	3.30	2.90	2.67	2.51	2.40	2.31	2.24	2.19	2.14
33	4.14	3.29	2.89	2.66	2.50	2.39	2.30	2.24	2.18	2.13
34	4.13	3.28	2.88	2.65	2.49	2.38	2.29	2.23	2.17	2.12
35	4.12	3.27	2.87	2.64	2.49	2.37	2.29	2.22	2.16	2.11

36	4.11	3.26	2.87	2.63	2.48	2.36	2.28	2.21	2.15	2.11
37	4.11	3.25	2.86	2.63	2.47	2.36	2.27	2.20	2.15	2.10
38	4.10	3.25	2.85	2.62	2.46	2.35	2.26	2.19	2.14	2.09
39	4.09	3.24	2.85	2.61	2.46	2.34	2.26	2.19	2.13	2.08
40	4.09	3.23	2.84	2.61	2.45	2.34	2.25	2.18	2.12	2.08
41	4.08	3.23	2.83	2.60	2.44	2.33	2.24	2.17	2.12	2.07
42	4.07	3.22	2.83	2.59	2.44	2.32	2.24	2.17	2.11	2.07
43	4.07	3.21	2.82	2.59	2.43	2.32	2.23	2.16	2.11	2.06
44	4.06	3.21	2.82	2.58	2.43	2.31	2.23	2.16	2.10	2.05
45	4.06	3.20	2.81	2.58	2.42	2.31	2.22	2.15	2.10	2.05
46	4.05	3.20	2.81	2.57	2.42	2.30	2.22	2.15	2.09	2.04
47	4.05	3.20	2.80	2.57	2.41	2.30	2.21	2.14	2.09	2.04
48	4.04	3.19	2.80	2.57	2.41	2.30	2.21	2.14	2.08	2.04
49	4.04	3.19	2.79	2.56	2.40	2.29	2.20	2.13	2.08	2.03
50	4.03	3.18	2.79	2.56	2.40	2.29	2.20	2.13	2.07	2.03
51	4.03	3.18	2.79	2.55	2.40	2.28	2.20	2.13	2.07	2.02
52	4.03	3.18	2.78	2.55	2.39	2.28	2.19	2.12	2.07	2.02
53	4.02	3.17	2.78	2.55	2.39	2.28	2.19	2.12	2.06	2.02
54	4.02	3.17	2.78	2.54	2.39	2.27	2.19	2.12	2.06	2.01
55	4.02	3.17	2.77	2.54	2.38	2.27	2.18	2.11	2.06	2.01
56	4.01	3.16	2.77	2.54	2.38	2.27	2.18	2.11	2.05	2.01
57	4.01	3.16	2.77	2.53	2.38	2.26	2.18	2.11	2.05	2.00
58	4.01	3.16	2.76	2.53	2.37	2.26	2.17	2.10	2.05	2.00
59	4.00	3.15	2.76	2.53	2.37	2.26	2.17	2.10	2.04	2.00
60	4.00	3.15	2.76	2.53	2.37	2.25	2.17	2.10	2.04	1.99
61	4.00	3.15	2.76	2.52	2.37	2.25	2.16	2.09	2.04	1.99
62	4.00	3.15	2.75	2.52	2.36	2.25	2.16	2.09	2.04	1.99
63	3.99	3.14	2.75	2.52	2.36	2.25	2.16	2.09	2.03	1.99
64	3.99	3.14	2.75	2.52	2.36	2.24	2.16	2.09	2.03	1.98
65	3.99	3.14	2.75	2.51	2.36	2.24	2.15	2.08	2.03	1.98
66	3.99	3.14	2.74	2.51	2.35	2.24	2.15	2.08	2.03	1.98
67	3.98	3.13	2.74	2.51	2.35	2.24	2.15	2.08	2.02	1.98
68	3.98	3.13	2.74	2.51	2.35	2.24	2.15	2.08	2.02	1.97
69	3.98	3.13	2.74	2.51	2.35	2.23	2.15	2.08	2.02	1.97
70	3.98	3.13	2.74	2.50	2.35	2.23	2.14	2.07	2.02	1.97
71	3.98	3.13	2.73	2.50	2.34	2.23	2.14	2.07	2.02	1.97
72	3.97	3.12	2.73	2.50	2.34	2.23	2.14	2.07	2.01	1.97
73	3.97	3.12	2.73	2.50	2.34	2.23	2.14	2.07	2.01	1.96
74	3.97	3.12	2.73	2.50	2.34	2.22	2.14	2.07	2.01	1.96
75	3.97	3.12	2.73	2.49	2.34	2.22	2.13	2.06	2.01	1.96
76	3.97	3.12	2.73	2.49	2.34	2.22	2.13	2.06	2.01	1.96
77	3.97	3.12	2.72	2.49	2.33	2.22	2.13	2.06	2.00	1.96
78	3.96	3.11	2.72	2.49	2.33	2.22	2.13	2.06	2.00	1.95
79	3.96	3.11	2.72	2.49	2.33	2.22	2.13	2.06	2.00	1.95
80	3.96	3.11	2.72	2.49	2.33	2.21	2.13	2.06	2.00	1.95
81	3.96	3.11	2.72	2.48	2.33	2.21	2.13	2.06	2.00	1.95
82	3.96	3.11	2.72	2.48	2.33	2.21	2.12	2.05	2.00	1.95
83	3.96	3.11	2.72	2.48	2.32	2.21	2.12	2.05	2.00	1.95
84	3.96	3.11	2.71	2.48	2.32	2.21	2.12	2.05	1.99	1.95
85	3.95	3.10	2.71	2.48	2.32	2.21	2.12	2.05	1.99	1.94

86	3.95	3.10	2.71	2.48	2.32	2.21	2.12	2.05	1.99	1.94
87	3.95	3.10	2.71	2.48	2.32	2.21	2.12	2.05	1.99	1.94
88	3.95	3.10	2.71	2.48	2.32	2.20	2.12	2.05	1.99	1.94
89	3.95	3.10	2.71	2.47	2.32	2.20	2.11	2.04	1.99	1.94
90	3.95	3.10	2.71	2.47	2.32	2.20	2.11	2.04	1.99	1.94
91	3.95	3.10	2.71	2.47	2.32	2.20	2.11	2.04	1.98	1.94
92	3.95	3.10	2.70	2.47	2.31	2.20	2.11	2.04	1.98	1.94
93	3.94	3.09	2.70	2.47	2.31	2.20	2.11	2.04	1.98	1.93
94	3.94	3.09	2.70	2.47	2.31	2.20	2.11	2.04	1.98	1.93
95	3.94	3.09	2.70	2.47	2.31	2.20	2.11	2.04	1.98	1.93
96	3.94	3.09	2.70	2.47	2.31	2.20	2.11	2.04	1.98	1.93
97	3.94	3.09	2.70	2.47	2.31	2.19	2.11	2.04	1.98	1.93
98	3.94	3.09	2.70	2.47	2.31	2.19	2.10	2.03	1.98	1.93
99	3.94	3.09	2.70	2.46	2.31	2.19	2.10	2.03	1.98	1.93
100	3.94	3.09	2.70	2.46	2.31	2.19	2.10	2.03	1.98	1.93

Source: (Hampton, 2006)

ANNEX 2: Map of Soil Erosion Rates in Rwanda



Source: REMA (2010)

ANNEX 3: Critical Values for the Tukey Q Test

$\alpha = 0.05$

k / df	2	3	4	5	6	7	8	9	10
1	18.0	27.0	32.8	37.1	40.4	43.1	45.4	47.4	49.1
2	6.08	8.33	9.80	10.88	11.73	12.43	13.03	13.54	13.99
3	4.50	5.91	6.82	7.50	8.04	8.48	8.85	9.18	9.46
4	3.93	5.04	5.76	6.29	6.71	7.05	7.35	7.60	7.83
5	3.64	4.60	5.22	5.67	6.03	6.33	6.58	6.80	6.99
6	3.46	4.34	4.90	5.30	5.63	5.90	6.12	6.32	6.49
7	3.34	4.16	4.68	5.06	5.36	5.61	5.82	6.00	6.16
8	3.26	4.04	4.53	4.89	5.17	5.40	5.60	5.77	5.92
9	3.20	3.95	4.41	4.76	5.02	5.24	5.43	5.59	5.74
10	3.15	3.88	4.33	4.65	4.91	5.12	5.30	5.46	5.60
11	3.11	3.82	4.26	4.57	4.82	5.03	5.20	5.35	5.49
12	3.08	3.77	4.20	4.51	4.75	4.95	5.12	5.27	5.39
13	3.06	3.73	4.15	4.45	4.69	4.88	5.05	5.19	5.32
14	3.03	3.70	4.11	4.41	4.64	4.83	4.99	5.13	5.25
15	3.01	3.67	4.08	4.37	4.59	4.78	4.94	5.08	5.20
16	3.00	3.65	4.05	4.33	4.56	4.74	4.90	5.03	5.15
17	2.98	3.63	4.02	4.30	4.52	4.70	4.86	4.99	5.11
18	2.97	3.61	4.00	4.28	4.49	4.67	4.82	4.96	5.07
19	2.96	3.59	3.98	4.25	4.47	4.65	4.79	4.92	5.04
20	2.95	3.58	3.96	4.23	4.45	4.62	4.77	4.90	5.01
24	2.92	3.53	3.90	4.17	4.37	4.54	4.68	4.81	4.92
30	2.89	3.49	3.85	4.10	4.30	4.46	4.60	4.72	4.82
40	2.86	3.44	3.79	4.04	4.23	4.39	4.52	4.63	4.73
60	2.83	3.40	3.74	3.98	4.16	4.31	4.44	4.55	4.65
120	2.80	3.36	3.68	3.92	4.10	4.24	4.36	4.47	4.56
∞	2.77	3.31	3.63	3.86	4.03	4.17	4.29	4.39	4.47

Source: (Hampton, 2006)

ANNEX 4 Cost of potable water production in Rwf / m^3 and monthly rainfall at Gisenyi station

	2012		2013		2014		2015	
	Rwf/ m3	mm	Rwf/ m3	mm	Rwf/ m3	mm	Rwf/ m3	mm
JANUARY		17.5	91.54	38.5	80.33	141.4	108.54	34.7
FEBRUARY		54.7	83.67	81.2	101.76	105.9	106.91	74.7
MARCH		104.8	75.67	222.6	98.34	123.4	77.44	111.7
APRIL		229.1	84.41	136.8	91.53	96.1	100.23	110.7
MAY		159.4	59.96	42.6	83.94	3.7	121.28	144.4
JUNE		40.4	56.42	5.9	93.36	117.7	89.83	143.2
JULY	96.13	53.2	103.32	9.2	108.65	15.8	56.48	20.9
AUGUST	95.47	68.9	92.19	158.3	101.29	97	81.60	15.8
SEPTEMBER	96.39	178.7	103.40	169.8	104.51	105.5	127.30	103.7
OCTOBER	93.74	247.7	120.29	86.5	123.32	129.1	119.50	244.6
NOVEMBER	110.44	131.9	162.15		211.32	151.8	124.34	177.4
DECEMBER	101.48	73	113.19	132.9	128.18	139.8	121.46	138.8

ANNEX 5: Questionnaire on perception of the local people and administration on the existence of erosion and its impacts on the population and the surrounding environment

Q1 Biodata

a. Sex: male female
b. Age: below 20 years 21-35 years 36-40 years 40-50years above 50 years
c. Education: primary school secondary school A_1 A_0 Masters
d. Studies in Water and Environmental Sciences
e. Studies in hydroelectricity and water supply
f. Experience in years (in domain of **d** and **e** at site or office): 1 2 3 4 5 5 - 10 10 - 20 > 20

Q2 **Existence of erosion**

a. Do you think there is erosion in Sebeya catchment?
b. If yes, how do you quantify it magnitude? Low, moderate, severe
c. If yes, what does cause it: deforestation, slope, rainfall, farming methods, mining activities, informal settlement, type soil, other.
d. Does it increase with the time (rate)? Yes, No
e. Is there any effort put in place to control (reduce) erosion? Yes No
f. If yes by whom? Government, NGOs, Development Partners, Local People, Others
g. Is WASAC contributing in erosion control the Sebeya Catchment? Yes, No, I don't know
h. If yes how?

___

___

i. Is Prime Energy Ltd contributing in erosion control the Sebeya Catchment? Yes, No, I don't know
j. If yes how?

___

___

Q3. Impacts of soil erosion

a. Do you think there are issues from soil erosion? Yes , No
b. If yes, what are they:
   - Decrease in land productivity
   - Soil loss
   - Water pollution
   - Death
   - House destruction
   - Others
c. Do you think Gihira water treatment plant is affected by erosion? Yes, NO
d. If yes what are the effects?

- Increase in cost of water treatment
- Increase of maintenance cost
- Damage of physical components like conveyance structures, and intake

- Reducing the amount of water purified
- Intermittent water supply
- I don't know

e. Do you think Gisenyi hydropower plant is affected by erosion? Yes, No.

f. If yes what are the effects?

- Increase of maintenance cost
- Damage of physical components of the plant like conveyance structures, and intake, turbines
- Reduction in amount of electricity generation
- I don't know

g. Do you think there is need for protection against erosion in Sebeya catchment? Yes, No

h. If yes, what do you think is needed to support erosion protection in Sebeya Catchment?

    - Financial assistance
    - Capacity building
    - Others (state it)