

DEPARTMENT OF CIVIL, ENVIRONMENTAL AND GEOMATIC ENGINEERING

MSc thesis title: **“ASSESSMENT OF SOIL EROSION IMPACTS ON WATER QUALITY AND ITS IMPLICATIONS ON THE PERFORMANCE OF KADAHOKWA WATER TREATMENT PLANT, RWANDA”**



This thesis was submitted in partial fulfillment of academic requirements for the award of the Degree of MASTER OF SCIENCE in Water Resources and Environmental Management

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August 2024



UNIVERSITY of
RWANDA

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BONAFIDE CERTIFICATE

This is to certify that the Master's thesis entitled "Assessment of Soil Erosion Impacts on Water Quality and its Implications on the Performance of Kadakokwa Water Treatment Plant" is a record of original bonafide work done by Desire Straton NSHUNGUYINKA (Reg. No. 220017219) in partial fulfillment of the requirement for the award of MSc Degree in Water Resources and Environmental Management at the University of Rwanda, College of Science and Technology during the Academic Year 2023-2024.

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DECLARATION

I, **Desire Straton NSHUNGUYINKA**, do hereby declare that this research project, being submitted to the University of Rwanda for the degree of MASTER'S OF SCIENCE in Water Resources and Environmental Management, is my own independent work; and complies with the Code of Academic Integrity, as well as other relevant policies, procedures, rules and regulations of the University of Rwanda, and has not been submitted before to any institution by myself or any other person in fulfillment (or partial fulfillment) of the requirements for the attainment of any qualification.

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DEDICATION

This research thesis is dedicated to:

Almighty God

My wife

My Supervisors

My workmates and classmates

ACKNOWLEDGEMENT

I m deeply intended to Almighty God who has guided me during the whole period of my studies. My sincere thanks go to my lovely wife. I would like to offer my honest thanks to the University of Rwanda for offering me an opportunity to undertake my studies of Master of Science in water resources and environmental management (WREM), my special heartfelt goes to my supervisors Associate Professor Felicien MAJORO and Associate Professor Leopold MBEREYAHU for their special and courageous supervision while undertaking this research, finally I express my gratitude to my lecturers for their guidance and support, my deep last not least thanks go to my classmates and workmates for their moral support and mentoring.

ABSTRACT

Soil erosion is one of the most important factors affecting water quality of catchment, it is important to assess the effect of soil erosion on water quality in a catchment, the transported sediments from soil erosion are deposited in catchment which lead to the increased pollutants in water treatment plant intake and reduce the performance of water treatment plant, the main objective of this study is to assess the impacts of soil erosion on water quality and its implications on the performance of Kadahokwa water treatment plant, to achieve this assignment, Kadahokwa water treatment plant and intake were visited to get primary data through informal and structural interviews on soil erosion status in the area, ArcGIS software was used to delineate the catchment and for mapping all USLE model factors, to assess the impact of Kadahokwa river sediment load on Kadahokwa water treatment plant, raw water samples were collected in Kadahokwa river during rain and dry seasons, laboratory tests of escherichia coli, turbidity, total suspended solid(TSS) ,sieve analysis and soil water content for bed load sediment were conducted.

Fifty respondents interviewed during this research, showed that the main causes of soil erosion in Kadahokwa catchment are mostly heavy rainfall (60%) and steep slope (30%),the results of laboratory experiment also revealed that turbidity of raw water and total suspended solid are too high during rainy season than dry season and it was contaminated by Escherichia coli, sieve analysis results showed that the soil of Kadahokwa catchment is sandy clay loam with high proportion of sand (84.74%) and the remaining one are silt and clay (15,26%) which cause the damage of valves and taps, filters blockages, fills of tanks and pipes with mud, silt and it can also be causing the delay in water treatment process, the effect of high turbidity of raw water is the increase of sulfate used in water treatment processes, the actual average annual soil loss by using USLE model is 56.69tons/ha/year, after application of various proposed soil erosion control measures, the annual average soil loss is diminished from 56.69 tons/ha/year to 12.23 tons/ha/year, by concluding, soil erosion control measures including soft and hard best management practices (BMPs)are proposed and recommended to be implemented in Kadahokwa catchment.

Keywords: Kadahokwa catchment, soil erosion causes and effects, soil erosion model, average annual soil loss, erosion control measures, rainy and dry season.

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LIST OF SYMBOLS, ABBREVIATIONS AND ACRONYMS

A: Average annual soil loss (tons/ha/yr)

ai: Area covered by SEC measure or LULC type

Ai: Soil loss induced by the i^{th} SEC measure of LULC type

CST: College of Science and Technology

Cc: Coefficient of curvature

Cu: Coefficient of uniformity

C: Crop management factor

D10: Diameter corresponding to the % finer of 10

D30: Diameter corresponding to % finer of 30

D60: Diameter corresponding to the % finer of 60

DEM: Digital elevation model

ESRI: Environmental systems research institutes

GIS: Geographic information system

Ha: Hectare

KE: Kinetic energy

KWTP: Kadahokwa water treatment plant

K: Soil erodibility factor (tons*hr*hr/ha*MJ*mm)

LL: Liquid limit

LULC: Land use and land cover

LS: Slope length

MoE: Ministry of environment

MPN: Most probable number

NTU: Nephelometric Turbidity Unit

NISR: National institutes of statistics of Rwanda

NGOs: Non Government organizations

PH: Hydrogen potential

PCR: Polymerase Chain Reaction

PI: Plastic index

PL: Plastic limit

PHC5: Fifth population and housing census

P: Conservation supporting practices factor

REMA: Rwanda environment management authority

RWB: Rwanda water resource board

RW: Raw water

R: Soil Erosivity factor

RSSP: Rural sector support program

SPSS: Statistical Package for the Social Sciences

SEC: Soil erosion control

SECM: Soil erosion control measures

TSS: Total suspended solids

TDS: Total dissolved solids

TS: Total solids

TW: Treated water

UR-GIS: University of Rwanda-Geographic information system

UV: Ultraviolet

UN: united Nations

USLE: Universal soil loss equation

USAID: United States Agency for International Development

WASAC LTD: Water and Sanitation Corporation limited

WTP: Water treatment plant

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CHAPTER I. INTRODUCTION

1.1 BACKGROUND OF THE STUDY

The primary cause of nonpoint pollution in catchment across the globe is soil erosion, with fine sediments being the most prevalent pollutant (RIWSP 2016) , it has made human civilization and the search for a better way to life worse, either natural factors create it, or social development throughout time induces it, both on- and off-site consequences of the eroded material from soil erosion are harmful to the flora and fauna(Sakinatu et al., 2017), interactions and intra-ecosystem interactions may intensify the consequences.

Three processes soil deposition, soil transport, and soil loosening are typically involved in soil erosion. these procedures typically result in the top soil which is rich in nutrients, organic matter, and soil life being moved either off-site and building up in drainage channels or elsewhere on the property, it usually affects exposed, messy areas severely, the development of a nation and its population depends heavily on surface water since it provides resources for transportation, food, recreation, and hydropower, as a result, excessive sediment concentrations in water affect the quantity and quality of raw water that must be carried for treatment (Majoro et al., 2020).

Globally, soil erosion increases the amount of sediment transported in rivers at a rate of 2.3 billion tons per year, in most watersheds of Rwanda, sediment transported in rivers varies proportionally to the rate of erosion, river runoff and the land slope, while soil nutrients (organic materials, nitrogen, phosphorus and potash) were lost due to soil erosion (Majoro 2023).

1.2 PROBLEM STATEMENT

One of the greatest difficulties faced by water treatment plants in Rwanda is the soil erosion on the catchment of public water sources, while rainfall movement can be the cause of continuous change in observed rainfall signals leading to soil erosion and storms, erosion is among the most destructive natural hazards in Rwanda, especially in Huye district, Kadahokwa river and catchment with severe socioeconomic and environmental impacts.

During rainy season, the top soil and nutrients are transported from upstream and deposited downstream of Kadahokwa river resulting the appearance of suspended sediments which cause turbidity of raw water to increase, sediments are the primary carrier of suspended pollutants such as nitrogen, phosphorous and heavy metals resulting the degradation of water quality, in fact, if high turbidity, high cost of coagulants to be used in water treatment and if the turbidity of raw water increases, the südfloc or sulfate consumption will also increase for the same quantity of raw water to be treated, low quantity of water to be supplied, damage of valves and taps, filters blockages, fills of tanks and pipes with mud and silt and it can also be causing the delay in water treatment process and finally the poor performance of Kadahokwa water treatment plant and the expected quantity of treated water to be produced always diminished during rainy season at Kadahokwa water treatment plant.

1.3. RESEARCH OBJECTIVES

1.3.1 Main objectives

To assess the soil erosion impacts on water quality and its implications on the performance of Kadahokwa water treatment plant.

1.3.2 Specific objectives

- To Assess actual status of Kadahokwa catchment after proposing adequate SEC measures.
- To assess water quality of Kadahokwa river.

- To investigate the effects of the raw water quality fluctuation on the performance of Kadahokwa WTP.
- To elaborate tangible strategies for a sustainable performance of Kadahokwa WTP

1.4 RESEARCH QUESTIONS

1. How does the integration remote sensing data enhance the accuracy and efficiency of soil erosion using USLE model in a specific geographic area?
2. What are the the primary drivers and implications of temporal fluctuations in water quality with in a watershed over an extended period, considering both natural variability and human induced factor?
3. How do variations in source water quality impact he performance and efficiency of water treatment plant over time
4. How do variations in raw water quality ,including seasonal changes and extreme weather events impact the overall efficiency and effectiveness of water treatment plant?
5. How can water treatment processes be optimized to adapt to the challenges posed by soil erosion and what innovative technologies or tangible strategies can be employed to enhance plant performance in such condition?

1.5 SIGNIFICANCE OF THE STUDY

1.5.1 Personal significance

This project will help me to get more information and more practical knowledge about erosion and water treatment and to be engaged together with the community in rural areas in solving the problem caused by soil erosion by using different soil erosion control techniques.

1.5.2. Public and administrative significance

This project will help in reinforcement of the government policies for achieving the goals in the future by improving water resources in country especially in Huy district; it may be used by rural sector support program (RSSP) which deals with marshland and watershed development.

1.5.3. Academic significance

As for other technical studies, once successful completed, the report will be used by any engineering students or professional as a reference document.

1.6. RESEARCH HYPOTHESIS

This thesis follows the motivation to contribute research results to the scientific community with the objective of assessing the impacts of soil erosion and sediments on water quality and improving the performance and productivity of water treatment plant.

The following main hypotheses is assumed:

- Soil conservation measures could reduce runoff and soil erosion.
- Assessment of sediments could improve both plant performance and water treatment plant productivity

CHAPTER II. LITERATURE REVIEW

Soil erosion is a complex process that results in soil and fertility losses from agricultural land and, ultimately, leads to river sedimentation(Majoro ,2023), water and wind erosion are two main agents that degrade soils, (Balasubramanian ,2017),runoff washes away the soil particles from sloping and bare lands while wind blows away loose and detached soil particles from flat and unprotected lands.

Geologic erosion is a normal process of weathering that generally occurs at low rates in all soils as part of the natural soil-forming processes, magnitude and the impacts of soil erosion on productivity depend on soil profile and horization, terrain, soil management, and climate characteristics, soil erosion is an important social and economic problem and an essential factor in assessing ecosystem health and function, soil erosion is one of the naturally occurring problems in soils, it will affect all landforms, soil erosion may also happen through forces associated with farming activities such as tillage.

Topsoil, which is rich in organic matter, high fertility and soil life, is relocated elsewhere "on-site" where it builds up over time or is carried "off-site" where it fills in drainage channels. Soil erosion reduces cropland productivity, soil erosion contributes to the pollution of adjacent watercourses, wetlands and lakes. (Balasubramanian, 2017).

2.1 DEFINITIONS AND TYPES OF SOIL EROSION

Soil erosion is a natural process of removal of soil material and transportation through the action of erosive agents such as water, wind, gravity, and human disturbance and it has been accelerated by human activities such as intensive agriculture, improper land management, deforestation, and cultivation on steep slopes.

Soil Erosion, whether it is by water, wind or tillage, involves three distinct actions: soil detachment, movement and deposition, accelerated erosion is largely the consequence of human activity, the primary causes are tillage, grazing, and cutting of timber, the rate of erosion can be increased by activities other than those of humans(Ram et al., 2019).

2.1.1 Sheet erosion

Sheet erosion is the removal of a fairly uniform layer of soil by raindrop splash and sheet flow (Oliver et al., 2006), it is defined as detachment of the fairly uniform layer of soil from the land surface by the action of rainfall and runoff. leaf/sheet erosion may not be evident but the soil under erosion of the leaves loses a fine layer of upper fertile soil every time, the flowing water moves in the form of a thin layer on the surface of the ground called the flow of leaves, it moves at a very slow pace.

2.1.2 Splash erosion

Detachment of soil by rain drop impact is the first stage of the soil erosion process by water, splash has more influence on detached soil particles than surface runoff, before the stage of rill and gully erosion is reached, bare soil surface exposed to rain drops changes its structural and hydraulic properties, which remarkably influences soil infiltration, soil water repellency, overland flow, and final soil erosion rates, the main driver for the splash detachment process is the kinetic energy (KE) of rainfall, which depends on the amount, size, and fall velocities of the drops (Zambona et al., 2021).

2.1.3 Rill erosion

Rills are frequently observed on slope farmlands and rill erosion significantly contributes to sediment yields, rill erosion is the elimination of the soil by the flowing water, forming areas of small branched canals.

It is a second phase of erosion and is considered as a transitional phase between the erosion of the sheet and the gully/ravine. (Liyang Sun et al., 2013).

The figure 2.1 describes rill erosion process.

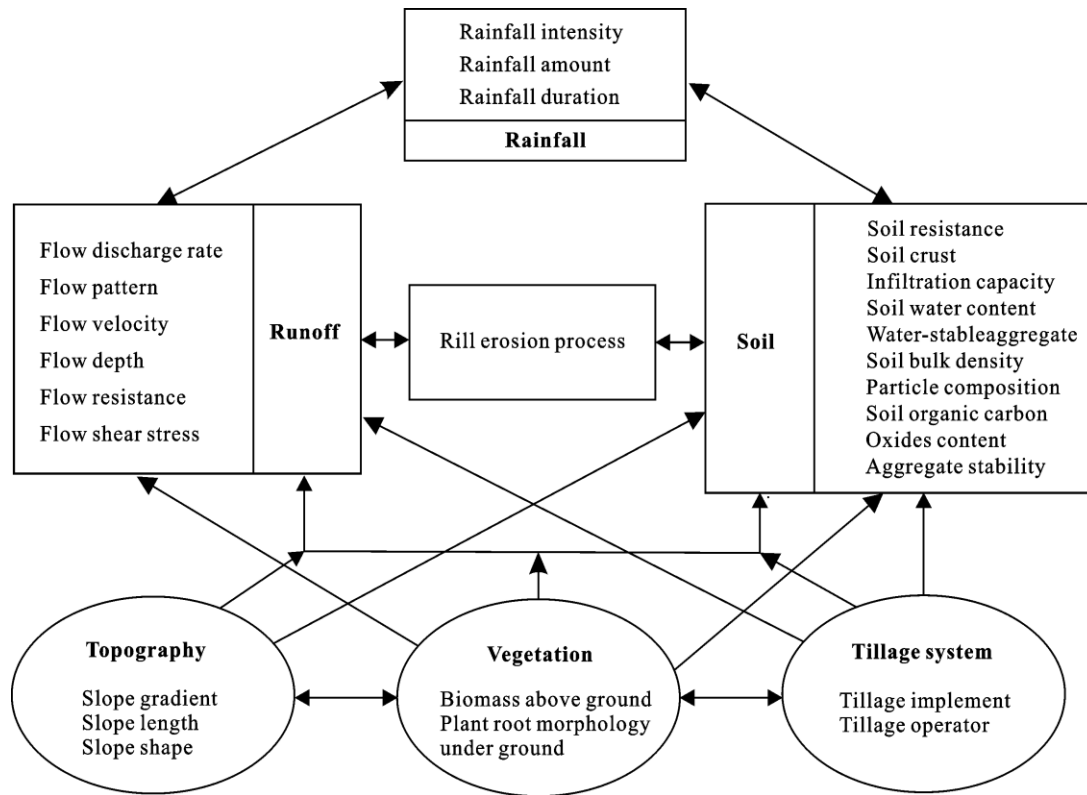


Figure 2.1 Rill erosion

2.1.4 Gully erosion

It is the advanced stage of the erosion of the furrow, it is the last phase of water erosion, when furrows are not cured, they grow in size and become ravines, the speed and degree of development of the canal are directly proportional to the velocity, gullies develop because of a decrease in soil surface resistance to erosion or an increase in the erosive forces acting on the land surface(Muhammad ,2011).

Gully erosion causes severe damage to agricultural lands, including soil loss, increase in surface runoff, lower soil water-holding capacity, lower quality and quantity of water, lower groundwater table, and lower agricultural production, it increased migration from villages to

cities and increased socioeconomic problems and poverty, it also caused substantial damages to construction sites such as bridges, roads, and settlements as well as rivers and reservoirs and increased sediment concentration in rivers.

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It increased migration from villages to cities and increased socioeconomic problems and poverty. It also caused substantial damages to construction sites such as bridges, roads, and settlements as well as rivers and reservoirs and increased sediment concentration in rivers, the figure 2.2 shows the types of water erosion.

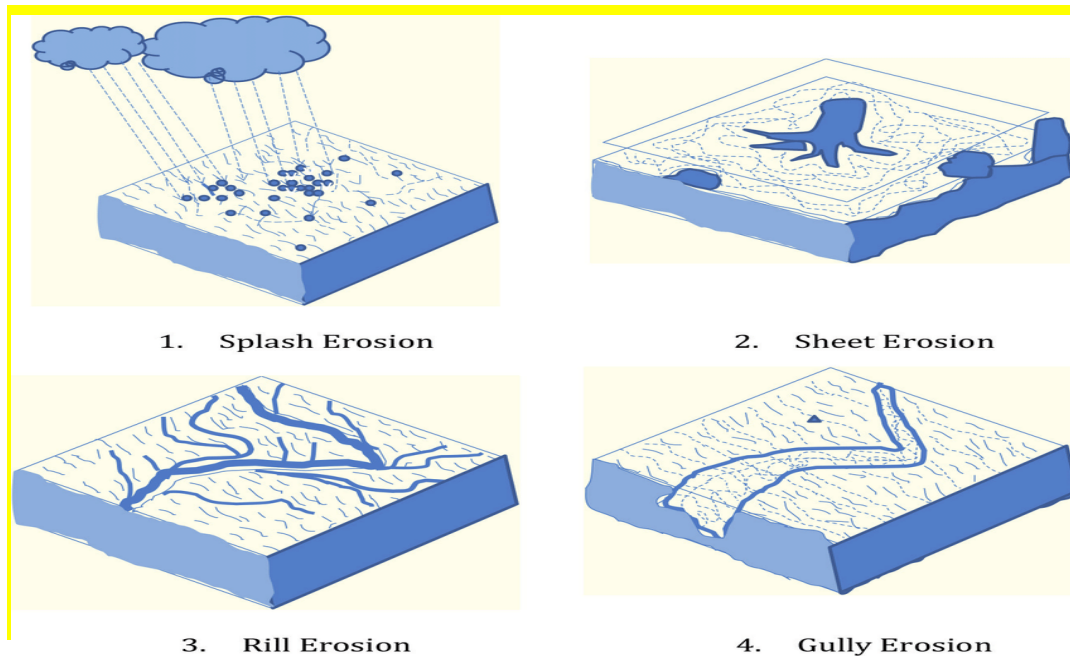


Figure 2.2 Types of water erosion

2.2 CAUSES OF SOIL EROSION

Soil erosion agents could be wind, water, ice, waves, and gravity, depending on external dynamics agent that generates posting, transport, and deposition of soil, the speed and extent of soil erosion are influenced by the intensity of rainfall, runoff, gradient, gradient length, vegetation, and control treatments, soil erosion is affected by natural and anthropogenic factors; natural factors affecting soil erosion are the soil plot, the soil structure, intensity of the rain, slope, type of terrain, climate, erosivity, erodibility, and the degree of land cover with vegetation, but above all, anthropogenic factors, through actions such as land cultivation, deforestation, and construction, are more serious(Chioma et al., 2017).

2.3 FACTORS AFFECTING SOIL EROSION

The soil erosion is strongly influenced by many distinguishable factors, some of them are described below:

2.3.1 The topography

Area of the catchment and the density of drainage are some of the factors linked to topography of catchment, overland flow velocity and consequently shear stress of particles on the surface of the land and capacity of transport are also remarkable factors, slope impacts including shape, gradient, and length of slope, the results of many studies revealed that the value of erosion have been increased by rising in slope gradient.

2.3.2 The soil

Soil has many aspects that impact erosion, such as soil crust, soil resistance, soil water content, infiltration capacity, etc, soil erodibility is defined as the susceptibility of soil to the erosion factors, which is linked with soil properties, containing chemical properties, physical properties, soil structure and texture ,soil physical properties including the soil bulk density, water-stable aggregates, water content of soil, and composition of particle may affect soil infiltration capacity and shear strength of soil and hence impact on rill erosion, soil oxides content and organic carbon content may change tightness of soil which impact soil erodibility, factors of soil erodibility can be obtained immediately from data of soil loss found from costly and time exhaustion process, or in a worst way, by absolutely measured properties for soil, containing clay content, aggregate stability, texture of soil, shear strength of soil, and cohesion strength, the result from some studies showed that the shear strength of soil may be applied as an index for erodibility for soil stability of aggregate have used as factor of soil erodibility by many researchers, they believed that it is more workable and easier to model of erosion prediction.

2.3.3 The land

Land use Soil erosion can be reduced by vegetation, its activity has shown during increasing of the density of roots continuity, rising of canopy and ground cover density, reduced rate of soil erosion can be affected effectively by roots through restricting the mass of soil to raise strength of soil to flow, vegetation recuperation has been utilized extensively for reducing the velocity of water flow and increase the strength of soil since it may increase soil anti-erodibility, soil infiltration, and stability of soil and decrease the erosivity due to rainfall, velocity of flow, and discharge of runoff.

2.3.4 The rainfalls

Raindrops impact is the main function of rainfall effects on erosion, the corrosion-ability of soil because of rainfall has realized as the latent energy onto soil erosion, rainfall affects soil erosion during many related parameters, like intensity of rainfall, amount of rainfall, and duration of rainfall.

2.3.5 The runoff

Sediments can erode and move directly by runoff, it is not difficult to study the effects of runoff functions on soil erosion from view point of dynamics of overland flow, containing pattern of flow, flow discharge rate, flow depth, flow velocity, flow shear stress and flow resistance, many efforts have been made for estimating erosion amounts by means of using the hydraulic parameters of flow, like Froude number and Reynolds number, when rills stand out, significant changes have been shown in hydraulic characteristics of over land, so the flow of rills is different from both river flow and overland flow.

2.3.6 The tillage system

Many actions of tillage have effects on the processes of erosion on cultivated soils, tillage implement using different cutting tools and the type of equipment can change the situations of soil and has potential to trigger rill, processes of tillage have contained tillage speed; tillage depth and frequency have effects on erosion during alteration runoff discharge, soil erodibility, and the infiltrations of soil (Shereen et al., 2021).

2.3 ONSITE AND OFFSITE EFFECTS OF SOIL EROSION

2.3.1 On health of soil

- The main on-site effect of soil erosion on soil is the reduction of soil quality (nutrient loss and decrease in water holding capacity) which significantly leads to the reduced soil productivity. Sediment in rivers is composed mainly by eroded soil and associated pollutants from agriculture and its impact on socio-economic development projects along the river course constitutes the main off-site effect of soil erosion, the removal of topsoil

can lead to compaction and reduced soil aeration, affecting root growth and microorganism activity.

- Erosion can wash away organic matter, essential for maintaining soil structure and fertility, leading to poorer soil health (Israel and Afework 2021).

2.3.2. On People Health

- Erosion can cause sediments to carry harmful pathogens and pollutants into water supplies, leading to outbreaks of diseases such as cholera, typhoid, and dysentery.
- Drinking contaminated water can cause stomach cramps, diarrhea, nausea, and other gastrointestinal problems
- Water erosion can trigger landslides and mudslides, which can lead to injuries or fatalities if they occur near human settlements
- Erosion can undermine roads, bridges, and buildings, leading to accidents and injuries.
- Stagnant water bodies created by erosion can become breeding grounds for mosquitoes, increasing the risk of diseases such as malaria and dengue fever.

2.4 OFF SITE EFFECTS OF SOIL EROSION

2.4.1. On downstream water quality

- High levels of suspended sediments reduce water clarity, affecting photosynthesis in aquatic plants and impairing the vision of aquatic animals.
- Turbid water can be less appealing for recreational activities such as swimming and fishing.
- Sediments can settle on the beds of rivers, lakes, and reservoirs, smothering habitats of fish, invertebrates, and other aquatic organisms
- Eroded soils often carry nutrients like nitrogen and phosphorus into water bodies, leading to excessive algal blooms. These blooms can deplete oxygen in the water, causing dead zones where aquatic life cannot survive
- Eroded soil can transport agricultural chemicals into water bodies, contaminating the water and affecting aquatic life and human health.

- oil erosion can carry heavy metals such as lead, mercury, and cadmium into water bodies, posing risks to both ecosystems and human populations who rely on the water.

2.4.2. On water treatment plant

- Increased sediments can clog intake structures, reducing water flow into the treatment plant and necessitating frequent cleaning
- Sediments can cause abrasive wear on pumps, pipes, and other mechanical components, leading to more frequent repairs and replacements.
- Sediment accumulation in treatment basins and filters can reduce the efficiency of treatment processes, requiring more energy and resources to maintain water quality standards.
- High sediment loads require additional sedimentation and filtration processes, increasing the operational burden and maintenance costs.
- To manage increased turbidity and sediment load, water treatment plants may need to use more coagulants and flocculants, raising chemical costs.

2.4.3. On Bridge and hydropower plant

- Erosion can cause scour around bridge foundations, piers, and abutments, leading to undermining and instability, this can compromise the structural integrity of the bridge, increasing the risk of collapse
- Eroded soil can accumulate in reservoirs, reducing their storage capacity and affecting water supply for power generation, this can lead to decreased efficiency and lower power output.
- Sediments carried by water can cause abrasive wear on turbine blades and other mechanical components, reducing their efficiency and lifespan
- High sediment loads can affect water quality, requiring additional treatment and filtration before it can be used for power generation.
- Regular dredging of reservoirs and intake structures is required to manage sediment accumulation, increasing operational costs.

2.5. EFFECTS OF SEDIMENT ON WATER QUALITY AND AQUATIC ECOSYSTEM

Reservoir sedimentation is filling of the reservoir over a period of time with sediment carried into the reservoir by the flowing water(Zeenat and Mohammad 2018), sediments enter a river either as fragments eroded from rocky channels or in dissolved form, the deposition of sediment into a waterway can significantly diminish the water quality and aquatic habitat, sediment deposition in a waterway makes the water more turbid and does not allow as much light to penetrate the water, this causes problems for aquatic plants that need sunlight in order to perform photosynthesis, deposition of sediment on the stream bottom can lead to the suffocation of fish eggs and benthic macro invertebrates and can cause the destruction of natural spawning substrate, also with an increased amount of particles in the water, dissolved oxygen levels are reduced because of higher water temperatures.

Pesticides, some metals and other toxins may sometimes cling to suspended sediments in water and increase the concentration of toxins in water with high amounts of suspended sediments. Similarly, phosphate can also enter a waterway by attaching to eroded particles.

When in high levels, phosphate in the water can lead to algal blooms and lower the amount of dissolved oxygen in a waterway(Joachim et al., 2014),the impact of erosion on soil and water resources are shown in figure 2.3.

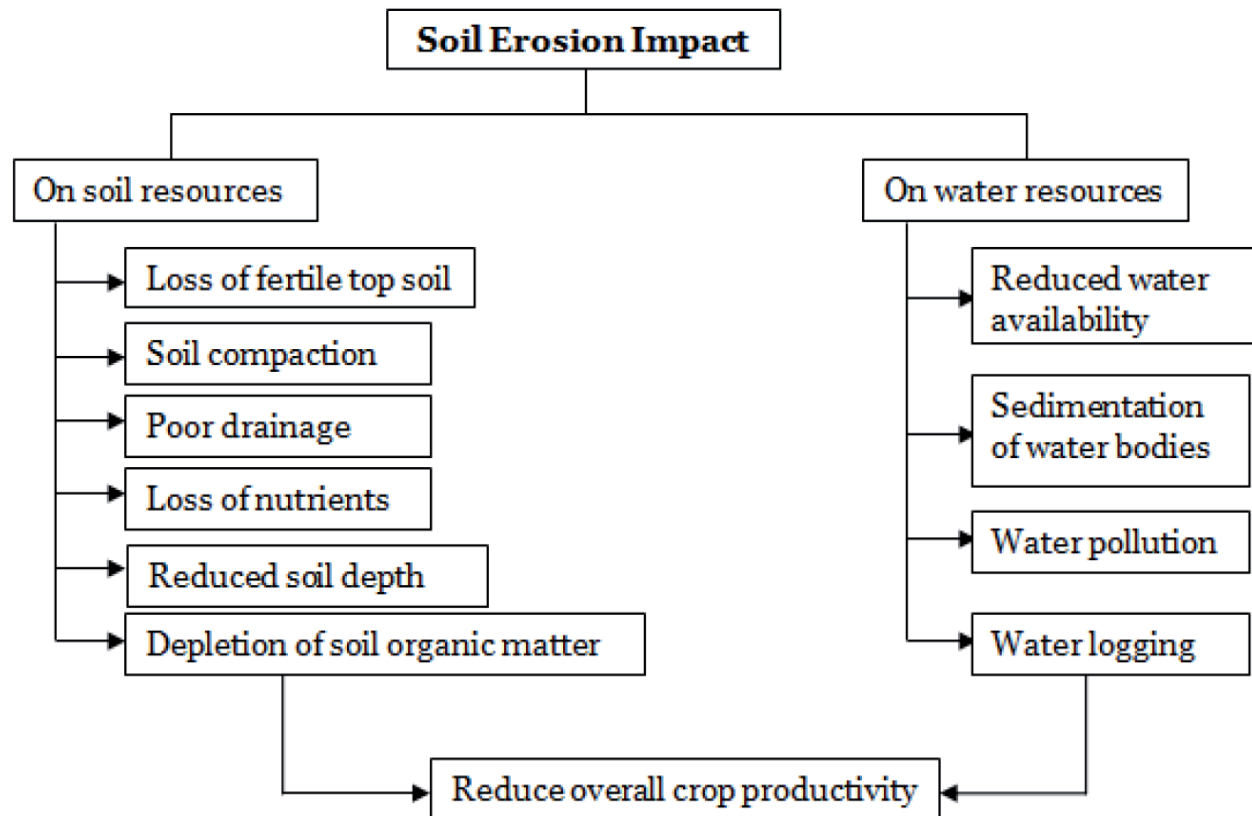


Figure 2.3 Impact of erosion on soil and water resources

2.6 SOIL EROSION MEASUREMENT

Soil erosion model such as the Universal Soil Loss Equation (USLE) and its variations, it is applied in various fields and are valuable tools for understanding, predicting, and managing soil erosion, USLE model is a good example of an empirical model which is well recognized, widely accepted and very much implemented in soil erosion studies(John et al., 2022), soil erosion measurement involves assessing the amount and rate at which soil is being worn away or displaced by various natural forces, such as water, wind, or human activities. Monitoring soil erosion is crucial for understanding and managing soil health, as erosion can lead to the loss of fertile topsoil, negatively impacting agriculture, water quality, and ecosystem stability, accurate and repeatable measurements of erosion processes are required both for understanding and realizing correct modeling, experiments provide an opportunity to investigate to what extent the

concepts used in models are a truly valid descriptions of the erosion processes occurring(Vito and Alessio, 2023).

2.6.1 Erosion Pin

The simplest way of measuring changes in ground level over time, in reality an erosion pin is a 250–300 mm long nail, 5-12 mm in diameter, driven into the soil, the head of the nail should be some 20–30mm above the soil surface and the base of the nail sufficiently far into the ground not to be disturbed by changes in soil volume due to wetting-and-drying (Majoro ,2023).

2.6.2 Erosion Plots

The head of the nail should be some 20–30mm above the soil surface and the base of the nail sufficiently far into the ground not to be disturbed by changes in soil volume due to wetting-and-drying, periodic measurements of the gap between the head of the nail and the ground level indicate the extent to which the surface has been lowered, his method is used to estimate the soil losses and the deposition that occur along the hill slopes of a catchment, a widely used method of quantifying surface erosion is to measure the amount of soil that washes from bounded plots. (Majoro, 2023).

2.6.3 Application of soil erosion models

- **Optimal Planting Strategies:** Soil erosion models help farmers determine the best planting strategies to minimize erosion, such as selecting appropriate crop rotations and cover crops.
- **Conservation Practices:** Models can evaluate the effectiveness of conservation practices like contour farming, strip cropping, and no-till farming
- **Erosion Hotspot Identification:** Soil erosion models help identify critical areas within a watershed that are prone to erosion, allowing for targeted interventions.
- **Sediment Yield Prediction:** Models can predict the amount of sediment that will be delivered to rivers and reservoirs, helping in the design of sediment control structures
- **Storm water Management:** Models help design effective storm water management systems to reduce runoff and erosion in urban areas

2.7 SOIL EROSION CONTROL: BMPS OF SOIL EROSION CONTROL

Soil erosion is the most serious environmental problem in many catchments areas in Rwanda(RWB, 2022), Soil erosion is a naturally occurring process that affects all landforms, the causes and effects should be studied in order to control soil erosion, whether it is by water, wind or tillage, involves three distinct actions ,soil detachment, movement and deposition. Erosion takes place all the time naturally, the erosion potential of any surface is determined by four basic factors: soil characteristics, vegetative cover, topography, and climate, detachment, transport, and deposition are basic processes that occur on upland areas, detachment of soil particles is a function of the erosive forces of raindrop impact and flowing water.

Table 2.1 shows various SEC measures mostly applied on agricultural land

S/N	Purposes	Typical SEC measures
1	BMPs for erosion control on farmlands	Terraces, contour bunds, no-tillage, cover crops, mulching, anti-erosive ditches, strip cropping, crop rotation, agroforestry, stabilizing grasses on farm bunds (vetiver grass, reed, cetaria, tripsacum, paspalum)
2	BMP for slope stabilization	Stabilizing trees (grevelia, bamboo), stabilizing grasses (vetiver grass, reed, cetaria, tripsacum, paspalum, etc.), retaining walls (use of gabions or stones)
3	BMPs for river banks stabilization	Stabilizing trees (grevelia, bamboo), stabilizing grasses (vetiver grass, reed, cetaria, tripsacum, paspalum, etc.), stone revetment, use of riprap, retaining wall (made of gabions); use of sand bags.
4	BMPs for sediments control	Sand trap, sediment basins, constructed wetlands, strip cropping along the river buffer zones; siltation ponds at the end of storm sewers; grassed waterways, protective sediment barriers
5	BMPs to prevent large velocities of runoff	Check dams, grassed waterways, stones blocks in a channel, stilling basins, storm sewer drains, roadside channels, ditches, and hillside water ponds.
6	BMPs to prevent significant volume low rates of runoff	Hillside water ponds, roof runoff and cisterns

Table: 2.1 Various SEC measures mostly applied on agricultural lands

Erosion control measures can be broadly categorized into three main types

- Structural measures
- Vegetative measures
- Management practices measure

2.7.1 Structural Erosion control measures (Hard BMPS)

Silt Fences, the purpose of a silt fence is to retain the soil on disturbed land, the three principal aspects of silt fence design are: proper placement of fencing, adequate amount of fencing, and appropriate materials, a silt fence is a temporary sediment barrier made of porous fabric, it's held up by wooden or metal posts driven into the ground, so it's inexpensive and relatively easy to remove, the fabric ponds sediment-laden storm water runoff, causing sediment to be retained by the settling processes, a temporary barrier of woven geotextile fabric is also used to intercept sediment laden runoff from small areas of soil disturbance, these are temporary barriers made of geotextile fabric, which are installed to trap sediment-laden water and prevent it from flowing into sensitive areas, Riprap, rock pieces are piled up to create a structure called as rip-rap. These are rubble composed of a variety of rock types including limestone and granite, which are used to armor embankments, shorelines, bridge abutments, streambeds and other seaside constructions to prevent soil erosion due to concentrated runoff or other water-related causes.

A limitation of riprap arises when the slopes of the considered area are greater than 2:1; the rubble becomes unstable and is itself prone to erosion, in these circumstances, gabions are used Terracing, building level steps or platforms on slopes to reduce the speed of water runoff and promote infiltration, Retaining wall, Constructing walls to hold back soil and prevent it from being washed away(A. Balasubramanian, 2017).

2.7.2 Vegetative measures for Erosion control (Soft BMPS)

Cover crop: Planting crops that cover and protect the soil, reducing the impact of raindrops and promoting root systems that stabilize the soil, grass Strip Planting strips of grass along the contours of slopes to slow down water flow, trap sediment, and provide stability, reforestation, planting trees and shrubs to establish a root system that helps bind soil particles and reduce

erosion Buffer strips, maintaining natural vegetation along water bodies to filter runoff and reduce sediment and nutrient transport(Sharma and Singh, 2013), contour cultivation ,in the cultivation of contours, all agricultural operations, such as sowing, tillage etc., are executed in the contour of the area, contour cultivation reduces surface flow velocity and delays soil erosion, this involves sowing crops through the slope instead of climbing and descending from the slope(Mehraj et al., 2019).

2.7.3 Management practices Erosion control measures

Crop rotation: alternating the types of crops grown in a field to maintain ground cover and improve soil structure, conservation tillage: Minimizing soil disturbance during planting to reduce erosion and maintain residue cover, mulching: Mulches are loose coverings or sheets of material placed on the surface of cultivated soil, organic mulches also improve the condition of the soil applying a layer of organic or inorganic material on the soil surface to protect it from raindrop impact and reduce runoff (Balasubramanian ,2017).

The figure 2.4 shows the major methods employed in controlling soil erosion with reference to runoff factors.

- Reducing runoff amount
- Reducing runoff velocity.

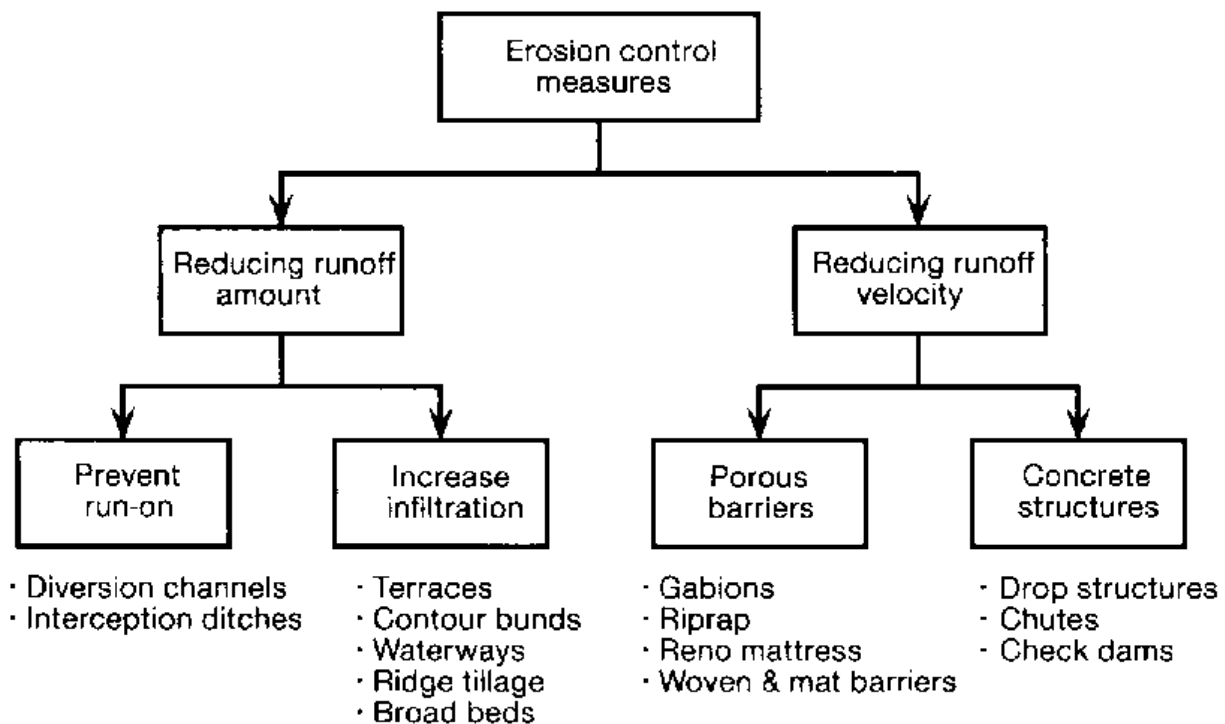


Figure 2.4 Erosion control methods

2.8 FUTURE PERSPECTIVES FOR SOIL AND WATER CONSERVATION

The burgeoning world population, food insecurity and natural resource degradation are the major issues in the present era of climate change. It has been projected that the world population will be ~10 billion in 2050(REMA, 2017), further, the rapid industrial growth and intensive farming practices are expected to increase the pressure on land and water resources in near future. Therefore, a paradigm shift in soil and water conservation, and its management is needed for agricultural sustainability, the some of the future concern for soil and water conservation and sustainable agriculture are the following:

- Formulation of new policies and development of new technologies based on social, economical and cultural aspect of a particular regional.
- Implementation and adoption of effective conservation measures for sustaining agricultural productivity.
- Existing soil and water conservation practices should be improved and developed based on the level of natural resources degradation. Greater emphasis should be given on participatory approach for effective soil and water conservation.
- Post impact assessment and monitoring of soil and water conservation measures should be done to evaluate their efficacy in increasing productivity, monetary returns, and livelihood of the stakeholders.
- Development of cost effective conservation practices to restore the degraded lands and to sustain agricultural productivity.
- The efficient technologies for soil and water conservation should be demonstrated on farmers' fields with their active participation.
- Emphasis on research, education and extension of soil and water conservation effective technologies to the stakeholders.
- Adoption of efficient management practices and judicious use of soil and water resources.(Devideen et al., 2020).

CHAPTER III . MATERIALS AND METHODS

This chapter describes the methods and principles that were used during this study, it is consisting of the description of study area, sample collection, research materials and data analysis methods.

3.1 STUDY AREA DESCRIPTION

Kadahokwa catchment is situated in the Huye district of southern Rwanda figure 3.1, this catchment area lies within the broader Nyabarongo river basin, covers a total surface area of 54.391Km², constituting 0.27% of Rwanda's total land area, which is integral to the region's water management and agricultural activities, the terrain is predominantly hilly with elevation ranging from 1580 to 2191 m and the region is characterized by its fertile soils, supporting diverse agricultural practices. the catchment contributes to the flow of rivers that feed into larger water treatment systems, the area is well-connected by road networks, facilitating access to nearby urban centers such as Butare, the main town in Huye district, the figure 3.1 shows the Kadahokwa catchment map.

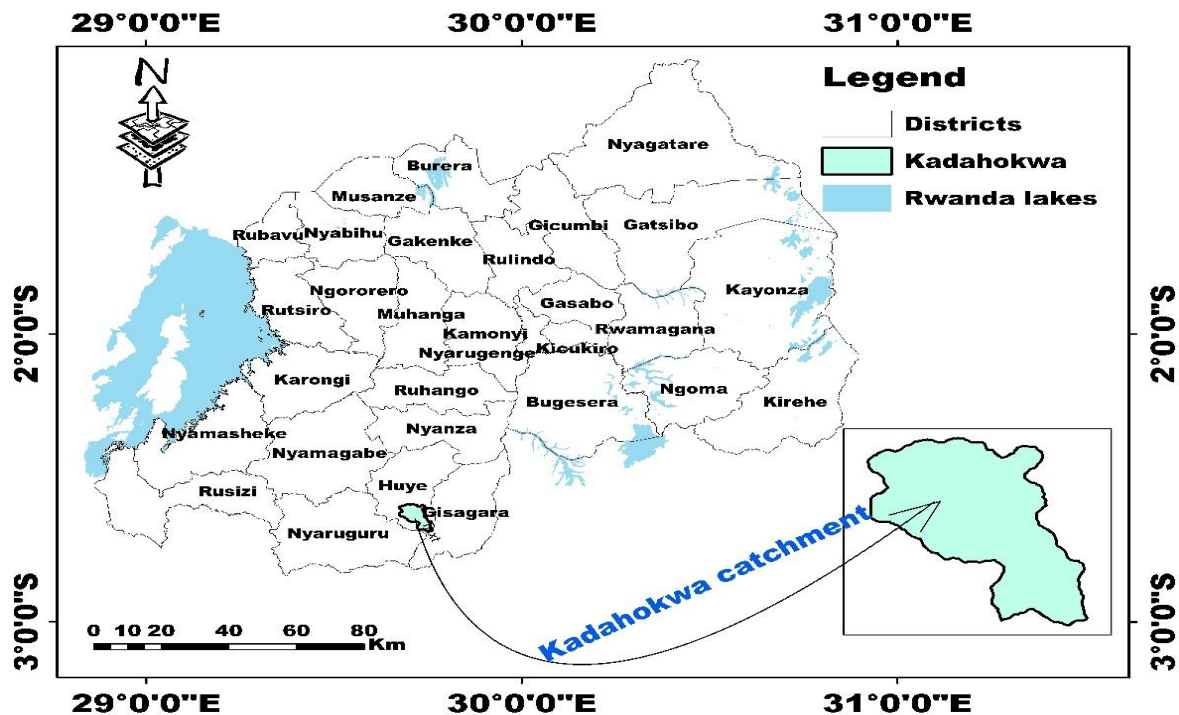


Figure 3.1 Kadahokwa catchment map

3.1.2 Kadahokwa water treatment plant

The Kadahokwa intake is direct river diversion system, the Kadahokwa water treatment plant started operating in 1983, at the beginning the raw water sources were Nyamasharaza, Kabakene, and Kidogo rivers, the discharge was estimated at 65 m³/h. In 1997, the second intake feeding the same water treatment plant was commissioned and the discharge increased to 504 m³/h, raw water reaches the plant by gravity flow, from the Kadahokwa river, water enters intake structures, along the intake structures there are gates that can be opened to allow the sands and other settled materials to be diverted back to river, Kadahokwa river is the surface water, then, when water of better quality is not available, surface water stored in dammed reservoirs often provides the best solution for providing water supplies.

This is particularly true for mountainous areas, where conveying water in tanker trucks from distant areas is the only other option for providing water, especially where groundwater sources of acceptable quality are not available, artificial lakes (often called dams or reservoirs) are created by constructing dams on flowing rivers, and the water impounded in such structures often is used for multiple purposes, if they are present, water also can obtain from natural lakes, the total capacity of dam is 600 thousand cubic meter, and it produces 85 thousand cubic meter per day for treatment, it contains aquatic habitats like fishes, and some aquatic plants (Celestin, 2015).

3.1.3 Population density

The 5th Rwanda population and housing census (PHC5) has enumerated 381,900 residents in Huye district, which represent 12.7 % of the total population of Southern province, the population distribution is slightly more females (193,041) than male(188,859) in Huye district (i.e 50.5% versus 49.5%).Population density is a measurement of population per unit land area, density of population in Huye district is 657pop/km²,Tumba sector is the only sector which has more population density of 2069 Population/km² (NISR, 2022).

3.1.4 Site topography

Huye borders with Nyanza district in the north, Gisagara in the east and south, Nyaruguru in the south west and Nyamagabe in the north west, the hilly landscape protrudes from east to west but develops into a steep hilly and mountainous area as one moves towards the west and north west, the western part of the district has tall undulating mountains, including the famous Huye mountain, the district has rainfall a distribution pattern of 1.200 mm and an average climate of 19 °C(Celestin, 2015).

3.1.5 Rainfall pattern of the site

Huye, Rwanda geographically situated in the highlands of East Africa, is categorized under the Köppen climate classification, in layman's terms, this signifies that Huye possesses a tropical wet and dry or savanna climate, with this type of climate, the weather throughout the year exhibits a distinctive seasonal shift in both rainfall and temperature.

Throughout the year, monthly average temperatures in Huye remain relatively steady, oscillating between 21.3°C (70.3°F) and 24.8°C (76.6°F), temperature highs typically peak at 24.8°C (76.6°F), while temperature lows can dip down to 12.8°C (55°F), humidity also exhibits minor fluctuations, predominantly wavering between 58% and 88%.

3.1.6 Hydrograph of kadahokwa catchment

The Kadahokwa intake is a direct river diversion system, the Kadahokwa water treatment plant started operating in 1983, at the beginning the raw water sources is K a d a h o k w a river, Nyamasharaza, Kabakene, and Kidogo rivers. (Celestin, 2015).

3.2 RESEARCH MATERIALS

During this study, primary and secondary data were used, to obtain primary data, materials used during this study are classified into three categories: the category one is sample collection and preservation materials, the second is in situ or onsite water quality parameters measurement, soil sample measurement (sieve analysis), the third one is the offsite measuring instruments i.e at CST biology ,chemistry and soil laboratories and Kadahokwa water treatment laboratory, the table 3.1 shows the materials used in Laboratory.

S/N	Categories	Measured parameters	Apparatus
1	Sample collection		Plastic container, bag for soil collection and sterilized bottle for raw water sample collection
2	In situ	Turbidity test,	Turbidity meter, Pipettes of measuring cylinders, Stirring rod of magnetic stirrer(if required),Gloves
3	Offsite/in Laboratory	Soil type, raw water quality parameter(E-coli test),pH,TSS,TDS,	Stack of sieves with a cover, Mortar and pestle or a mechanical soil pulverized, Balance, sensitive to 0.1 g, Oven, Mechanical sieve shake, Brush

Table 3.1 Apparatus used in Laboratory

3.3 RESEARCH METHODS

3.3.1. Site visit and observation

Kadahokwa water treatment plant and Kadahokwa intake are located in Mpare cell ,Tumba sector Huye district southern province of Rwanda, it is located in 4km away from University of Rwanda Huye campus and 6km from Butare city, the Kadahokwa water treatment plant was created in 1980 and started working in July 1983, with a treatment capacity of 100m³/day from the stream of kadahokwa located at the latitude and longitude coordinates of -2.642 and

29,7373.it was an extension of Ngoma WTP constructed in 1950 to treat water from Huye source with treatment capacity of 228m³/day.

In 1997, the pumping system (raw water) used from intake had been replaced by the transport by gravity system, In 2005, the kadahokwa WTP rehabilitation and extension works were focused on increasing the overall water treatment capacity, it was constructed in order to supply treated water to Mpare, Tonga and Huye, now it has capacity of 5000m³/day with storage tank of 600m³.

3.3.2. Questionnaire and interviews

The structured interview was conducted to get constructive view from 50 people on the current status of soil erosion rate and implementation of control measures in Kadahokwa catchment, interview was done to Kadahokwa water treatment plant manager as well as to all disciplines involved in all plant such as laboratory staff, plumbers, pump operators and maintenance technicians), interview also done to the people nearest to the catchment who know well erosion issue in catchment, the total respondent are 50,the questionnaire containing 25 questions was used to interview to total number of 50 people, some are plant staff and others are people living near Kadahokwa catchment, interview was done during two days, from 12th to 13th January 2024.

S/N	Kind of people interviewed	District	Sector	Number of interviewees
1	Kadahokwa WTP Staff	Huye	Tumba	5
2	People living around Kadahokwa catchment	Huye	Tumba	45
Total				50

Table 3.2 Type of people interviewed

3.3.3 Soil Sampling and Analysis

Two types of samples (soil sample and raw water sample) were collected in two sites, where soil sample was collected in Kadahokwa catchment while raw water sample was collected in Kadahokwa River.

A. Soil test (Sieve analysis)

Soil sample was collected in Kadahokwa catchment to do the analysis on soil properties by using sieve analysis for the purpose of classifying soil permit much infiltration or not, sieve analysis test was used, this test gave relative proportions of soil particles in a given soil and soil particles are grouped into gravel, sand, silt and clay, this test was performed on disturbed samples taken from Kadahokwa catchment.

Total mass: 2500g, shaking time: 6min, calculation of percentage retained for each sieve, calculation of percentage passing for each sieve(or percent finer) by starting with 100% and subtracting the percentage retained on each sieve as cumulative procedures.

Objective

The sieve analysis determines the grain size distribution curve of soil samples by passing them through a set of sieves of decreasing mesh opening sizes and by measuring the weight retained on each sieve, the sieve analysis is generally applied to the soil fraction larger than 75 μm , grains smaller than 75 μm are sorted by using sedimentation (e.g hydrometer or pipette analysis), sieving can be performed in either wet or dry conditions.

Dry sieving is used only for soils with a negligible amount of plastic fines, such as gravels and clean sands, whereas wet sieving is applied to soils with plastic fines.

Significance

The distribution of different grain sizes affects the engineering properties of soil, grain size analysis provides the grain size distribution, and it is required in classifying the soil into clay, silt, sand, gravel, cobbles and boulders.

This test method is used primarily to grade aggregates; the results are used to determine the compliance of the particle size distribution with applicable specification requirements and to provide necessary data for controlling the production of various aggregate products and mixtures containing aggregates.

The data may also be useful in developing relationships concerning porosity and packing, information obtained from the particle size analysis (uniformity coefficient C_u coefficient of curvature, C_c , and effective size, D_{10} , etc.) is used to classify the soil as clay, silt, sand and gravel, cobbles and boulders.

Particle size is one of the criteria used to ascertain whether the soil is suitable for building roads, embankments, dams, etc.

Information obtained from particle size analysis can be used to predict the soil-water movement if the permeability test is not available.

Apparatus

Stack of sieves with a cover, Mortar and pestle or a mechanical soil pulverizer, Balance, sensitive to 0.1 g, Oven, Mechanical sieve shaker, Brush.

Procedures

- Fit the set of sieves and pan (mesh size) decreasing downward
- Record the weight of the given dry soil sample
- Carefully pour the soil sample into the top sieve and place the cap over it.
- Place the sieve stack in the mechanical shaker for about five minutes.
- Remove the stack from the shaker and carefully weigh and record the weight of retained soil for each sieve.

Data analysis for soil test

- Obtain the mass of soil retained on each sieve by subtracting the weight of the empty sieve from the mass of the sieve + retained soil, and record this mass as the weight

retained on the data sheet. The sum of these retained masses should be approximately equals the initial mass of the soil sample, a loss of more than two percent is unsatisfactory.

- Calculate the percent retained on each sieve $= \frac{\text{weighth Of soil retained}}{\text{total original soil weighth}} \times 100$
- Calculate cumulative retained on any sieve
- Calculate the percent passing (or percent finer) by starting with 100 percent and subtracting the percent retained on each sieve as a cumulative procedure.
- Make a semi logarithmic plot of grain size vs. percent finer.
- Compute C_c and C_u for the soil.

$$C_C = \frac{D_{30}^2}{D_{60} \times D_{10}} \text{ where } C_C : \text{coefficient of gradation or curvature}$$

$$C_u = \frac{D_{60}}{D_{10}} \text{ where } C_u: \text{uniformity coefficient}$$

The value of D_{10} , D_{30} , and D_{60} which are the diameters that correspond to the percentage finer of 10%, 30% and 60%, respectively can be determined from the grain- size distribution curve (Desire et al., 2016).

B. Soil water content test

The moisture content at which the soil will pass from a liquid state to plastic, from a plastic to a semisolid state and from a semisolid state to a solid state is known as the liquid limit, plastic limit, and shrinkage limit respectively, these tests are performed to give the plastic index (IP) and liquid index (IL) of the soil from liquid limit value and plastic limit value (Brendan C, O 2021).

❖ Liquid limit test

liquid (LL) is arbitrarily defined as the water content, in percent, at which a part of soil in a standard cup and cut by a groove of standard dimensions will flow together at the base of the groove for a distance of 13 mm (1/2 in.) when subjected to 25 shocks from the cup being

Dropped 10 mm in a standard liquid limit apparatus operated at a rate of two shocks per second, this method of measuring the liquid limit of soil was refined by (Casagrande ,1932), who standardized the test such that it would give repeatable results and in the process developed the liquid limit test apparatus and procedures currently defined in (ASTM, 2010).

Apparatus

Porcelain evaporating dishes., Spatula, about 3in.(75mm) long and approximately $\frac{3}{4}$ in.(19mm) wide, Balance sensitive to 0.01g, Watering bottle, Drying tares with covers, such as metal cans with lids, which will prevent moisture loss, Mechanical Liquid Limit Device(s), Grooving Tool.

Procedures

- Weigh the mass of moisture cans to be used and recorded as W1.
- 250 g of air-dried soil sample finer than no. 40 (425 μ m) sieve was mixed with water thoroughly to make a smooth paste in a dish.
- The paste prepared in step two was put in the brass cup of the liquid limit device to 8 mm depth approximately and smoothened using a spatula
- Using grooving tool grooves in the centerline of the soil in the brass cup.
- Turned the crank of the liquid limit device at the rate of 2 rev/ sec approximately until both parts of the soil came in contact along about 13mm distance.
- For N (Number of blows) that gave the groove closure of 13mm, took a moist soil sample from the brass cup, put in moisture can for oven drying to obtain moisture content
- The mass of wet soil and can was weighed and recorded as W2.
- The mass of the can and dried soil sample at 105°C after 24 hours in the oven was determined as W3, Procedures from step 3 to 8 were repeated with different moisture content.
- The relationship between moisture content and N (number of blows) was plotted on a semi-log graph.
- The moisture content w (%) tie in with 25 blows is the liquid limit.

❖ Plastic limit test

The plastic limit (PL) is the water content, in percent, at which a soil can no longer be deformed by rolling into 3.2mm (1/8 in.) diameter threads without crumbling. (Brendan C, O 2021).

Apparatus

Liquid limit device, Porcelain (evaporating) dish, Flat grooving tool with gage, Eight moisture cans, Balance, Glass plate, Spatula, Wash bottle filled with distilled water, Drying oven set at 105°C.

Procedures

- Take 40 g of air –dried soil sample passing through No.40 (425micron) I.S sieve was thoroughly mixed with water in a porcelain evaporating dish
- Weigh the mass of moisture cans to be used (W1)
- Allow the soil to dry partially until it becomes plastic enough to be shaped into a ball
- Mould the ball of soil between the fingers and roll it between the palms of the hands until the heat of the hands has dried the soil sufficiently for slight cracks to appear on its surface
- One ellipsoidal-shaped soil mass was rolled using the hand on a glass plate. Use enough pressure to reduce the diameter of the thread to about 3 mm in 5 to 10 complete, forward and back, movements of the hand
- A thread of about 3mm in diameter rolled in step five was broken up into several small fragments.
- The small fragments thread was put in a moisture can and the mass of was weighed and recorded as W2.
- The cans containing the moist soil were put in the oven at 105oC for 24 hours. After the mass of cans and the dry soils was weighed and recorded as W3
- Determine the water content from each trial by using the same method used in the first laboratory. Which calculated as follow: $\frac{w1-w2}{w3}$

Data analysis and interpretation

- Calculate the water content of each of the plastic limit of the moisture cans after removing in the oven for at least 16hours
- calculate the average of the water contents to determine the plastic limit PL. Check to see if the difference between the water contents is greater than the acceptable range of 2 results(2.6).if the 2 or 3 result differ by more than 0.5% moisture , repeat the whole test
- Calculate the plasticity index, $PI = LL - PL$. Report the liquid limit, plastic limit and plasticity index to the nearest whole number. Omitting the percent designation (ASTM 2010).
- Test of some parameters of Water quality

3.3.4 Water sample and Analysis

A. Turbidity Test

Objectives

The turbidity test measures the cloudiness or haziness of a liquid caused by large particles, it is often used in water quality analysis to assess the presence of suspended solids.

Apparatus

Turbidity meter or turbidimeter (can be a handheld device or a laboratory instrument, Sample containers (typically glass or plastic), Distilled water (for calibration if required), Turbidity standards (if required), Pipettes of measuring cylinders, Stirring rod of magnetic stirrer(if required), Gloves and protective eyewear (for safety)

Procedures

- Calibrate the meter or Nephelometer with standard cuvettes or distilled water.
- Fill a cuvette or test cell with your sample water and rinse it 3 times.
- Clean the outside of the cuvette or test cell and avoid fingerprints on it.

Place the cuvette or test cell inside the meter or Nephelometer and take your reading.

Turbidity meter is a complex and delicate instrument which needs to be calibrated before its use, in this study, a 50 ml raw water sample was taken from Kadamukwa intake poured in a turbidity glass which was then placed in the turbidity meter to allow readings of the turbidity values in NTU.

B. Escherichia coli test

Objective: An E-coli test or Escherichia coli test is a microbiological examination that assesses the presence of bacterium e-coli in water sample.

E-coli is commonly used as an indicator organism in water testing because its presence suggests potential fecal contamination and the possible presence of harmful pathogens, the test typically involves collecting a water sample and analyzing it for the presence of E-coli through various methods, such as culture based techniques or molecular methods like polymerase chain reaction PCR, detection of E- coli is significant as it indicate the potential presence of fecal matter and consequently the risk of waterborne diseases.

Apparatus

Microbiological cabinet(Biosafety cabinet),Incubator,Petri Dishes,Agar Plates,Inoculation loop or swab,Microscope.

Procedures

- Prepare agar plates according to the manufacturer's instructions
- Sterilize all equipment that will come into contact with bacterial samples using an autoclave or appropriate sterilization method
- Using aseptic techniques, transfer the bacterial sample onto the agar plates either by streaking with an inoculation loop or swabbing the surface
- Place the inoculated agar plates in the incubator and allow them to grow for a specified period (usually 24-48 hours for E. coli)

- After incubation, observe the agar plates for the presence of bacterial colonies. E. coli colonies typically appear pink on MacConkey agar or have a metallic green sheen on Eosin Methylene Blue agar
- If quantitative analysis is required, count the colonies using a colony counter or by manual enumeration
- Optionally, confirm the identity of the colonies using biochemical tests or molecular techniques such as PCR
- Analyze the results to determine the presence or absence of E. coli and quantify the bacterial load if necessary
- Record the results in a laboratory notebook or electronic database, including the sample ID, date of testing, and any relevant observations.

C. pH (Hydrogen potential) test

Water has a pH of around (7.0), making it neither alkaline nor acidic, alkaline is defined as a pH value greater than (7.0), the power of water to neutralize acids is measured by its alkalinity, the pH scale ranges from (pH = 0 to 14), with anything above (pH = 7.0) being alkaline, and anything below (7.0) being acidic(Heshman et al., 2021).

D. Solids (TSS,TDS)

Solids occur in water either in solution or in suspension, these two types of solids can be identified by using a glass fiber filter that the water sample passes through, by definition, the suspended solids are retained on the top of the filter and the dissolved solids pass through the filter with the water, if the filtered portion of the water sample is placed in a small dish and then evaporated, the solids as a residue, this material is usually called total dissolved solids or TDS

$$\text{Total solid (TS)} = \text{Total dissolved solid (TDS)} + \text{Total suspended solid (TSS)}$$
(Nayla, 2019) ,the level of dissolved oxygen in water is one of the most important parameters in determining its quality, because it indirectly indicates whether there is some kind of pollution, common processes that pollute surface waters include the discharge of organic matter derived from municipal sewage or industrial wastes.

3.3.5 Secondary data collection

Secondary data include on desk view about soil erosion and water treatment in Rwanda, regulations and institutions in charge of water treatment (WASAC Ltd) and soil erosion, the information related to soil erosion rate and soil erosion control in Rwanda has been obtained from different published journal, articles, and from different reports of government bodies like Rwanda water resource board (RWB), REMA.

3.3.6. Results analysis

Results obtained from laboratories and interviews were analyzed using Microsoft excel, and statistical package for social sciences (SPSS) program from international business machine Armonk.

CHAPTER IV . RESULTS AND DISCUSSIONS

This chapter presents the results obtained, the analysis and discussion on the study that was aimed at assessing in details the impacts of soil erosion on water quality at Kadahokwa water treatment plant.

4.1. INTERVIEW'S RESULTS

4.1.1 Identification of the respondents

Among the people surveyed, 60% were female and 40% were men with the ages ranging from 20 to 75 years old, the large number of interviewees were found ranging from 35 to 60 years old and 90% of people interviewed are married, Comparatively, the number of people interviewed ranging from 20-30 years old were young because many of young people was going at school (some studying in Universities others in secondary school) and others are at work, figure 4.1 shows sex percentage of the respondents.

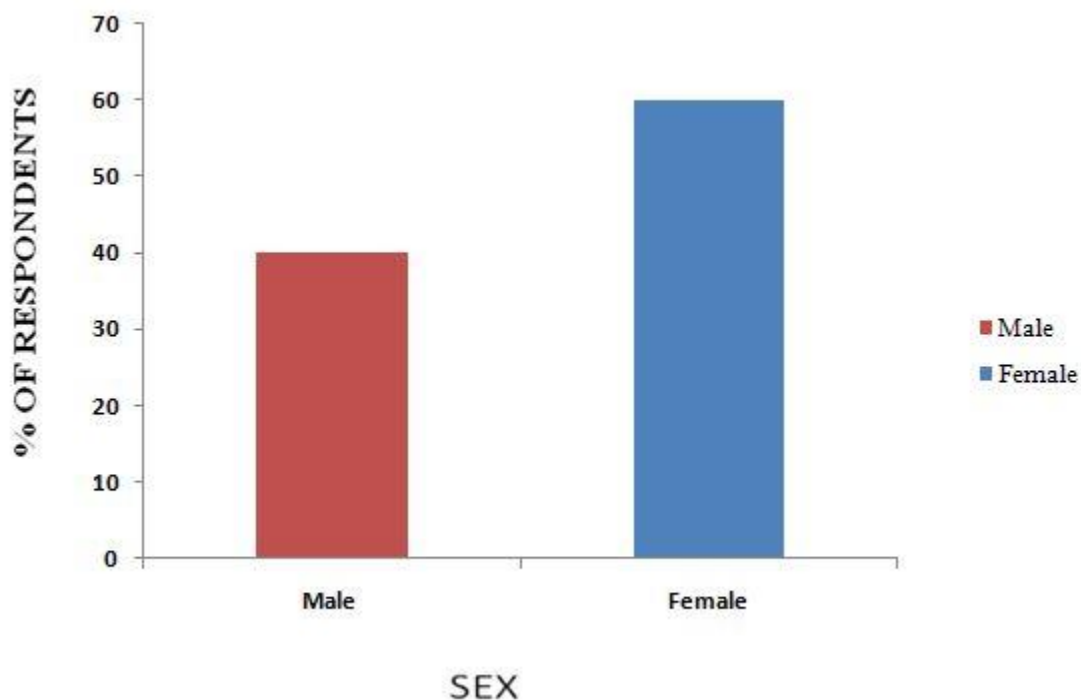


Figure 4.1 Sex percentage of the respondents.

4.1.2 People knowledge about soil erosion in Kadahokwa catchment

Soil erosion is considered to be severe when visible sign such as rills and gullies appear on the field, various signs of soil erosion in Kadahokwa catchment are shown in table 4.1 indicate that soil erosion in Kadahokwa catchment is known almost 100% of people living around the catchment.

S/N	Signs of Erosion	Number of Respondents	%
1	Rain drops which dig holes in the field(Splash erosion)	4	8
2	Channel formation in the fields	8	16
3	Soil detachment by rain and runoff	20	40
4	Soil detachment, transport and deposition of materials	10	20
5	Landslides	4	8
6	Flood: High run off which overtops channels and can damage agriculture crops, lives and properties	4	8
7	Wind erosion: Detachment, transport and deposition of soil materials by wind	0	0
Total		50	100 %

Table 4.1.Tangible indicators(signs)of soil erosion in kadahokwa catchment

The majority of people interviewed argue that the soil erosion appear in form of sheets, rills and gullies erosion as shown in table 4.2

S/N	Type	Number	%
1	Sheet erosion(or inter rill erosion)	12	24
2	Rill erosion	15	30
3	Gully erosion	20	40
4	Stream bank erosion	3	6
Total		50	100%

Table 4.2 Types of soil erosion in kadahokwa catchment

4.1.3 Causes of soil erosion in Kadakokwa catchment

The main cause of soil erosion in Kadahokwa catchment are mostly natural causes such as heavy Rainfall and runoff, which break down and move soil from hillside to catchment, the slope of the land, which affects the speed and direction of water, and anthropogenic activities also cause soil erosion and soil disturbance such as Agriculture, which removes vegetation and exposes soil to water and wind erosion, grazing, which reduces the grass cover and makes soil vulnerable to erosion, logging and mining, which clear the land of trees and disturb the soil structure, construction, which disturbs the natural drainage and compacts the soil, Figure 4.2 shows the main natural causes of soil erosion in Kadahokwa Catchment.

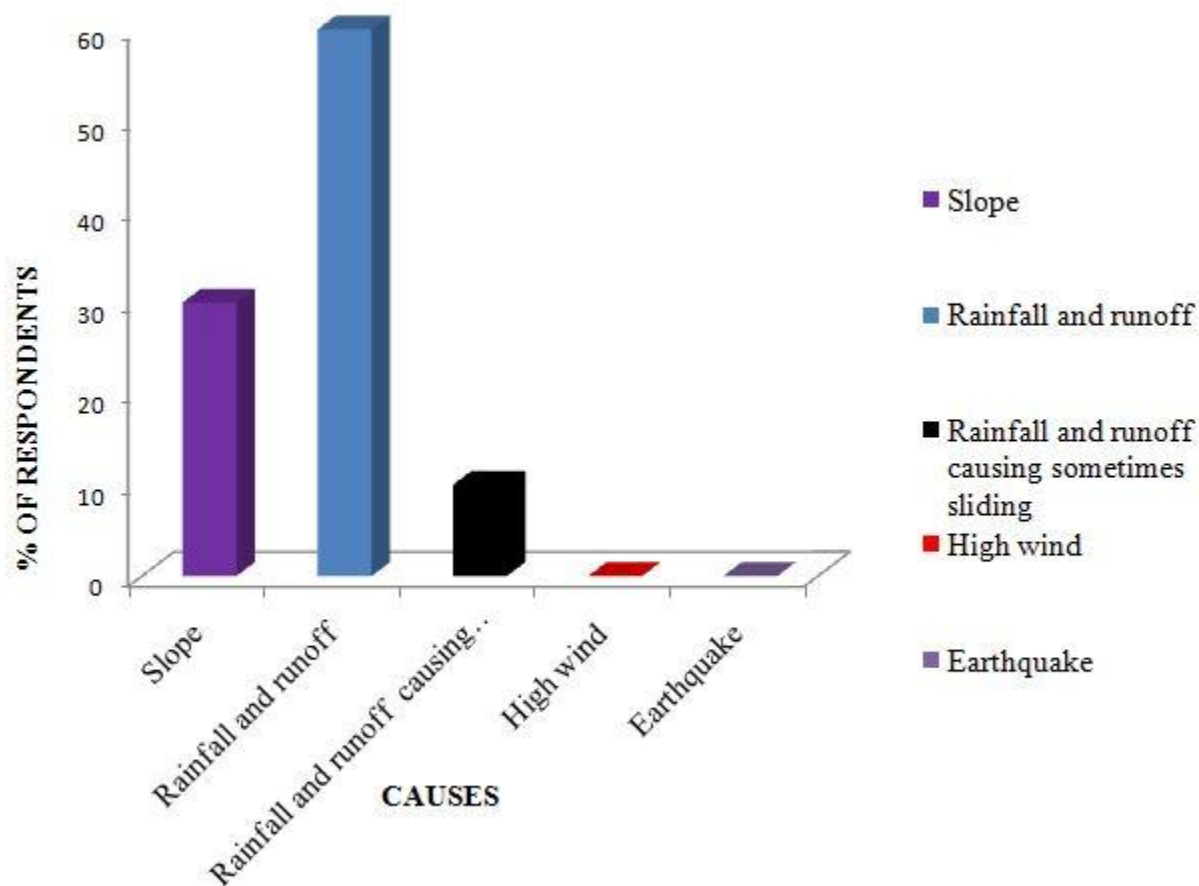


Figure 4.2 Main Causes of soil erosion in Kadahokwa catchment

4.1.4 Effects of soil erosion in Kadakokwa Catchment

Soil erosion has far-reaching consequences, affecting not only land but also water bodies and ecosystems, implementing erosion control measures is essential for maintaining healthy catchment systems and sustainable land management, some of the effects of soil erosion in Kadahokwa catchment are described in table 4.3 such as water quality deterioration, loss of human lives loss of fertile soil and degradation, properties loss, reduced water retention in catchment, wetland degradation.

S/N	Damage	Number	%
1	Loss of human lives	8	16
2	Water quality deterioration	15	30
3	Soil loss due to land slide	8	16
4	Loss of domestic animals	4	8
5	Crops removed with landslide	4	8
6	Crops covered by soil erosion materials	5	10
7	Wetland degradation	6	12
Total		50	100%

Table 4.3.Effects of soil erosion in Kadahokwa catchment

Due to the high slope of the area, the best suitable way to control soil erosion in Kadahokwa catchment, I propose to practice soil erosion control measures such as constructing deep soil erosion control ditches to retain flood, establish buffer strips along water body stream banks and drainage channel within the catchment to help filter sediment, trap pollutants, reduce nutrient runoff, and stabilize banks, thereby reducing erosion and improving water quality , planting vegetation such as grass, trees, shrubs, and cover crops in vulnerable areas within the catchment. Vegetative cover helps stabilize soil, reduce surface runoff, enhance infiltration, and prevent erosion caused by wind and water, construct terraces or bench terraces on steep slopes to create flat areas or steps that intercept and retain water, allowing it to infiltrate slowly into the soil rather than causing rapid runoff and erosion.

By concluding, I recommend Government, NGO to Conduct and participate in awareness campaigns, training sessions, and workshops for landowners, farmers, community members, and local stakeholders on soil conservation practices, erosion control techniques, and the importance of watershed management.

4.1.5 Local community perceptions on Kadahokwa river Floods

Understanding local community perceptions of Kadahokwa river floods is essential for developing effective flood risk management strategies, these perceptions highlight the importance of incorporating local knowledge, building trust between authorities and communities, and ensuring comprehensive education and training programs, addressing these factors can lead to more resilient communities capable of better coping with and recovering from flood events.

- Many community members are well aware of the flood risks posed by the Kadahokwa River, largely due to recurring flood events.
- Knowledge about the causes of flooding varies, with some attributing it to natural factors such as heavy rainfall and others to human activities like deforestation and poor land management
- The severity of floods is perceived differently among community members, influenced by factors such as personal experiences, property damage, and economic losses.
- While some view floods as catastrophic, others consider them a manageable part of life in the region.
- Communities adopt various strategies to prepare for floods, such as building raised platforms, using sandbags, and creating community alerts.
- During flood events, immediate responses include evacuating to higher ground, moving valuables, and seeking assistance from neighbors and authorities.
- Community solidarity is often strong, with residents helping each other in times of crisis.

4.1.6 Local community perception on the impacts of soil erosion on water quality

Soil erosion has become a significant environmental issue in many regions, including the areas surrounding the Kadahokwa river, the perceptions of local communities regarding the impacts of soil erosion on water quality are vital for understanding the broader environmental and health implications, local community perceptions of the impacts of soil erosion on water quality highlight the complex interplay between environmental degradation and human health.

- Many community members are aware of soil erosion and recognize it as a serious problem that affects their daily lives.
- Educational campaigns and government programs also play a role in raising awareness about the issue.
- Community members frequently observe increased sedimentation in local water bodies following heavy rains and soil erosion events.
- Sedimentation is seen as a major issue, as it leads to the clouding of water, which affects its quality and usability for drinking, cooking, and irrigation.
- There is a widespread perception that soil erosion contributes to the contamination of water sources with pollutants such as pesticides, fertilizers, and other chemicals.
- Contaminated water is believed to cause health problems, including gastrointestinal illnesses and skin infections, particularly among children and the elderly
- Residents note that soil erosion negatively impacts aquatic ecosystems, leading to the decline aquatic populations
- Many community members attribute soil erosion to both natural factors (e.g., heavy rainfall) and human activities (e.g., deforestation, improper farming practices).
- There is a sense of shared responsibility, with some residents acknowledging their role in contributing to soil erosion through activities such as farming on steep slopes without adequate soil conservation measures.

4.1.7 Climate changes impacts and mitigation measures at Kadahokwa WTP

Climate change poses significant challenges to water treatment facilities worldwide, and the Kadahokwa Water Treatment Plant is no exception, understanding the impacts of climate change on this plant and implementing effective mitigation measures is crucial for ensuring the continuous supply of safe and clean water.

- Heavy rainfall can lead to flooding, which can damage infrastructure and overwhelm the plant's capacity to treat water effectively.
- Intense rainfall can cause soil erosion, leading to increased sedimentation in water sources, this increases the turbidity of the water, making it more challenging to treat.
- Higher temperatures and irregular rainfall patterns can increase the concentration of pollutants, such as pesticides and industrial runoff, in water sources.
- During dry spells, the plant experiences reduced inflow, which affects its ability to maintain consistent water supply levels.
- Constructing levees, floodwalls, and drainage systems around the plant can help protect it from floodwaters.
- Developing alternative water sources, such as groundwater or rainwater harvesting, can help ensure a more reliable supply during periods of scarcity.
- Implementing watershed management practices, such as reforestation and sustainable agriculture, can reduce soil erosion and improve water quality.
- Educating the community about the impacts of climate change on water resources and the importance of conservation can help reduce demand and improve water use efficiency.
- Working with local governments, NGOs, and other stakeholders can facilitate the sharing of resources and expertise, and promote integrated water resource management.

4.2. KADAHOKWA CATCHMENT SOIL CLASSIFICATION

4.2.1 Sieve analysis test results

This analysis consists of using sieves typically woven wire mesh decreasing in open size to separate or classify a sample by particle size, a known mass of sample is added to the top of sieve, and then dispersed through the mesh opening until a stable mass is reached on each sieve in the stack.

The figure 4.3 shows the particle size distribution curve of Kadahokwa catchment soil.

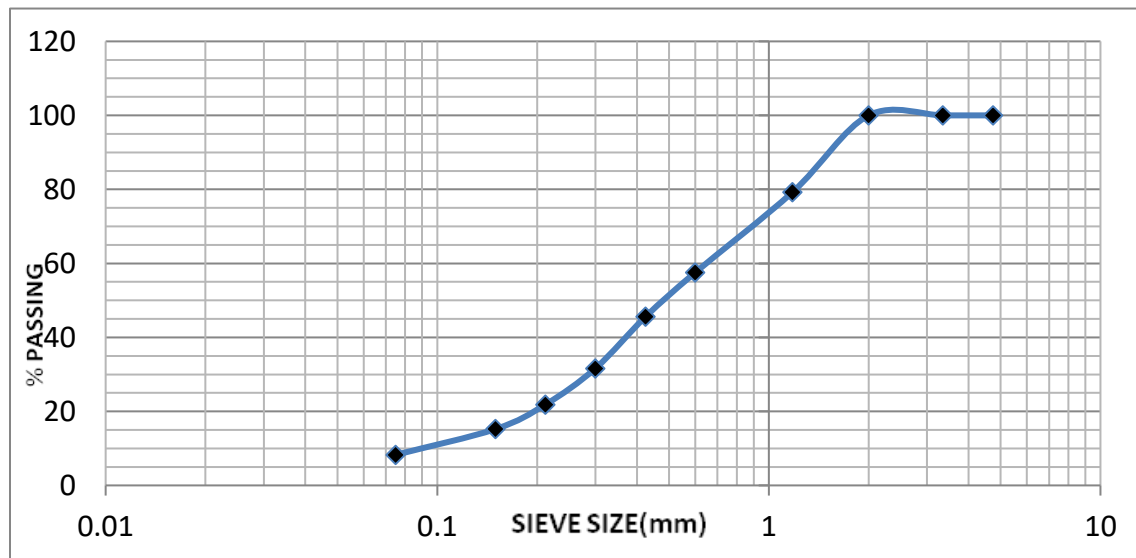


Figure 4.3 Particle size distribution curve

D₁₀ represents the particle size/diameter for which 10% of the sample will finer than it, D₃₀ is the particle size for which 30% of the sample is finer than it, D₆₀ is the particle size for which 60% of the sample is finer than it.

A soil of Kadahokwa catchment is well graded with the coefficient of curvature C_c lies between 1-3, ($C_c=1.53$), with C_u is greater than 6 for sand, ($C_u= 7.2$).

The figure 4.4 shows different soil types which helped to classify the soil of Kadahokwa catchment.

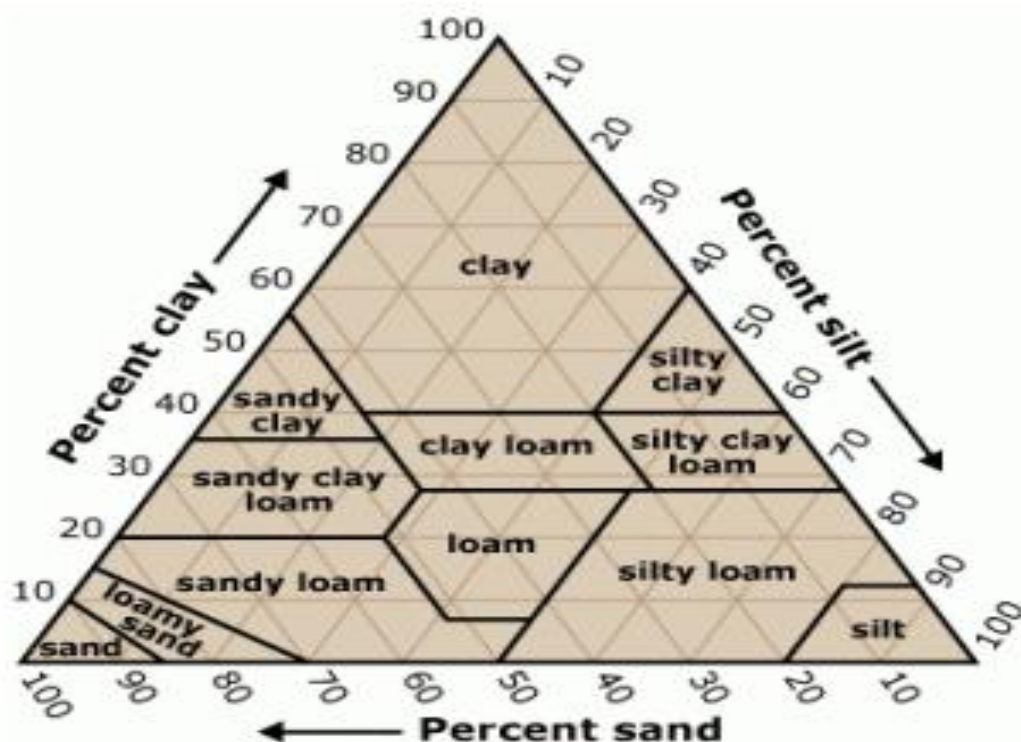


Figure 4.4. Soil classification

By referring to the figure 4.4, the soil type of Kadahokwa catchment is sand clay loam, soil erosion hazard is high on this soil type because of the poor surface soil structure, the presence of non-wetting sands in some places, slope and slope length.

4.2.2 .Liquid Limit (LL)

The moisture content at which soil begins to behave as a liquid material and starts to flow, is liquid limit, the results of moisture content of Kadahokwa catchment soil are shown in figure 4.5.

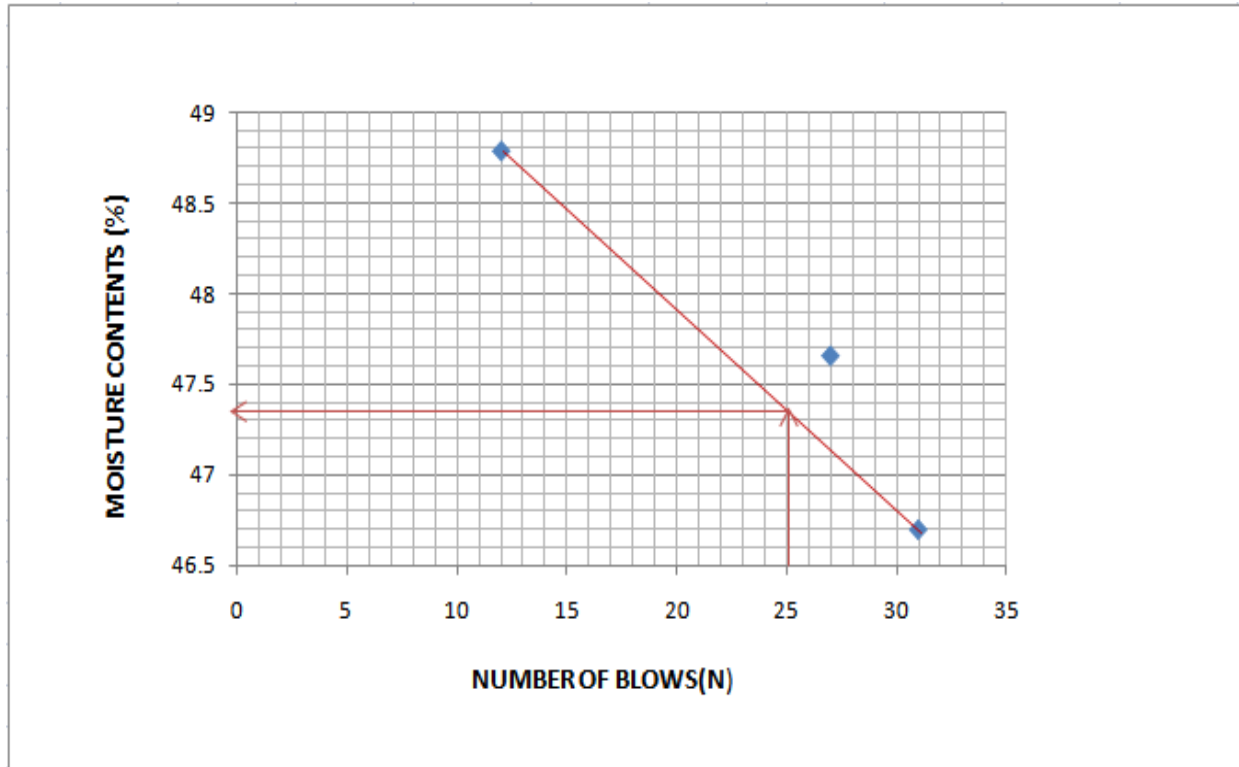


Figure 4.5. Moisture content curve

By using the above curve of liquid limit, it is found that, liquid limit of kadahokwa catchment soil is 47.65.

4.2.3. Plastic Limit (PL)

The moisture content at which soil begins to behave as a plastic material is plastic limit, the plastic limit of Kadahokwa catchment is shown in table 4.4

PLASTIC LIMIT TEST			
Container No.	05	20	40
Mass of container (M_1)	71	81.2	69.4
Mass of wet soil +container(M_2)	86.3	96.2	79.5
Mass of dry soil +container(M_3)	82.68	92.61	77.15
Mass of moisture(M_2-M_3)	3.62	3.59	2.35
Mass of dry soil(M_3-M_1)	11.68	11.41	7.75
Moisture content($(M_2-M_3)/(M_3-M_1)*100$)	30.99	31.46	30.31
Plastic limit is $(30.99+31.46+30.31)/3=30.65\%$			

Table 4.4.Plastic limit

Plasticity index is the difference in water content between the liquid limit and plastic limit of the soil ($PI=LL-PL$)

Where: $LL = 47.65$, $PL = 30.65$, $PI = 47.65 - 30.65 = 17$

The table 4.5 shows the plastic index range(Sobhan.K, 2014)

Plastic index (PI) value	Description
0	Non plastic
1-5 %	Slightly plastic
5-10 %	Low plasticity
10- 20 %	Medium plasticity
20 – 40 %	High plasticity
>40	Very high plasticity

Table 4.5.Range of plastic index(PI)values

According to the range of PI list above show that PI of Kadahokwa rely between 10- 20, with a value of 17 therefore the soil of Kadahokwa is in medium plasticity index, this soil can lead to a decline in soil quality, reduced water retention, increase runoff and sedimentation, soil structure degradation, loss of topsoil and reduction of agriculture potential.

4.2.4 Susceptibility of the soil to water erosion in Kadahokwa catchment

- Steeper slopes of Kadahokwa catchment increase the velocity of surface runoff, leading to higher erosion rates.
- Few Dense vegetation cover ,the impact of raindrops is more efficacy and they are not able to reduces surface runoff
- Soil of Kadahokwa catchment is high proportion of sand and silt which is more prone to erosion compared to clay or coarse sand soils.
- Practices such as deforestation, overgrazing, and poor agricultural practices reduce vegetation cover and increase erosion in Kadahokwa catchment
- The way water flows through a catchment affects erosion ,areas with poor drainage or high runoff rates are more susceptible
- High intensity rainfall events cause more erosion due to the impact of raindrops on the soil and the volume of water

4.3 RAW WATER QUALITY OF KADAHOKWA RIVER

4.3.1 Turbidity test.

Measurement of turbidity reflects the transparency in water. It is caused by the substances present in water in suspension. In natural waters it is caused by clay, silt, organic matter, phytoplankton and other microscopic organisms(Abel, 2018).

The figure 4.6 illustrates the variation of the measured turbidity in Kadahokwa catchment along rain and dry seasons, during rainy season both suspended sediments and turbidity increase due to soil erosion.



Figure 4.6 Turbidity variation in rainy and dry season

The high turbidity of raw water in Kadahokwa catchment in rain season may have been caused by high flow rate during rainfalls that might have carried sediments and other materials into catchment, the results of experiment carried out in Kadahokwa water treatment plant laboratory showed that high turbidity of raw water appears during rainy season as shown in figure 4.5, during rainy season silt, clay and other suspended particles contribute to the turbidity values, while during dry season settlement of clay and silt results to low turbidity values

4.3.2 Escherichia coli test

Escherichia coli are considered as the indicator of fecal matter, these bacteria are very useful in giving us the level of contamination of raw water and treated water, the contamination of raw water was very high in rain seasons compared to dry seasons due to the soil erosion and rainwater runoff from the uphill areas to the Kadahokwa catchment.

The pollution of raw water is enhanced by the rainfall which naturally burdened sediments and other wastes into water courses and this in turn tends to increase the water pollution probability, the figure 4.7 shows the variation of Escherichia coli during RS and DS

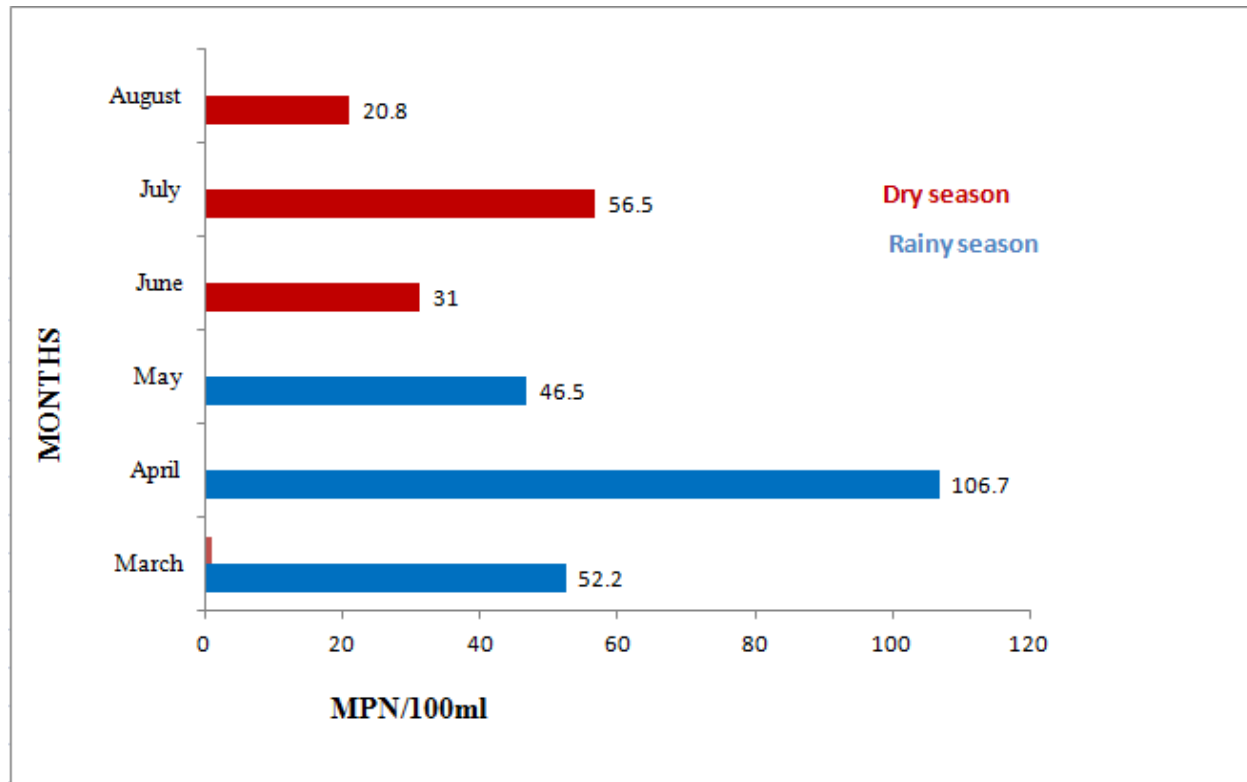


Figure 4.7. Variation of Escherichia coli (MPN/100ml)

According to international standard, the range of Escherichia coli is described below:

- A count of 1–10 MPN/100 ml is regarded as low risk
- 11–100 MPN/100 ml is medium risk.
- E. coli count greater than 100 MPN/100 ml is adjudged high risk.

By referring to the figure 4.6 observation showed that during rainy season, there is increase in concentration of viable microorganisms in water (MPN/100ml) especially in April because MPN/100ml is above the tolerable range and during dry season, the number of microorganisms in raw water reduced, this variation is caused by many factors such as:

- Due to there is no SEC measure appeared, storm water runoff from streets, lawns and uphill around the catchment can carry E-coli from various sources including pet waste and leaking sewage pipe wild animals such as birds can also contribute to E-coli contamination through their droppings.
- Untreated sewage or feces from human and animals, especially in rural area like Kadahokwa catchment, agriculture runoff can carries E-coli from livestock manure into water source or catchment.

4.3.3. pH Test results

pH of raw water during the treatment is essential for the removal of organic compounds and heavy metals, alkaline pH favors the precipitation of most metals in form of insoluble solids, the table 4.6 shows the variation of pH of raw water and treated water in different seasons in 2023.

Rain season			
S/N	Months	pH	
		RW	TW
1	March	7.0	6.9
2	April	7.0	6.8
3	May	7.0	6.86
Dry season			
1	June	7.6	6.83
2	July	7.5	6.80
3	August	7.56	6.99

Table 4.6.Variation of pH in rain and dry season in both raw and treated water

By referring to the table above, the results indicate that the pH levels is increased in rain season more than dry season, it is significantly impacts water quality, highly acidic water tends to have

higher dissolved oxygen levels, higher turbidity and higher chemical oxygen demand, on the other hand highly alkaline water has lower dissolved oxygen levels, lower turbidity and higher conductivity. These findings highlighted the importance of maintaining the optimal pH levels for water quality management, it is important to note that the pH levels in natural water bodies are influenced by various factors including, , soil erosion, geological formation, human activities

4.3.4 Total suspended solid (TSS) test results

Total suspended solids (TSS) are a measure of particulate matter suspended in water (Businge Rachael 2019). TSS also used to describe the extent of pollution in water. It is a good indicator of turbidity of the water, Total suspended solids (TSS) for rainy and dry season are plotted in figure 4.8.

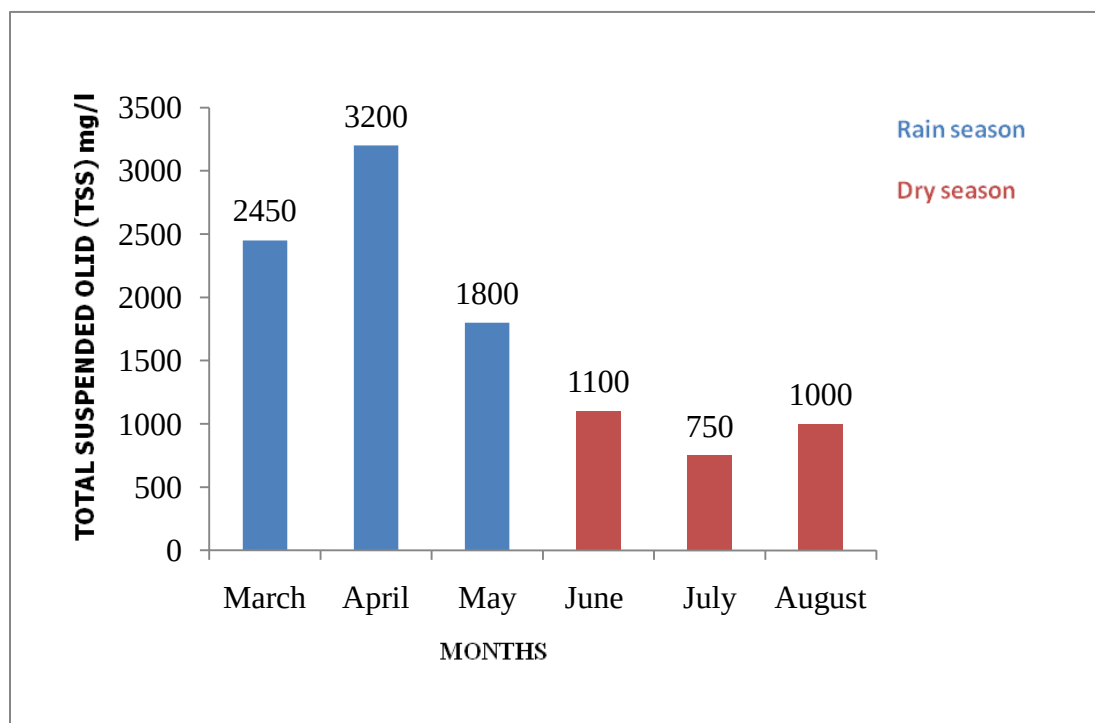


Figure 4.8 Variation of TSS in rain and dry season

The total suspended solid (TSS) values for rainy season are higher compared to the dry season, this increment of TSS in rain season is mainly caused by soil erosion and low conservation measure in Kadahokwa Catchment.

The total suspended solids are critical parameters in the water treatment process as they can significantly impact both treatment process and the quality of treated water:

TSS can cause clogging of filters and membranes, increasing the maintenance requirements and reducing the efficiency of filtration systems, high level of TSS can lead the blockage in pipelines and pumps causing operational disruptions and increased maintenance and treatment costs, suspended solids can interfere with disinfection process by providing shelter to pathogens making harder for disinfectants to reach and kill harmful microorganisms.

Understanding seasonal variation is crucial for water treatment facilities to optimize their operations ensure water quality and treatment costs effectively.

4.4. APPLICATION OF USLE MODEL TO ASSESS SEDIMENT YIELDS

Calculating soil loss using Geographic Information Systems (GIS) involves integrating various spatial data layers and applying erosion models to estimate the amount of soil that is eroded from a particular area, firstly, relevant data layers such as rainfall data, soil type maps, digital elevation models (DEM) for slope maps were corrected from University of Rwanda-Center of Geographical Information System (UR-CGIS) figure 4.9 and Sentinel-2 image for land use/ land cover maps were retrieved from the link: (<https://livingatlas.arcgis.com/landcoverexplorer/>), figure 4.8, these layers provide critical information about the terrain, soil characteristics, land cover, and rainfall patterns, which are essential inputs for erosion modeling.

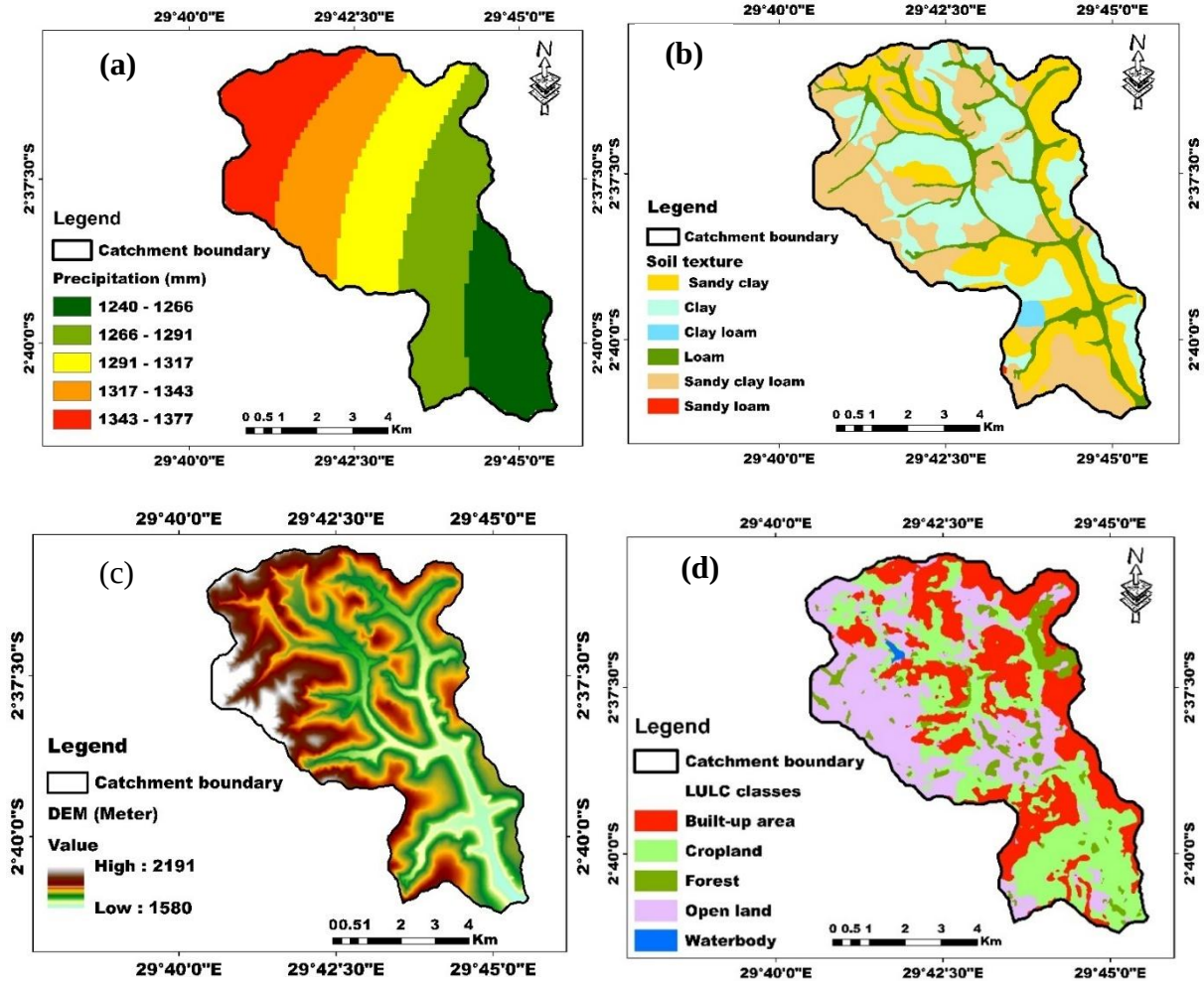


Figure 4.9 (a) Average rain fall,(b) Soil texture,(c)DEM,(d) LULC

Once the data is collected, erosion models such as the Universal Soil Loss Equation (USLE) was employed with GIS, the USLE, is a widely used mathematical model developed to predict long-term average annual soil loss due to sheet and rill erosion caused by rainfall and surface runoff. As presented in Figure 4.8, the equation integrates multiple factors, including rainfall erosivity (R), soil erodibility (K), slope length and steepness (LS), crop management (C), and conservation practices (P) (Girmay et al., 2020), each factor quantifies the influence of specific environmental and management conditions on soil erosion rates, the output typically includes maps indicating soil erosion risk levels, erosion hotspots, and estimated soil loss in terms of tons per hectare per year (t/ha/year).

The USLE equation is a multiplicative function of five factors controlling the rill and inter-rill erosion(Chako et al. 2022) and can be expressed as:

$$A=R*K*LS*C*P \quad \text{Equation(1)}$$

Where, A is the mean annual soil loss expressed in ton/ha/yr, R is rainfall and runoff erosivity index (in MJ*mm/h*yr), K is soil erodibility factor (in ton*ha*h/ha*MJ*mm), LS is sloping Steepness and slope Length factor (dimensionless), C is the cover factor (dimensionless), and P is the conservation practice factor (dimensionless),annual soil loss flow chat is shown in figure 4.10.

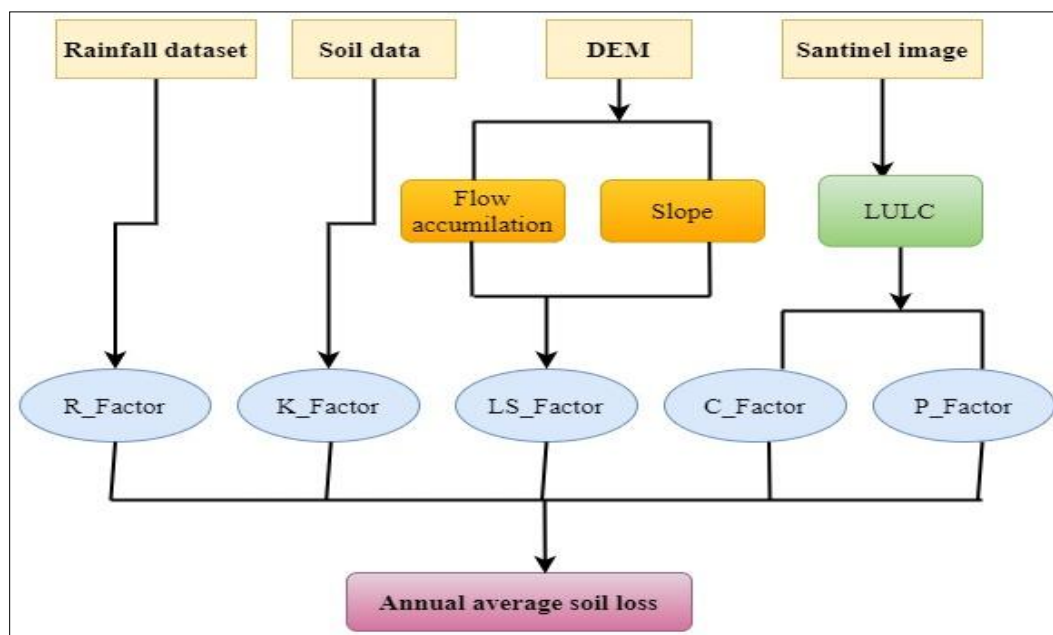


Figure 4.10 Methodological flowchart for preparation of soil loss assessment map

4.4.1 Rainfall erosivity (R) factor

The erosivity factor of rainfall (R) is a function of the falling raindrop and the rainfall intensity, and is the product of kinetic energy of the raindrop and the 30-minute maximum rainfall intensity(Girmay et al., 2020), but in Rwanda context that kind of detailed meteorological data is less available. Therefore, empirical equation proposed by (Benavidez et al. 2018), has been used for estimating annual and seasonal R factors in context of our study area, and it is applicable for areas where annual precipitation ranges from 340 and 3500 mm, Equation (2) was selected

because its range of validity includes all precipitation events of this study (Benavidez et al. 2018), the annual erosion index was as follows:

$$R = 81.5 + 0.38\bar{p} \quad \text{Equation (2)}$$

where: R = rainfall erosivity in MJ·mm·h⁻¹·year⁻¹; P = average precipitation on the parcel in mm, in the present study, R was computed by analyzing the rainfall data available from 10 rain-gauge stations (Kansi, Kigembe, Gakoma, Save, Runyombyi, Cyahinda, Kibeho, Nyakibanda, Karama (Gahororo) and Simbi) located in the Kadahokwa catchment. Spatial distribution of precipitation in the study area is estimated using Kriging method of interpolation by considering 40 years rainfall data for 10 rain-gauge stations, and the R factor is estimated using equation R. The figure 4.8 indicated the spatial distribution of rainfall erosivity of Kadahokwa catchment.

4.4.2 Soil erodibility factor (K)

Determining the soil erodibility factor using soil texture data involves analyzing the composition of soil particles to assess their susceptibility to erosion (Wang et al. 2016). Soil texture data typically categorize soil into various texture classes such as sand, silt, and clay. Each texture class has different properties affecting its erodibility, with finer particles (such as clay) being more prone to erosion than coarser ones (such as sand) (Suraj et al. 2019). On the basis of the Rwanda soil data corrected from University of Rwanda Center of Geographical Information System (UR-CGIS) table 4.8, soil erodibility index factor (K) values of different soil texture of Kadahokwa catchment have been estimated based on different published research and there after the soil erodibility map of the study area has been prepared by plotting the K values on map.

A comprehensive table has been created based on distinctive attributes of various soil texture, and the K values for soil texture have been meticulously determined Table 4.7.

SN	Texture	K-Factor	Reference
1	Loam	0.3	(Oruk et al., 2012)
2	Sandy loam	0.23	(Chaudhary and Kumar 2018)
3	Clay loam	0.31	(Girmay et al., 2020)
4	Clay	0.22	(Oruk et al., 2012)
5	Sandy clay loam	0.2	(Wasie et al., 2020)
6	Sandy clay	0.12	(Emeribeole and Iheaturu 2015)

Table 4.7.K factor values of different soil texture

4.4.3 Topographic Erosivity Factor (LS)

Determining the topographic Erosivity Factor (LS) using GIS involves analyzing the terrain characteristics of a study area to assess its influence on soil erosion. GIS allows for the integration of digital elevation models (DEMs) to derive slope and slope length, key components in calculating LS, firstly, slope is computed from the DEM, representing the steepness of the terrain, with steeper slopes generally associated with higher erosion rates, then, slope length, the distance water travels downslope, is determined, considering the topographic curvature and flow accumulation patterns, using GIS tools, the LS factor is derived by combining slope and slope length, often employing algorithms such as the USLE, the resulting LS factor provides a spatially explicit representation of topographic erosivity, highlighting areas prone to accelerated erosion due to their slope and drainage characteristics.

Topographic erosivity factor (LS) has been considered as one of the most important model parameters in USLE analysis (Khassaf and Al Rammahi ,2021). When the slope length increases, the soil erosion by water also increases as due to the greater accumulation of surface runoff. Slope gradient and slope length factor is calculated from the flow accumulation and slope values (Khassaf and Al Rammahi, 2021).

Finally, the Topographic Erosivity Factor (LS) map has been derived using the following formula in ArcGIS spatial analysis raster calculator function (Bera 2017). $LS = \text{power}(\text{Flow Accumulation} * \text{cell size} / 22.13, 0.4) * \text{power}(\sin(\text{slope}) * 0.01745) / 0.09, 1.3)$

The topographic factor LS is defined as the ratio of soil loss under the given conditions to that at the site with the “standard” slope steepness of 9% and the slope length of 22.13m (Ganasri and Ramesh ,2016). This study used the Equation below for computation of LS based on the upslope contributing area suggested by(Janecek et al., 2015).

$$LS = (As/22.13)^m (\sin \beta / 0.0896)$$

Where **As** is the up slope contributing area per unit width (m), β is the steepest slope angle (radian) and m and n are slope length exponent and slope steepness exponent, respectively. For rill flow, the values of exponents are m = 0.4 and n = 1.3.

4.4.4 Crop Management Factor (C) and Conservation Supporting Practice Factor (P)

The C and P factor is derived from Land use and land cover data prepared from Sentinel-2 of 10 m image Of 2023 downloaded from (<https://livingatlas.arcgis.com/landcoverexplorer/>),The Crop Management Factor (C) and Conservation Supporting Practice Factor (P) are key components used in erosion models like the Universal Soil Loss Equation (USLE) to estimate soil erosion rates. The Crop Management Factor (C) accounts for the influence of different crop management practices on soil erosion. It considers factors such as crop type, tillage methods, residue cover, and crop rotation, with values ranging from 0 to 1, where lower values indicate practices that reduce erosion potential (Panagos et al., 2015). This implies that the soil is well-protected against erosion, either through extensive vegetative cover and residue (C factor). On the other hand, the Conservation Supporting Practice Factor (P) represents the effectiveness of conservation practices in reducing soil erosion, range from 0 to 1 where 0 suggests maximum to effectiveness in erosion control (Ebabu et al., 2022), the C factor indicates the proportion of soil loss from a specific land use type compared to the loss observed in an experimental plot.

The P factor represents the ratio of soil loss from a land utilizing a particular support practice to the loss observed in an experimental plot employing standard agricultural practices (Swarnkar et al., 2018). C and P factor map were prepared on the basis of land use-land cover map of the study area. The land use land cover of the Kadahokwa catchment were classified with six major types of land use-land cover classes. In this study the C and P factor values were determined based on literature review Table 4.8

SN	LULC	C-Factor	Reference	P-Factor	Reference
1	Forest	0.01	(Miheretu and Yimer 2018)	0.001	(Lu et al., 2016)
2	Open land	0.34	(Devatha and Renukaprasad 2015)	0.02	(Molla and Sisheber 2017)
3	Built-up	0.2	(Devatha and Renukaprasad 2015)	0.3	(Kumar and Kushwaha 2013)
4	Cropland	0.5	(Chuenchum et al., 2020a)	0.5	(Chuenchum et al., 2020a)
5	Bare land	0.45	(Girmay et al., 2020)	1	(Gafforov et al., 2020)
6	Water body	0	(Nwaogu et al., 2018)	0	(Gafforov et al., 2020)

Table 4.8. C and P factor values used in the current study

Defining the C factor and P factor for numerous SECM in the Kadahokwa catchment involves measuring the impact of crop cover and Best Management Practices (BMPs) on controlling soil erosion (Panagos et al., 2015). The C factor quantifies the effectiveness of these elements. Table 17 presenting different C values proposed by various researchers (Panagopoulos, 2015), the P factor, which assesses the effectiveness of SECM, BMPs, and cropping patterns in reducing soil erosion, ranges from 0 to 1, with lower values indicating more effective soil conservation practices. Table 17 also provides typical P factor values for different SECM based on literature, highlighting their role in mitigating excessive erosion rates in the Kadahokwa catchment table 4.9.

S. N	Recommended SECM	C	Reference	P	Reference
1	Afforestation	0.02	(Alqurashi and Kumar 2014)	0.001	(Bagarella et al., 2015)
2	Agroforestry	0.08	(Panagos et al. 2015)	0.5	(Sánchez-Bernal et al., 2014)
3	Bamboo to close gullies	0.01	(Endalamaw et al. 2021)	0.5	(Tardio et al. 2018)
4	Contour bank terraces	0.15	(Endalamaw et al. 2021)	0.15	(Kuok et al., 2013)
5	Contour bunds	0.5	(De Roos et al 2017)	0.6	(Kuok et al.,2013)
6	Hedgerows	0.2	(Endalamaw et al. 2021)	0	N/A
7	No-till	0.25	(Panagos et al.,2015)	0.1	(Fiener et al. 2017)
8	Perennial crops	0.23	(Panagos et al., 2015)	0.8	(Duguma,2022)
9	Reforestation	0.02	(Kumar and Kushwaha 2013)	0.001	(Bagarella et al.,2015)
10	River side bamboo	0.01	(Endalamaw et al. 2021)	0.5	(Tardio et al.,2018)
11	Rainwater harvesting tank	0	N/A	0.8	(Chen et al.,2019)
12	Drainage channels	0.58	(Gao et al. 2022)	0.8	(Chen et al. 2019)
13	Dense forest	0.001	(Chuenchum et al.,2020b)	1	(Chuenchum et al.,2020b)

Table 4.9 Crop management factor (C) and erosion control factor (P) for diverse soil erosion control measures.

4.4.5 Estimation of existing soil erosion in the Kadahokwa catchment

The input factors for USLE were incorporated into the ArcGIS 10.8 raster calculator to produce a soil erosion map for the study area (Figure 4.10f). Significant natural contributors to the high soil loss rates in the area include high average annual precipitation of 1302.5 mm and predominantly average slope of 23.31°, the results indicated that the R factor value ranged from 553 to 605 MJ mm/Ha/h/year, with the highest values located in the Northwestern part of the catchment and the lowest in the Southeastern region, the soil erodibility results, represented by the K-factor in the

USLE, reveal the susceptibility of soil in the study area to erosion based on its inherent properties such as texture.

In this study it is ranging from 0.12 to 0.31, with an average of 0.20 (t.ha/ha/mj/mm), soil with high erodibility values are more prone to detachment and transport by rainfall and runoff. Moreover, the topographic Factor (LS) values for the entire catchment ranged from 0.03 to 463.99, longer and steeper slopes significantly increase the velocity and volume of surface runoff, which enhances the soil's detachment and transport capacity. In areas with high LS values, the risk of soil erosion is markedly elevated due to the intensified erosive force exerted by water flow, In additional, crop management considers the protective effects of vegetation cover, and support practice evaluates the effectiveness of soil conservation practices such as terracing or contour farming, together, these factors provide a comprehensive assessment of potential soil loss, allowing for targeted soil conservation measures to mitigate erosion effectively. In this study C-factor and P-factor was chosen based the published literature and the results ranged from 0-0.5 for both C and P, with an average of 0.32 and 0.25 respectively, figures 4.11 show USLE factor maps (a,b,c) and final estimated average annual soil loss (f).

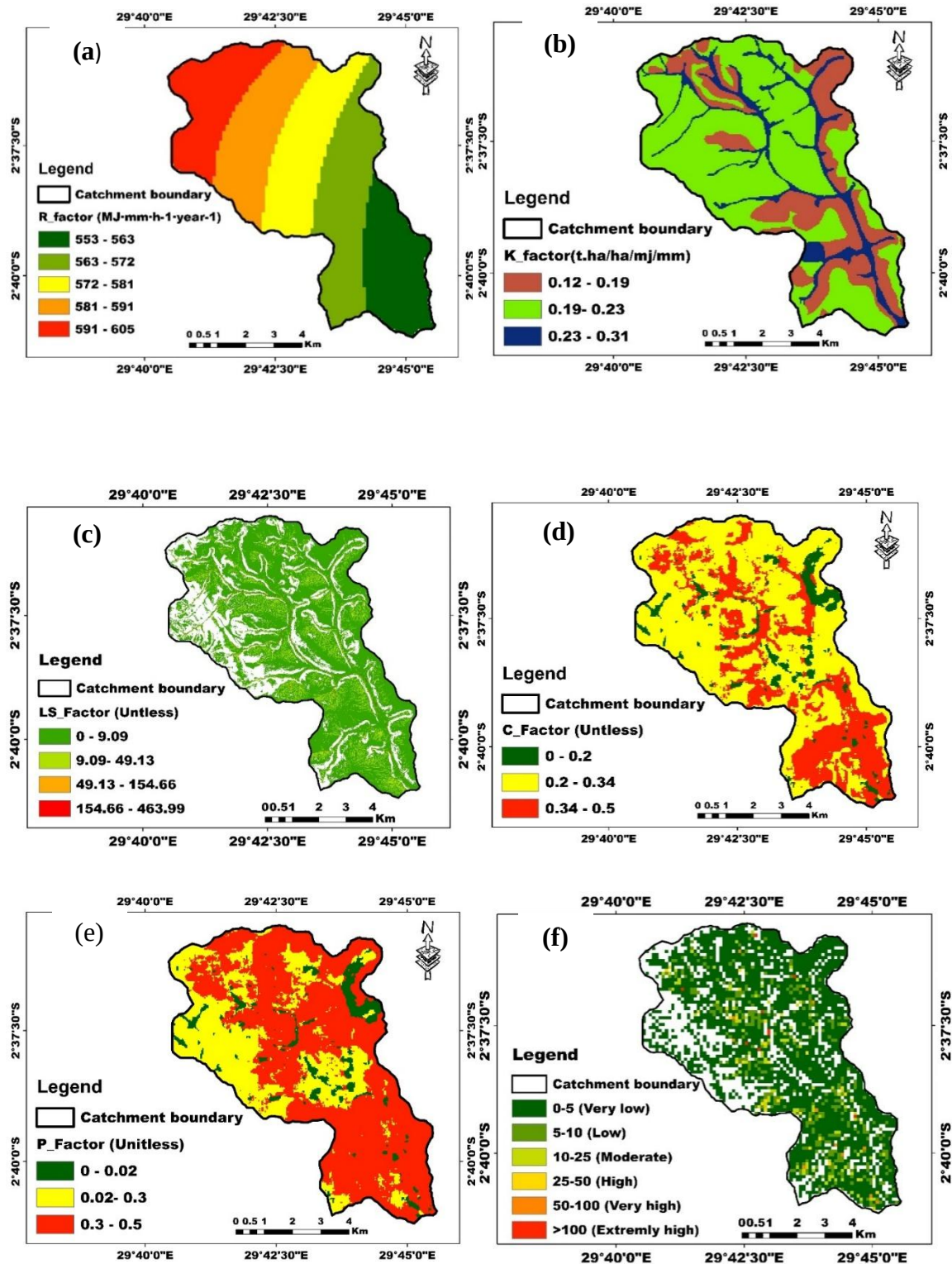


Figure 4.11 USLE Factor maps (a,b,c) and final estimated average annual soil loss(f)

A Rwandan soil erosion risks map was developed and erosion prevention measures were proposed, the Ministry of Environment (MoE) is utilizing the "Catchment Restoration Opportunity Mapping" (CROM) model, created by Environmental Systems Research Institute (ESRI) Rwanda Ltd, to classify soil erosion risks in Rwanda (RWB 2022b). These classification ranges are: 0-5 very low, 5-10 low, 10-25 moderate, 25-50 high, 50-100 very high, and >100 extremely high, the estimated annual average soil loss in Kadahokwa catchment is 56.69 t/ha/yr falling in the range of very high, this is the reason why the effective erosion control measures are required for this study.

4.5 IMPLICATIONS OF SOIL EROSION ON THE PERFORMANCE OF KADAHOKWA WATER TREATMENT PLANT

4.5.1 Relationship between water quality depletion and soil erosion

The relationship between water quality and soil erosion is intrinsically linked, as soil erosion significantly impacts the quality of water in nearby rivers, lakes, and reservoirs (Merz ,2013); (Issaka and Ashraf ,2017), when soil is eroded, particularly from agricultural lands or deforested areas, sediments are carried into water bodies. These sediments can carry nutrients, pesticides, and other pollutants, leading to a decline in water quality (Kaur and Sinha ,2019). High sediment loads can increase turbidity, reducing the amount of sunlight that penetrates the water and disrupting aquatic ecosystems. Additionally, the excess nutrients from eroded soils can cause eutrophication, leading to algal blooms and subsequent oxygen depletion in the water, which negatively affects fish and other aquatic life, Moreover, soil erosion can alter the physical and chemical properties of the water. The introduction of sediments can damage waterways and reservoirs, reducing their capacity and efficiency ((Issaka and Ashraf ,2017) . In agricultural areas, the loss of topsoil reduces the land's productivity, prompting increased use of fertilizers and pesticides to maintain crop yields, which further exacerbates the pollution of water bodies (Majoro et al., 2020). Effective soil conservation practices are thus essential not only for maintaining soil health and agricultural productivity but also for ensuring the quality of water resources, highlighting the need for integrated land and water management strategies.

4.5.2 Water quality fluctuations of Kadahokwa river.

Water quality also comprises the physical, chemical, and biological characteristics of a water body, the water body acquires these characteristics from a suite of complex interactions among the water, atmosphere, soils, and lithology.

Human activities affect both water quality and quantity, human activities also change land use and land cover, which changes the water balance and usually changes the relative importance of processes that control water quality, furthermore, most human activities generate waste ranging from gases to concentrated radioactive wastes (Norman et al., 2006).

Storm water is a leading cause for water pollution. It runs off solid surfaces and collects pollutant such as oil, pesticides, sediments, bacteria, and other chemicals, and then deposits them into Nyasharaza rivers and Kadahokwa reservoirs, Kadahokwa catchment is the only source of water for Kadahokwa water treatment plant.

4.5.3 The effects of raw water quality fluctuation on the performance of Kadahokwa water treatment plant.

The results obtained from the collected data in Kadahokwa office in 2023 and data from the laboratory test done in 2024, showed that the rainy season has more impacts on the produced water, by referring to the rainy and dry season of two successive years 2023 and 2024, i.e from March to May and from June to August, it has seen that the produced treated water in rainy season were diminished comparing to the dry season with the difference of 4400 m³ this decreasing of water produced by the plant is mostly caused by several reasons like soil erosion from uphill to catchment leads to deposition of sediments, organic matters and increase turbidity level of raw water, finally they affect the quality of water and efficiency of treatment plant processes due to it requires more products (sulfates and hypochlorite) in order to disinfect and to make raw water clear as shown in table 4.10.

Year	Seasons	Months	Discharge in m ³	Turbidity (NTU)	AL ₂ (SO ₄) ₃ in Kg	Ca(ClO) ₂ in Kg
2024	Rain season	March	198,977	66.7	3,050	885
		April	187,668	113.64	3,050	895
		May	206,503	98.55	2,950	920
	Dry season	June	206,108	21.49	2,150	885
		July	210,169	13.13	2,200	920
		August	220,794	17.25	2750	904

Table 4.10 Comparison of treated water and sulfate consumed in RS and DS

After referring to the table 4.10, comparing the water produced and sulfate used in rain and dry season , showed clearly the effects of raw water quality fluctuation on the performance of Kadahokwa water treatment plant such as:

- Change in raw water quality, such as variation in turbidity, organic matter contents, PH levels, and presence of contaminants affect the efficiency of treatment processes, for example, high turbidity level of raw water can reduce the effectiveness of filtration
- The fluctuations in raw water quality require adjustments in chemical dosages to maintain treatment i.e higher organic content might necessitate increase coagulant dosage,
- High level of suspended solids in raw water accelerates the clogging of filters.
- Fluctuations in raw water quality can challenge a water treatment plant's ability to consistently meet regulatory standards for treated water quality, this lead to compliance issues and potential fine and sanctions.
- Treating water with varying quality may demand more energy , especially if higher dosages of chemical are needed, this increase operational costs and environmental impacts.

4.6. ADAPTATION STRATEGIES TO MITIGATE THE IMPACT OF SOIL EROSION ON KWTP

4.6.1. Recommended soil erosion control measures and its associated soil loss rates

The study also took advantage of this initiative to gather various shapefiles for existing and site-specific recommended Soil Erosion Control Measures (SECM) from the Rwanda Water Resources Board (RWB), table 4.11 shows the amount of the areas for each site-based soil erosion control measure.

The estimated values of all five USLE parameters are displayed in table 4.12. In addition, table 4.12 demonstrates the approximation erosion rates associated with the proposed SECM in the Kadahokwa catchment.

S. N	Recommended erosion control measures	R	K	L.S	C	P	A (t/ha/yr)	Area covered ai (Ha)	Weighted soil loss (Ai*ai)
1	Afforestation	576.45	0.2	4.44	0.02	0.001	0.010	22.86	0.23
2	Agroforestry	576.45	0.2	4.44	0.08	0.5	20.476	9.01	184.52
3	Bamboo to close gullies	576.45	0.2	4.44	0.01	0.5	2.559	9.17	23.46
4	Contour bank terraces	576.45	0.2	4.44	0.15	0.15	11.517	1445.35	16646.81
5	Contour bunds	576.45	0.2	4.44	0.5	0.6	153.566	10.71	1645.09
6	Hedgerows	576.45	0.2	4.44	0.2	0	0.000	185.97	0.00
7	No-till	576.45	0.2	4.44	0.25	0.1	12.797	48.04	614.82
8	Adequate SEC measures in place	576.45	0.2	4.44	0.22	0.341	38.402	1203.69	46223.84
9	Perennial crops	576.45	0.2	4.44	0.23	0.8	94.187	1.54	145.04
10	Reforestation	576.45	0.2	4.44	0.02	0.001	0.010	126.02	1.29
11	River side bamboo	576.45	0.2	4.44	0.01	0.5	2.559	12.03	30.79
12	Rainwater harvesting pond	576.45	0.2	4.44	0	0.8	0.000	656.02	0.00
13	Drainage channels	576.45	0.2	4.44	0.58	0.8	237.516	0.62	147.52
14	Dense forest	576.45	0.2	4.44	0.001	1	0.512	1708.07	874.34
	Total							5439.11	66537.77
Average soil loss =5439.106/ 66537.77 = 12.23 t/ha/yr									

Table 4.11 Erosion rates induced by the site-based suggested soil erosion control measures in the Kadahokwa catchment.

Figure 4.12 shows numerous site-based SECM recommended to lessen the excessive erosion rates of 56.69 t/ha/y.

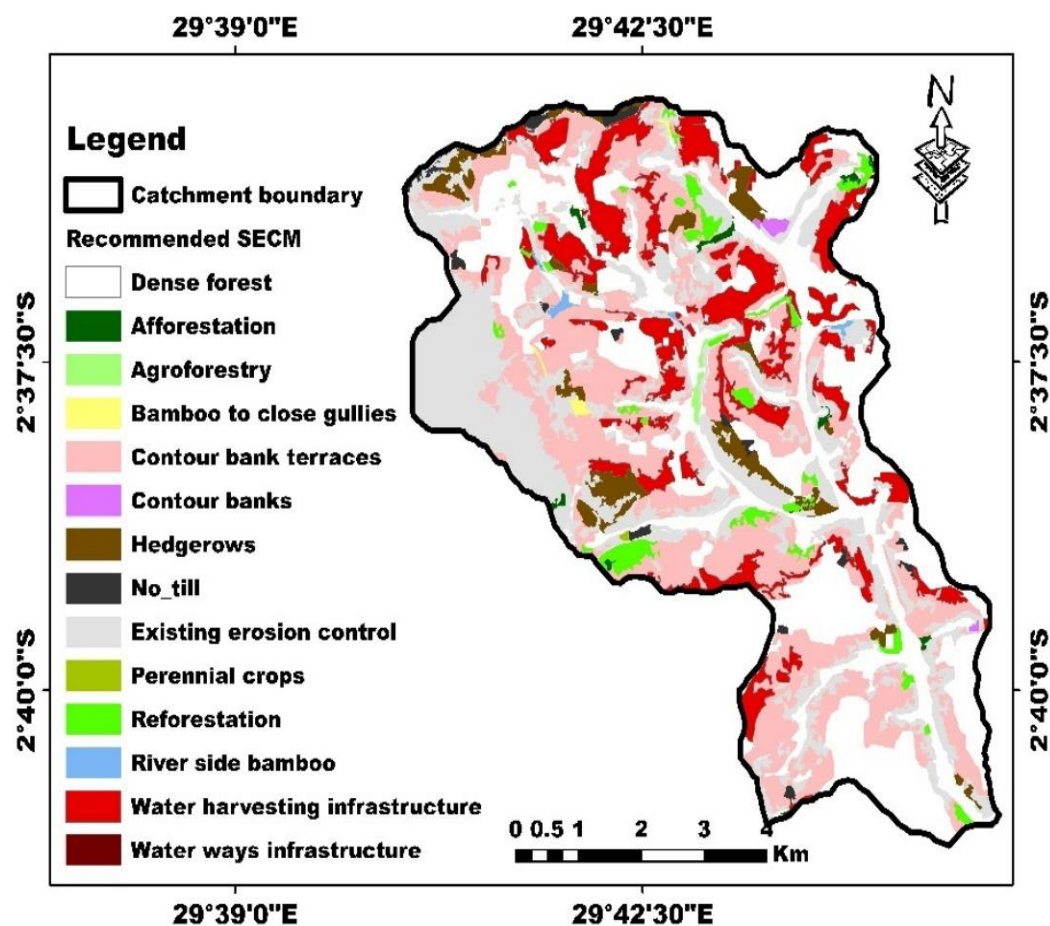


Figure 4.12 Recommended soil erosion control in Kadahokwa catchment

Without implementing proper Best Management Practices (BMPs), soil erosion will continue to escalate over the years. Therefore, continuous improvement in soil erosion control is necessary, and achieving the T-value (the maximum soil loss tolerance rate) may seem like an idealistic goal within the catchment. Using various shapefiles from the Rwanda Water Resources Board, Figure 4.11 shows the simulated site-specific recommended SECM aimed at reducing the high erosion rates tolerant soil loss in the Kadahokwa catchment, the following subsections detail the

procedures adopted for predicting soil erosion rates A (t/ha/y) using the USLE model, defined by its five parameters in A , this study highlights the important of implementing SECM, where the proposed Soil Erosion Control Measures (SECM) effectively reduced soil loss from 56.69 t/ha/y to 12.23 t/ha/y (Table 4.11), achieving a 78.43% efficiency.

Implementing these measures can significantly lower soil loss rates, enhance water infiltration, and improve soil structure, ultimately contributing to sustainable land management and agricultural productivity and increase water quality due to better functioning of water treatment machine.

4.6.2 Tangible strategies for a sustainable performance of Kadahokwa water treatment

The provision of high quality drinking water and assurance of hygienic safety is one of the most basic needs of any society, and hence an essential factor for the sustainable development of rural or municipal areas. Decentralized water management should be seriously taken into account in the present scenario of extremely varying climatic changes and the resulting drying up of the potential water resources of the world (Asha and Pawels ,2022).

To ensure the sustainable performance of water treatment plant, it involves a combination of strategies focused on efficiency, resource management impact.

- Regularly monitor and optimize the treatment processes to ensure that they are operating at peak efficiency, this includes adjusting chemical dosages flow rates, and filtration parameters as needed
- Implement water conservation measures such as recycling and reusing of treated water where possible within the plant, this reduces the overall water demand and promote sustainability
- Regular inspections, preventive maintenance and timely repairs help avoid costly downtime and extend asset life, Implement a proactive maintenance program to ensure equipment reliability and longevity
- Educate the public about water conservation, pollution prevention, and importance of clean water resources.

Consider implementing green infrastructure solution such as rain gardens, forestation, permeable pavement, vegetated swales and construct deep soil erosion control ditches to retain flood in order to manage storm water runoff effectively, this helps to reduce pollution of catchment and protect water quality.

4.6.3 Impacts of soil erosion on Kadahokwa water treatment plant

Water pollution is caused mainly by run off as when it flows, it collects pollutants such as oil, pesticides, sediments, bacteria, and other chemicals, and then deposits them into waterways and may alter aquatic life and make waterways toxic to human life, aquatic ecosystem nutrients create water treatment problems, Soil erosion can create negative impact on water quality and aquatic ecosystems due to the high concentration of sediments and associated nutrients from land into water bodies.

The effects of sediments load on the performance of Kadahokwa water treatment plant are the following:

High turbidity, high cost of coagulants to be used in water treatment, low quantity of water to be supplied, damage of valves and taps, filters blockages and stoppages from working effectively, fills of tanks and pipes with mud and silt and it can also be causing the delay in water treatment (Israel and Afework 2021).

4.6.4 Challenges and barriers to adaptation in mitigating the impact of soil erosion on KWTP

Soil erosion poses a significant threat to the Kadahokwa water treatment plant by increasing sedimentation and degrading water quality, while various mitigation measures can be implemented to address these issues, several challenges and barriers hinder effective adaptation.

- Securing adequate funding for infrastructure upgrades and advanced treatment technologies is often challenging, the costs associated with implementing comprehensive erosion control measures can be prohibitive.

- Competing demands for limited financial resources can result in the prioritization of other urgent needs over long-term investments in soil erosion mitigation.
- Unpredictable weather patterns and extreme events exacerbate soil erosion, making it difficult to plan and implement effective mitigation measures
- The topography and soil composition of the region may inherently contribute to higher rates of erosion, complicating efforts to manage and reduce sedimentation.
- Much of the existing infrastructure may be outdated and not designed to handle the increased sediment loads resulting from soil erosion.
- High levels of poverty and economic pressure can limit the ability of local populations to adopt sustainable land management practices that reduce soil erosion.
- Traditional farming practices and resistance to changing long-established land use patterns can be a barrier to adopting new soil conservation techniques

CHAPTER V. CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

This study was designed to assess the impacts of sediments eroded from hillside and deposited into intake of Kadahokwa water treatment plants ,high turbidity due to soil erosion, how both affects water quality as well as the performance of WWT and to apply mitigation measures for the purpose of obtaining sufficient quality and quantity of water supply.

During this study, qualitative and quantitative data were collected and analyzed, interviews have been conducted and 50 people including Kadahokwa water treatment staff and people living near catchment were interviewed in terms of knowledge of soil erosion, causes ,effects and control measures, the results from interviews showed that the main natural causes of soil erosion in Kadahokwa catchment is heavy rainfall which result runoff (60%) and slope of the terrain (30%),Laboratory experiments were also conducted, the results from sieve analysis showed that sand is dominant in the composition of Kadahokwa river bed load materials where 42.45% is coarse sand,35.69% is medium sand ,6.6% is fine sand and the remaining 15.26% is silt, this affects, the results from TSS,E-coli and turbidity laboratory tests were found to be high in rain season compared to dry season, this difference in both season due to soil erosion which deposit solid particles in catchment, high sediment load and turbidity of raw water affect the efficiency and effectiveness of water treatment plant processes, and increased sediment load and turbidity which require high doses of coagulants and flocculants to effectively aggregate particles for removal,this cause the increase of chemical cost, and lead to inconsistent performance of coagulation and flocculation processes, making it challenging to maintain optimal conditions and achieve desired water quality and quantity, The presence Escherichia coli in raw water leads to the higher dosages of disinfectants like chlorine, longer contact time and it require to use of additional disinfection methods such as ultraviolet(UV) radiation or ozonation which are more expensive.

5.2 RECOMMENDATIONS

Protection of water treatment plant intake from soil erosion is crucial to ensure sustainability and efficiency of water treatment processes, soil erosion lead to turbidity, sedimentation and contamination which can compromise the quality of water entering the water treatment plant, Here are several recommendations to mitigate soil erosion and others issues which can disturb the quality of water in kadahokwa water treatment plant intake:

5.2.1 Recommendation to WASAC Ltd and Kadahokwa water treatment plant Authorities

- Establishing vegetation such as grasses, shrubs and trees on the bank and surrounding areas can stabilize the soil, the root systems of these plants help bind the soil and reducing soil erosion
- Creating buffer strips of native plants along waterways can act as barrier, filtering runoff and trapping sediments before they reach the water intake
- Constructing retaining wall can provide support the steep slope and prevent soil from eroding into the water
- Wire mesh basket filled with rocks (Gabions) can be used to stabilize slopes and prevent soil movement.
- Installing sediment basins upstream of the intake to capture eroded soil particles before they reach into the intake.
- Application of Best Management Practices (BMP) such as contour plowing, no till farming and cover crops, they can reduce runoff and soil erosion.
- Implementing the method of rain water harvesting to reduce the volume and velocity of runoff minimizing erosion potential.

5.2.2 Recommendation local authorities and NGO

- Educating the community about the importance of soil conservation and proper land use practices can foster cooperation in erosion control efforts.
- Advocating for policies and incentives that promote soil conservation practices among land owner and farmers can enhance erosion control efforts.
- Habitation near Kadahokwa catchment must be resettled.

REFERENCES

- A. balasubramanian,. 2017. “Methods of Controlling Soil Erosion. Karnataka, India.”
- Abel Augustine. 2018. “seasonal variation in water quality parameters of river mkomon kwande local government area, nigeria.”
- Alqurashi, Abdullah F, and Lalit Kumar. 2014. “Investigating the Use of Remote Sensing and GIS Techniques to Detect Land Use and Land Cover Change : A Review.” *Advances in Remote Sensing*, no. June 2013. <https://doi.org/10.4236/ars.2013.22022>.
- Asha,Pawels. 2022. “Sustainable Water Treatment Technologies.Cochin,India.”
- ASTM. 2010. *Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils. ASTM Standard D4318-10. American Society for Testing and Materials. West Conshohocken, Pa.*
- Bagarella, G, R Lazzarin, and M Noro. 2015. “ScienceDirect On the Activation Strategy of the Chiller in Water- Loop Self-Contained Refrigeration Systems : An Experimental Analysis Gie d ’ Activation Du Refroidisseur Dans Les Syst e Mes Strat e Boucle d ’ Eau : Analyse Frigorifiques Autonomes a Rimen.” *International Journal of Refrigeration* 57:94–102. <https://doi.org/10.1016/j.ijrefrig.2015.05.003>.
- Balasubramanian. 2017. “Soil Erosion: Causes and Effects. India.”
- Benavidez, Rubianca, Bethanna Jackson, Deborah Maxwell, and Kevin Norton. 2018. “A Review of the (Revised) Universal Soil Loss Equation ((R)USLE): With a View to Increasing Its Global Applicability and Improving Soil Loss Estimates.” *Hydrology and Earth System Sciences* 22 (11): 6059–86. <https://doi.org/10.5194/hess-22-6059-2018>.
- Bera, Amit. 2017. “Estimation of Soil Loss by USLE Model Using GIS and Remote Sensing Techniques: A Case Study of Muhuri River Basin, Tripura, India.” *Eurasian Journal of Soil Science (Ejss)* 6 (3): 206–206. <https://doi.org/10.18393/ejss.288350>.

- Brendan C, O. 2021. “Review of Recent Developments and Understanding of Atterberg Limits Determinations. Dublin.”
- Businge Rachael. 2019. “Comprehensive Assessment of Industrial Wastewater Treatment System at Selected Industries in Rwanda.”
- Casagrande. 1932. “Standard Method of Test for Determining the Liquid Limit of Soils. AASHTO Standard T89-07. American Association of State Highway and Transportation Officials (AASHTO). Washington DC.”
- Celestin,. 2015. “Intenship Report Conducted at Kadahokwa Water Treatment Plant. Huye,Rwanda.”
- Chako, Isaac Chunga, Jean Augustin Rubabura Kituta, Thoko Seunda Banda, Prosper Mweze Rugomba, Victor Mituga Ntwali, Louis Pasteur Mukungilwa Myango, Ghislain Kabumba Rubega, Valery Muhaya Ntamusimwa, and Kavimba Kahindo Jacques. 2022. “Mapping of Soil Erosion Risk in Bukavu (Democratic Republic of Congo): Using RUSLE, Remote Sensing and GIS.” *Open Access Library Journal* 09 (11): 1–21.
<https://doi.org/10.4236/oalib.1109216>.
- Chaudhary, B S, and Sanjeev Kumar. 2018. “Soil Erosion Estimation and Prioritization of Koshalya-Jhajhara Watershed in North India,” no. February 2019.
- Chen, Guokun, Zengxiang Zhang, Qiankun Guo, Xiao Wang, and Qingke Wen. 2019. “Quantitative Assessment of Soil Erosion Based on CSLE and the 2010 National Soil Erosion Survey at Regional Scale in Yunnan Province of China.” *Sustainability (Switzerland)* 11 (12). <https://doi.org/10.3390/su10023252>.
- Chioma et al.,. 2017. “Adaptations to Soil Erosion.Anambra State,Nigeria.”
- Chuenchum, Pavisorn, Mengzhen Xu, and Wenzhe Tang. 2020a. “Estimation of Soil Erosion and Sediment Yield in the Lancang-Mekong River Using the Modified Revised Universal Soil Loss Equation and GIS Techniques.” *Water (Switzerland)* 12 (1).
<https://doi.org/10.3390/w12010135>.

- Desire et al., 2016. “Analysis of Effectiveness of Interdisciplines Involved in Planning, Design, Implementation and Operation and Maintenance of Irrigation and Drainage Project, Eastern Province, Rwanda.”
- Devatha, C P, and M S Renukprasad. 2015. “Estimation of Soil Loss Using USLE Model for Kulhan Watershed , Chattisgarh- A Case Study.” *Aquatic Procedia* 4 (Icwrcoe): 1429–36. <https://doi.org/10.1016/j.aqpro.2015.02.185>.
- Devideen et al., 2020. “Soil and Water Conservation Measures for Agricultural Sustainability. India,” June.
- Duguma, Timketa Adula. 2022. “Soil Erosion Risk Assessment and Treatment Priority Classification : A Case Study on Guder Watersheds , Abay River Basin , Oromia , Ethiopia Heliyon Soil Erosion Risk Assessment and Treatment Priority Classification : A Case Study on Guder Watersheds , .” *Heliyon*, no. August, e10183. <https://doi.org/10.1016/j.heliyon.2022.e10183>.
- Ebabu, Kindiye, Atsushi Tsunekawa, Nigussie Haregeweyn, Mitsuru Tsubo, Enyew Adgo, Ayele Almaw Fenta, Derege Tsegaye Meshesha, et al. 2022. “Global Analysis of Cover Management and Support Practice Factors That Control Soil Erosion and Conservation.” *International Soil and Water Conservation Research* 10 (2): 161–76. <https://doi.org/10.1016/j.iswcr.2021.12.002>.
- Emeribeole, Augustine C, and Chima J Iheaturu. 2015. “Mapping of Potential Soil Erosion Risk Areas in IMO State Using the Revised Universal Soil Loss Equation (RUSLE), Remote Sensing (RS) and Geospatial Information System (GIS) Techniques.” *INTERNATIONAL JOURNAL FOR RESEARCH IN EMERGING SCIENCE AND TECHNOLOGY*, 2 (10): 36–44.
- Endalamaw, Nega T, Mamaru A Moges, Yadeta S Kebede, Bekalu M Alehegn, and Berhanu G Sinshaw. 2021. “Potential Soil Loss Estimation for Conservation Planning , Upper Blue Nile.” *Environmental Challenges* 5 (July): 100224. <https://doi.org/10.1016/j.envc.2021.100224>.

- Fiener, Peter, Karl Auerswald, J. Delgado, G. Sassenrath, and T. Mueller. 2017. "Grassed Waterways," 131–50. <https://doi.org/10.2134/agronmonogr59.2013.0021>.
- Gafforov, Khusen Sh, Anming Bao, Shavkat Rakhimov, Tie Liu, Farkhod Abdullaev, Liangliang Jiang, Khaydar Durdiev, Eldiir Duulatov, Moldir Rakhimova, and Yerbolat Mukanov. 2020. "The Assessment of Climate Change on Rainfall-Runoff Erosivity in the Chirchik-Akhangaran Basin, Uzbekistan." *Sustainability (Switzerland)* 12 (8). <https://doi.org/10.3390/SU12083369>.
- Ganasri, B. P., and H. Ramesh. 2016. "Assessment of Soil Erosion by RUSLE Model Using Remote Sensing and GIS - A Case Study of Nethravathi Basin." *Geoscience Frontiers* 7 (6): 953–61. <https://doi.org/10.1016/j.gsf.2015.10.007>.
- Gao, Zechao, Qinxue Xu, Qin Si, Shuaipu Zhang, Zhiyong Fu, and Hongsong Chen. 2022. "Effects of Different Straw Mulch Rates on the Runoff and Sediment Yield of Young Citrus Orchards with Lime Soil and Red Soil under Simulated Rainfall Conditions in Southwest China." *Water*.
- Girmay, Gebrehana, Awdenegest Moges, and Alemayehu Muluneh. 2020. "Estimation of Soil Loss Rate Using the USLE Model for Agewmariyam Watershed , Northern." *Agriculture & Food Security*, 1–12. <https://doi.org/10.1186/s40066-020-00262-w>.
- Heshman et al.,. 2021. "Drinking Water Treatment: pH Adjustment Using Natural Physical Field."
- Israel,Afework. 2021. "Onsite and Offsiteeffects of Soilerosion. Mizan-Aman, Ethiopia."
- Issaka, Sakinatu, and Muhammad Aqeel Ashraf. 2017. "Impact of Soil Erosion and Degradation on Water Quality: A Review." *Geology, Ecology, and Landscapes* 1 (1): 1–11. <https://doi.org/10.1080/24749508.2017.1301053>.
- Janecek et al.,. 2015. "Comparison of Different Approaches to LS Factor Calculations Based on a Measured Soil Loss under Simulated Rainfall Michaela." *Soil & Water Res.*, 2–9." In .

- Joachim et al., 2014. “Effects of Soil Erosion and Sediment Deposition on Surface Water Quality. Owerri, Nigeria.”
- John et al., 2022. “Soil Loss Assessment Using the Revised Universal Soil Loss Equation (USLE) Model. Kilifi, Kenya.”
- Kaur, Tejinder, and Anil Kishore Sinha. 2019. “Pesticides in Agricultural Run Offs Affecting Water Resources: A Study of Punjab (India).” *Agricultural Sciences* 10 (10): 1381–95. <https://doi.org/10.4236/as.2019.1010101>.
- Khassaf, Saleh, and Ali Al Rammahi. 2021. “Estimation of Slope Length Factor (L) and Slope Steepness Factor (S) of Rusle Equation in the Euphrates River Watershed By Gis Modeling.” *Kufa Journal of Engineering* 9 (3): 81–91. <https://doi.org/10.30572/2018/kje/090307>.
- Kumar, Suresh, and S P S Kushwaha. 2013. “Modelling Soil Erosion Risk Based on RUSLE-3D Using GIS in a Shivalik Sub-Watershed.” *J. Earth Syst. Sci* 122 (2): 389–98.
- Kuok, KK.K, Darrien, Y. S, P Mah, and C. Chiu. 2013. “Evaluation of C and P Factors in Universal Soil Loss Equation on Trapping Sediment : Case Study of Santubong River.” *Journal of Water Resource and Protection* 2013 (December): 1149–54.
- Liyong Sun et al., 2013. “Rill Erosion Process and Its Influencing Factors. Yangling 712100, China.”
- Lu, Jacqueline W.T., Erika S. Svendsen, Lindsay K. Campbell, Jennifer Greenfeld, Jessie Braden, Kristen L. King, and Nancy Falxa-Raymond. 2016. “Biological, Social, and Urban Design Factors Affecting Young Street Tree Mortality in New York City.” *Urban Forests: Ecosystem Services and Management* 3 (1): 211–32. <https://doi.org/10.15365/cate.3152010>.
- Majoro. 2023. “Soil Erosion Potential and Its Control i the Sebeya Catchment, Rwanda.”

- Majoro et al., 2020. “Sediment Transport and Its Impacts on Lake Kivu, Gihira Water Treatment Plant and Various Hydropower Plants along Se-Beya River in Rwanda.”
- Majoro, Félicien, Umaru Garba Wali, Omar Munyaneza, François-Xavier Naramabuye, and Concilie Mukamwambali. 2020. “On-Site and Off-Site Effects of Soil Erosion: Causal Analysis and Remedial Measures in Agricultural Land - a Review.” *Rwanda Journal of Engineering, Science, Technology and Environment* 3 (2): 1–19.
<https://doi.org/10.4314/rjeste.v3i2.1>.
- Mehraj et al., 2019. “Soil Erosion and Management Strategies.Kansas,USA.”
- Merz, Sinclair Knight. 2013. “Characterising the Relationship between Water Quality and Water Quantity.” *Water Quality Australia*, no. August, 1–116.
- Miheretu, Birhan Asmame, and Assefa Abegaz Yimer. 2018. “Estimating Soil Loss for Sustainable Land Management Planning at the Gelana Sub-Watershed, Northern Highlands of Ethiopia.” *International Journal of River Basin Management* 16 (1): 41–50.
<https://doi.org/10.1080/15715124.2017.1351978>.
- Molla, Tegegne, and Biniyam Sisheber. 2017. “Estimating Soil Erosion Risk and Evaluating Erosion Control Measures for Soil Conservation Planning at Koga Watershed in the Highlands of Ethiopia.” *Solid Earth* 8 (1): 13–25. <https://doi.org/10.5194/se-8-13-2017>.
- Muhammad. 2011. “Causes and Effects of Gully Erosion on Agricultural Lands and the Environment.Arizona ,USA.”
- National institute of statistics of Rwanda(NISR). 2022. “Fifth Population and Housing Census,.”
- Nayla. 2019. “Water Quality Parameters.Khartoum,Soudan.” In .
- Norman et al., 2006. “Effects of Human Activities on Water Quality,Georgia.”
- Nwaogu, Chukwudi, Onyedikachi Joshua Okeke, and Simon Assuah Adu. 2018. “GIS Ostrava 2017 – Dynamics in GIScience risk management as a stimulus for a settlement and

- landscape transformation? soil erosion threat assessment in the fields of four deserted villages based on lidar-derived DEMs and ‘USLE.’” *Springer International Publishing AG*, no. February. <https://doi.org/10.1007/978-3-319-61297-3>.
- Oliver et al.,. 2006. “Sheet and Rill Erosion,France.”
- Oruk, Egbai J., Ndik J. Eric, and A U. Ogogo. 2012. “Influence of Soil Textural Properties and Land Use Cover Type on Soil Erosion of a Characteristic Ultisols in Betem , Cross River State , Nigeria” 5 (7). <https://doi.org/10.5539/jsd.v5n7p104>.
- Panagopoulos, Thomas. 2015. “Simulation Model for Predicting Soil Erosion in a Large Reservoir of Southern Portugal” *Simulation Model for Predicting Soil Erosion in a Large Reservoir of Southern Portugal* Thomas Panagopoulos * Anda Cakula Vera Ferreira and André Samora Arvela.” *Int. J. Sustainable Agricultural Management and Informatics*, no. September 2014. <https://doi.org/10.1504/IJSAMI.2015.069043>.
- Panagos, Panos, Pasquale Borrelli, Katrin Meusburger, Christine Alewell, Emanuele Lugato, and Luca Montanarella. 2015. “Estimating the Soil Erosion Cover-Management Factor at the European Scale.” *Land Use Policy* 48:38–50. <https://doi.org/10.1016/j.landusepol.2015.05.021>.
- Panagos, Panos, Pasquale Borrelli, Jean Poesen, Cristiano Ballabio, Emanuele Lugato, Katrin Meusburger, Luca Montanarella, and Christine Alewell. 2015. “The New Assessment of Soil Loss by Water Erosion in Europe.” *Environmental Science and Policy* 54:438–47. <https://doi.org/10.1016/j.envsci.2015.08.012>.
- Ram et al.,. 2019. “Soil Erosion and Management Strategies,Sustainable Management of Soil and Environment (Pp.73-122),Kansas,USA.”
- REMA,. 2017. “National Wetland Management Framework of Rwanda.”
- RIWSP. 2016. “Sediments Fingerprinting for the Nyabarongo Upper Catchment,Rwanda.”

- Roos, Shannon De, L P H Van Beek, and G Sterk. 2017. "Effect of Contour Bunds on Surface Runoff and Soil Erosion in the Bokole Watershed, Southwest Ethiopia," no. June.
- RWB. 2022a. "The State of Soil Erosion Control in Rwanda."
- Sakinatu et al.,. 2017. "Impact of Soil Erosion and Degradation on Water Quality: A Review, Geology, Ecology, and Landscapes.Lumpur,Malaysia."
- Sánchez-Bernal E.1*, Ortega-Baranda V.1, Domínguez-Hernández F. 2, Ortega- Escobar M. 3, Can-, and Sarmiento-Bustos D. Chulim Chulim Á.4. 2014. "Soil Erosion Control Using Agroforestry Terraces in San Pedro Mixtepec , Oaxaca , Mexico." *International Journal of AgriScience* 3 (5).
- Sharma & Singh. 2013. "Agronomic Practices for Erosion Control.India."
- Shereen et al.,. 2021. "Soil Erosion and the Influenced Factors: A Review. Wasit Kut, Iraq."
- Sobhan.K. 2014. *Principle of Geotechnical Engineering,California*.
- Suraj, Baruah, R Kumaraperumal, Balaji Kannan, and K P Ragunath. 2019. "Soil Erodibility Estimation and Its Correlation with Soil Properties in Coimbatore District." *International Journal of Chemical Studies* 7 (3): 3327–32.
- Swarnkar, Somil, Anshu Malini, Shivam Tripathi, and Rajiv Sinha. 2018. "Assessment of Uncertainties in Soil Erosion and Sediment Yield Estimates at Ungauged Basins: An Application to the Garra River Basin, India." *Hydrology and Earth System Sciences* 22 (4): 2471–85. <https://doi.org/10.5194/hess-22-2471-2018>.
- Tardio, Guillermo, Slobodan B. Mickovski, Hans Peter Rauch, Joao Paulo Fernandes, and Madhu Sudan Acharya. 2018. "The Use of Bamboo for Erosion Control and Slope Stabilization: Soil Bioengineering Works." *Bamboo - Current and Future Prospects*, no. May 2018. <https://doi.org/10.5772/intechopen.75626>.

- Vito & Alessio. 2023. "Soil Erosion Measurement Techniques and Field Experiments. Palermo,Italy." In .
- Wang, Guoqiang, Qingqing Fang, Yanguo Teng, and Jingshan Yu. 2016. "Determination of the Factors Governing Soil Erodibility Using Hyperspectral Visible and Near-Infrared Reflectance Spectroscopy." *International Journal of Applied Earth Observation and Geoinformation* 53:48–63. <https://doi.org/10.1016/j.jag.2016.08.006>.
- Wasie, Dessale, Fantaw Yimer, and Shiferaw Alem. 2020. "Effect of Integrated Soil and Water Conservation Practices on Vegetation Cover Change and Soil Loss Reduction in Southern Ethiopia." *American Journal of Environmental Protection* 9 (3): 49. <https://doi.org/10.11648/j.ajep.20200903.12>.
- Zambona et al.,. 2021. "Splash Erosion Affected by Initial Soil Moisture and Surface Conditions under Simulated Rainfall. Prague,Czech Republic."
- Zeenat & Mohammad. 2018. "Reservoir Sedimentation Analysis,USA." In .

APPENDIX1: RESEARCH QUESTIONNAIRE

Thesis title: ASSESSMENT OF SOIL EROSION IMPACTS ON WATER QUALITY AND ITS IMPLICATION ON THE PERFORMANCE OF KADAHOKWA WATER TREATMENT PLANT,RWANDA

Questionnaire for people and farmers interviews conducted in Kadahokwa catchments (people living near catchment) on 12/02/2024

The following interview questions search to clarify erosion causes and process, its effects on catchment and water treatment plant.

Section A: RESPONDENT IDENTIFICATION

1. Names

Sector...

District: ...

2. Sex:

- A. Male
- B. Female

3. Age (years):

- A. 18-30
- B. 31-50
- C. 51-70
- D. >71

4. Marital Status:

- A. Single
- B. Married
- C. Divorced
- D. Widowed

5. Education Level:

- A. Illiterate (can't write & can't read)

- B. Primary education
- C. Secondary education
- D. University

6. Residential information

- A. Urban
- B. Rural
- C. Suburban

7. How long have you been living in this area?

- A. Less than one season
- B. One season
- C. 2 seasons
- D. More than 3seasons

SECTION B: PERSONAL OBSERVATION OF SOIL EROSION

8. What are the main causes of soil erosion in this catchment? (Yes or NOT)

- A. Slope of the terrain
- B. Rainfall and runoff
- C. Earthquakes
- D. High wind
- E. Human activities (deforestation)

Note: Human activities (agricultural tillage, terracing, anti-erosive ditches and other drainage channels)

9. Which of the following factors do you think contribute to soil erosion in catchment area?

- A. Deforestation
- B. Agricultural activities
- C. Urbanization and construction
- D. Heavy rainfall and flooding

10. What are the issues caused by soil erosion in this area?

- A. Soil loss
- B. Properties loss
- C. People life loss
- D. Water quality deterioration
- E.

11. Where do you get improving knowledge on soil erosion? (Yes or NOT)

- A. Socio-media (Radio, Television or Newspapers)
- B. Training
- C. Community work (group discussion, directives by local authorities or by an agriculture officer: umukangurambaga w'ubuhinzi)

d. No source of information

12. What are the tangible indicators of soil erosion in this catchment? (Yes or NOT)

- A. Rain drops which dig holes in the field (splash erosion)
- B. Soil detachment by rain and runoff: crop and tree roots exposed
- C. Channels formation in the fields
- D. Reduced soil depth
- E. Compaction of the bare soil

SECTION C: SOIL CONSERVATION MEASURES

13. Do you have soil erosion control measures in Catchment?

- A. To adopt progressive terraces (if steep slope: 16-40%)
- B. To adopt bench terraces (if steep slope: 40-60%)
- C. Afforestation (if very steep slope: >60%)
- D. To adopt contour bunds (To adopt farm bunds)
- E. To adopt contour tillage practice
- F. To use compost fertilizers

15. Do you plan to implement sufficient soil erosion control measures in your farmland?

- A. To adopt progressive terraces (if steep slope: 16-40%)
- B. To adopt bench terraces (if steep slope: 40-60%)
- C. Afforestation (if very steep slope: >60%)
- D. To adopt contour bunds (To adopt farm bunds)
- E. To adopt contour tillage practice
- F. To use compost fertilizers

- The following interview questions search to clarify erosion causes and process, its effects on catchment and on the performance of water treatment plant.

SECTION A. SOIL EROSION IN CATCHMENT

1. Have you noticed any visible signs of soil erosion such as gullies or sedimentation in the catchment?

- A. Differences in your landscape, such as rocks that weren't there before.
- B. Bald spots where vegetation was once plentiful.
- C. Exposed roots, which is a sign of severe erosion.
- D. Cracks, rills, and floating islands.
- E. Rills (small channels) and gullies that wash away the top layer of soil or mulch.
- F. Edges of roads that are exposed, pavements that crack and break off at the edges, and shoulder material that is washed away.
- G. Soil surface that appears hard and pavement-like or coarse and gravelly if finer material has been removed.

2. Which of the following do you believe is the primary factors contributing to soil erosion in this catchment area?

- A. Deforestation
- B. Agricultural practices
- C. Urban development
- D. Rainfall
- E. Wind

3. In your opinion, What is the possible changes in raw water quality caused by soil erosion

- A. Turbid water
- B. Raw water with Odor
- C. Raw water mixed with Sediments

SECTION B: SOIL CONSERVATION MEASURES

4. Have you witnessed any specific erosion control measures being implemented in our catchment area?

- A. Yes, I have seen erosion control measures in place.
- B. No, I haven't noticed any erosion control measures.
- C. I'm not sure

5. What are the current erosion control measures available around catchment areas?

- A. Terracing
- B. Contour Farming
- C. Reforestation
- D. Tillage
- E. Anti-erosive ditches

6. Which of the following soil conservation practices do you think would be most effective in reducing soil erosion in our catchment area? (Select all that apply)

- A. Planting trees and vegetation along riverbanks and hillsides

- B. Implementing terracing or contour farming techniques
- C. Adopting cover cropping or no-till farming methods
- D. Enforcing regulations on land use and development

7. Which of the following community activities are better for soil erosion control in catchment area?

- A. Planting Vegetation This method involves planting crops with deep roots that can hold the soil in place.
- B. Contour Farming Preparing and cultivating on slopes can be challenging and can easily lead to soil erosion.
- C. Applying Mulches
- D. Avoiding Overgrazing
- E. Reforestation...
- F. Use Plastic Sheeting
- G. Use of Silt Fencing
- H. Applying Terracing Method