EVALUATING THE PERFORMANCE OF GABION RETAINING STRUCTURES IN MITIGATING GULLY EROSION

BY

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CERTIFICATION

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DEDICATION

With profound gratitude, I dedicate this report to God Almighty, whose boundless grace, wisdom, and unwavering presence have illuminated my path. His divine guidance has strengthened me in moments of doubt, provided clarity in times of uncertainty, and granted me the resilience to navigate in every stage.

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ABSTRACT

The project addresses the growing concern of gully erosion in regions like Benin City, Nigeria, where intense rainfall and poor land management have caused severe soil degradation, loss of agricultural land, and infrastructure damage. Traditional erosion control methods have often been costly, rigid, and unsustainable. This study introduces gabion retaining structures as a flexible, cost-effective, and environmentally friendly alternative. Gabions, which are wire mesh baskets filled with stones, offer the ability to withstand flowing water and adapt to unstable ground while promoting soil stability and water conservation.

The study involves evaluating the performance of gabion structures in mitigating gully erosion in a specific location Federal College Road, Benin City. Site reconnaissance to identify critical erosion-prone areas was done. Hydrological analysis using the Rational Formula estimate streamflow was carried out whilst designing, assembling, and installation of gabion baskets in affected zone was done with key design considerations including appropriate stone size, mesh type (Type 60: 60×80 mm), and structural layout. The performance of the gabions was assessed through regular visual inspections for deformation and settlement.

The project demonstrated that gabion structures are a sustainable and practical solution for controlling minor gully erosion. Results showed improved soil stability and there was a clear reduction in both the depth and speed of water flow from 0.71 m to 0.52 m in depth and from 1.54 m/s to 1.39 m/s in speed helping to stabilize the gully and prevent further soil loss. Additionally, the structure was able to withstand environmental stresses without major maintenance, offering a scalable model for other erosion-prone regions. This result provides useful insights for engineers, policymakers, and local communities seeking cost-effective solutions for land protection and sustainable infrastructure.

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LIST OF ACRONYMS

Acronym	Full Meaning
ASCE	American Society of Civil Engineer
CHANLPRO	Channel Protection Software
IECA	International Erosion Control Association
NRCS	Natural Resources Conservation Service
PVC	Polyvinyl Chloride
USFWS	United States Fish and Wildlife Service
USDA	United States Department of Agriculture

CHAPTER ONE

INTRODUCTION

1.1 Background of Study

Soil erosion is widely acknowledged as a primary driver of land degradation globally. Historically, research has focused on agricultural issues at the plot scale, particularly rill and inter-rill erosion. However, gully erosion has recently gained significant attention, as evident from two international conferences: the first held in Leuven, Belgium (Poesen and Valentin, 2013), and the second in Chengdu, China (Li et al., 2014), highlighting the growing interest in addressing this critical issue. The growing concern over off-site impacts of soil erosion, which can only be effectively addressed at the catchment scale, explains this shift in focus. It is increasingly recognized that intensified land use in upper catchment areas leads to higher sediment yields and increased nutrient loads in runoff, ultimately compromising water quality and availability for downstream users.

Effective control of reservoir sedimentation requires identifying all significant sediment sources and sinks. Recent research (Wasson et al., 2012; Krause et al., 2013; de Vente et al., 2015; Huon et al., 2015) highlights gully erosion as a primary sediment source. Historically, gully erosion has been overlooked due to its complexity and challenges in study and prediction. Gully processes are complex and three-dimensional, influenced by multiple factors. While land use change (Chaplot et al., 2015a; Chaplot et al., 2015b) and extreme climatic events often trigger or accelerate gully erosion, it is also shaped by a longer-term history that must be considered when analyzing spatial erosion patterns. Furthermore, gullies often develop rapidly and reach significant sizes (Nachtergaele et al., 2012; Vanwalleghem et al., 2015a; Thomas et al., 2014), rendering effective control challenging due to technical difficulties or high costs.

This is why in this study, we shall be designing and evaluating gabion structures for gully erosion control and water conservation.

Water erosion is one of the problems in the country that reduces soil fertility, environmental degradation, food security threats, and the filling of dams' reservoirs. Therefore, the use of sedimentation control methods such as Gabion structures is considered important.

Gabions consist of large, rectangular-shaped baskets made of galvanized steel wire mesh, filled with stones that exceed the mesh opening size, allowing for flexibility and drainage (D'Addario, 2019). Gabions offer a low-tech, flexible, cost-effective, and eco-friendly solution for various water management applications. Widely adopted globally, gabion structures can serve multiple purposes, including flood control, land development, sediment regulation, and catchment restoration. Unlike rigid water barriers, gabions can adapt to intense water runoff, sinking into the earth to protect land from damage and minimize environmental and economic impacts.

Traditional gabions are structures composed of metal frames and zinc-coated wire mesh, filled with rocks such as river stone or broken stone, and come in various forms like parallelepiped or cylindrical boxes and mattresses (Ciocan et al., 2020). Gabions are utilized for various applications, including riverbank protection, localized infrastructure protection (e.g., bridge foundations), buried weirs, retaining walls for slope stabilization, and addressing lateral erosion issues in watercourses and torrential areas (Ciocan et al., 2020).

Gabions' flexibility enables them to withstand differential settlement without failing, making them ideal for unstable ground or areas prone to scouring from waves or currents (Brown & Clyde, 2019; Simons & Şentürk, 2012). Their inherent permeability allows for free drainage while retaining earth. For use in polluted or saltwater environments, gabions can be coated with PVC. Gabions are widely used globally for various applications, including canalization, irrigation, flood control, dam construction, and retaining walls (Peyras et al., 2012; Agostini et al., 2017). Additionally, gabions' natural appearance and ability to support vegetation growth make them an attractive option for environmentally conscious projects, allowing them to blend seamlessly into their surroundings.

1.2 Problem Statement

Gully erosion poses significant environmental and economic challenges, particularly in regions with heavy rainfall and poor land management practices (Poesen et al., 2013), such as Benin City, Edo State, Nigeria. The consequences of gully erosion include loss of fertile land, increased sedimentation in water bodies, and decreased water quality, ultimately affecting agricultural productivity, water resources, and ecosystem health (Morgan, 2015; Valentin et al., 2015). Traditional erosion control methods often rely on rigid structures that can be costly, disrupt natural hydrological processes, and fail to address the root causes of erosion (D'Addario, 2019). Therefore, this project aims to evaluate the performance of gabion structures in mitigating gully erosion.

1.3 Aim and Objectives

The aim of this study is to evaluate the performance of gabion structures in mitigating gully erosion in Benin City, Edo State.

The objectives for the study are to;

i. assess the current extent and severity of gully erosion at the selected location

ii. develop a gabion structure design for gully erosion control in a selected area in Benin City, Edo State.

iii. evaluate the structural stability

1.4 Scope of Study

The scope of the study will involve;

i. Selection of a suitable area in Benin City, Edo State, for gabion structure design and suitability assessment.

ii. Estimation of the rate of water flow in the study area using the Rational Formula Method.

iii. Carry out stability analysis using relevant engineering principles and formulas, and assessment of gabions' resistance to failure modes like sliding, overturning, and settlement

iv. Compare the gabion structure design with relevant standards for soil erosion control, such as ASCE or IECA guidelines, to ensure compliance and identify potential areas for improvement.

1.5 Justification of Study

i. The study will contribute to the development of effective solutions for controlling gully erosion, which can help protect infrastructure, agricultural land, and communities.

ii. By assessing the potential water conservation benefits of gabion structures, the study can inform strategies for sustainable water management.

iii. The study will provide insights into the design and performance of gabion structures, which can inform the development of sustainable infrastructure projects.

iv. By controlling gully erosion and conserving water, the study can contribute to environmental protection and conservation efforts.

v. The study's findings can help communities in Nigeria and other regions develop more resilient and sustainable solutions for managing gully erosion and water resources.

CHAPTER TWO

LITERATURE REVIEW

2.1 What is Erosion?

Soil, rock, and dissolved materials are removed from one location and transported to another through erosion, a process driven by surface forces like water flow or wind (Encyclopedia, 2015). Unlike weathering, erosion involves the movement of materials (Encyclopedia, 2015). There are two main types of erosion: mechanical erosion, where rock or soil is transported as clastic sediment, and chemical erosion, where materials are dissolved and removed (Louvat et al., 2018). Once eroded, sediment or solutes can travel short or long distances, sometimes spanning thousands of kilometers (Allaby 2013).

Human activities have significantly accelerated soil erosion, increasing it by 10-40 times globally (Dotterweich, 2013). In agricultural areas like the Appalachian Mountains, intensive farming practices can lead to erosion rates 100 times higher than natural rates (Reusser et al., 2015). Excessive erosion causes both on-site and off-site problems, including decreased agricultural productivity, ecological collapse, and desertification (Blanco-Canqui & Lal, 2008). Off-site effects include sedimentation of waterways, eutrophication, and damage to infrastructure (Blanco-Canqui & Lal, 2008; Toy et al., 2002). Water and wind erosion are the primary causes of land degradation, accounting for approximately 84% of degraded land worldwide (Blanco-Canqui & Lal, 2008; Toy et al., 2002). Human activities such as intensive agriculture, deforestation, roads, anthropogenic climate change, and urban sprawl significantly contribute to erosion (Julien, 2010). However, various prevention and remediation practices can mitigate or limit soil erosion.

Effective erosion control measures require a comprehensive understanding of the underlying geological and hydrological processes (Morgan, 2005). By adopting sustainable land use practices, we can reduce the risks associated with erosion and promote more resilient ecosystems (Lal, 2001).

2.2 Types of Erosion

Generally, erosion is of several types:

2.2.1 Coastal Erosion

Shoreline erosion occurs on both exposed and sheltered coasts, primarily through the action of currents and waves, although sea level changes can also contribute (Geddes, 2015). Various processes contribute to shoreline erosion, including hydraulic action, where compressed air in joints is suddenly released, causing cracks (Geddes, 2015). Wave pounding, where the energy of waves breaks off pieces of rock or cliff, is another significant process (Geddes, 2015). Abrasion or corrasion, caused by waves launching sediment at the cliff, is the most effective and rapid form of shoreline erosion (Geddes, 2015). Corrosion, the dissolving of rock by carbonic acid in seawater, particularly affects limestone cliffs (Geddes, 2015). Attrition occurs when particles carried by waves are worn down, making them easier to transport (Geddes, 2015). Additionally, bioerosion, the boring, scraping, and grinding of organisms, significantly contributes to erosion on carbonate coastlines (Glynn, 1997).

Coastal sediment is transported by longshore drift, driven by prevailing currents. Erosion occurs when the sediment supply is insufficient to meet the demand, while excess sediment leads to deposition, forming sand or gravel banks. These banks can migrate along the coast, alternately shielding and exposing shoreline areas. At coastal bends, sediment often accumulates, forming a spit. Natural barriers like armored beaches and offshore sandbanks can protect shorelines from erosion, but shifting shoals can redirect erosion to other areas (Bell, 1999). A combination of coastal erosion and subsequent sea level drop can create a raised beach, a distinctive landform (Pinter, 2010).

2.2.2 Glacial Erosion

Glaciers primarily erode through three processes: abrasion, plucking, and ice thrusting. Abrasion occurs when debris in the basal ice scrapes and polishes the underlying rocks, similar to sandpaper. Research has shown that glaciological processes, including erosion, influence cross-valley variations, in addition to temperature's role in valley-deepening. In homogeneous bedrock, glacial erosion creates a curved, U-shaped channel cross-section beneath the ice. As the glacier continues to incise vertically, the channel shape eventually reaches a steady-state, parabolic form characteristic of glaciated valleys.

Subglacial erosion rates exhibit a remarkable range, spanning multiple orders of magnitude. At one end of the spectrum, slow-moving, cold-based glaciers can preserve underlying surfaces with minimal alteration, occasionally revealing relict surfaces with intact vegetation (Lowell et al., 2013). In stark contrast, other glaciers erode at rates rivaling the fastest fluvial systems, yielding sediment volumes comparable to those produced by the most erosive rivers (Hallet et al., 1996; Koppes and Montgomery, 2009). Even relatively slow erosion rates can have significant geomorphic implications if sustained over extended periods, such as the prolonged ice cover in Antarctica, which has persisted for over 30 million years (Cuffey et al., 2000; Pagani et al., 2011). This discussion will focus on the conditions that produce moderate to high subglacial erosion rates, typically in the range of 10^-4 to 10^-2 meters per year, although slower rates can prevail on resistant substrates.

Research on glacial erosion's role in shaping landscapes has highlighted the importance of sliding velocity as a key controlling factor (Oerlemans, 1984; MacGregor et al., 2000). Ice discharge is often used as a proxy for sliding velocity (Anderson et al., 2006). Theoretical analyses support this focus, particularly for abrasion (Hallet, 1979). Quarrying's relationship with sliding rate is more complex, influenced by factors like effective pressure and ice-bed contact area (Hallet, 1996; Iverson, 2012). Observational studies confirm that faster sliding can increase erosion rates (Herman et al., 2015). Numerical models linking erosion rate to sliding velocity can generate realistic glacial landscapes (Herman and Braun, 2008; Pedersen and Egholm, 2013), although accurately predicting sliding rates remains a challenge (Cuffey and Paterson, 2010).

2.2.3 Chemical Erosion

Chemical erosion involves the loss of matter in a landscape through the removal of solutes. This process is often measured by analyzing the solutes present in streams. Anders Rapp's 1960 study on Kärkevagge was a pioneering work in this field (Dixon and Thorn, 2005). A notable example of extreme chemical erosion is the formation of sinkholes and other features characteristic of karst topography (Lard et al., 1995).

2.2.4 Wind Erosion

Wind erosion is a significant geomorphological force, particularly in arid and semi-arid regions. It contributes to land degradation, desertification, airborne dust, and crop damage. Human activities like deforestation, urbanization, and agriculture have exacerbated wind erosion beyond natural rates (Zheng and Huang, 2009; Cornelis, 2006).

Wind erosion occurs through two main processes: deflation, where loose particles are picked up and carried away, and abrasion, where surfaces are worn down by airborne particles. Deflation has three categories: surface creep (larger particles sliding or rolling), saltation (particles bouncing across the surface), and suspension (small particles lifted and carried long distances) (Blanco-Canqui and Lal, 2008; Balba, 1995). Saltation accounts for 50-70% of wind erosion, followed by suspension (30-40%) and surface creep (5-25%) (Blanco-Canqui and Lal, 2008; Balba, 1995). Wind erosion is particularly severe in arid areas and during droughts, with soil loss potentially being thousands of times greater in dry years compared to wet years (Wiggs, 2011).

2.2.5 Water Erosion

Water erosion occurs when rain or snowmelt displaces soil, with increased water flow leading to greater soil particle transport. Bare land, such as fields without vegetation after harvest, is particularly susceptible to erosion due to the lack of roots to hold soil in place and vegetation to absorb water or mitigate raindrop impact. Intense weather events like heavy rains, flash floods, or rapid snowmelt can accelerate soil erosion.

Soil Erosion is the physical removal of topsoil by various agents, including falling raindrops, water flowing over the soil profile, and gravitational pull (Lal 2014). Soil erosion poses a significant environmental threat, causing on-site problems such as deterioration of soil properties (Lal et al., 2012), nutrient loss (Lal, 2013), reduced agricultural productivity (Lal, 2019), and cropland loss (Pimentel, 2016). Additionally, soil erosion leads to off-site damages, including fluvial sediment deposition, reservoir sedimentation, and channel silting (Mullan, 2013a), resulting in substantial economic losses. Land and soil degradation, caused by wind and water erosion, leads to loss of soil fertility, biodiversity, and crop productivity (Ayoubi et al., 2018; Babur et al., 2016; Maximillian et al., 2019). Sustainable land use management and soil erosion control rely on land capability classification (Atalay, 2016). Soil properties are influenced by land use, especially with changing land use patterns due to population growth (Adeyemi et al., 2020; Diatta et al., 2020; Havaee et al., 2015; Somasundaram et al., 2013; Spurgeon et al., 2013). Understanding soil characteristics and land use capabilities is crucial to prevent soil loss through erosion (Kiflu, 2013; Oyetola and Philip, 2014). Soil preservation depends on determining soil properties under current land use and anticipating the impact of future changes on soil health (Duguma et al., 2010; Tufa et al., 2019). Maintaining good soil health is essential for sustainable agriculture, food production, and environmental sustainability (Adnan et al., 2020; Bore and Bedadi, 2016; Liu et al., 2010).

Rapid population growth demands more efficient resource use and sustainable agricultural practices (Battaglia et al., 2019; Hunter et al., 2017). Intensive land use, including overgrazing, has negatively impacted soils (Mustapha, 2007), leading to decreased crop yields and land use changes, such as deforestation (Ayoubi et al., 2012; Fite, 2017). Poorly managed pastures have resulted in soil degradation and reduced productivity (Uslu and Hatipoğlu, 2005). Research shows land use affects soil quality, with forests often storing more organic carbon than agricultural lands (Babur, 2012; Yimer et al., 2008). In regions like Turkey, where agricultural land is scarce and intensively used, comprehensive land assessment and sustainable practices are crucial for future sustainability (Yimer and Abdulkadir, 2011). Soil degradation, caused by improper land management and poor environmental policies, reduces land productivity. Key factors include lack of forest preservation, fires, inadequate soil conservation, scarce vegetation, irregular rainfall, deforestation, and overgrazing (Gökbulak and Özcan, 2008). Agricultural practices and land slope also significantly impact soil quality (Pavlů et al., 2007). Protecting natural resources, increasing agricultural productivity, and ensuring food security are crucial for future sustainability (Qadir et al., 2014). Land use type is a major factor affecting soil properties at the local scale (Wang et al., 2001), and understanding these factors is essential for protecting river basins (Genç and Dengiz, 2015).

Raindrops striking bare soil break up soil aggregates, and the fragments clog soil pores, reducing water infiltration. This leads to increased surface runoff, which carries soil particles away, resulting in erosion. Well-structured soils with plant or litter cover are more resistant to water erosion. A soil's vulnerability to erosion depends on factors like:

1. Rainfall intensity (erosivity) - High-intensity rainfall increases erosion risk.

2. Soil nature (erodibility) - Clay soils vary in their ability to withstand raindrop impact.

3. Slope length - longer slopes increase runoff speed and soil loss.

4. Slope steepness - steeper slopes accelerate runoff, enhancing erosion.

These factors combined determine the likelihood and severity of water erosion.

2.3 Factors of Water Erosion

Water erosion on farm fields is influenced by a combination of factors, including rainfall intensity and water runoff, soil type, quality, and texture, as well as the length and steepness of the land. When rainfall is heavy and water flows rapidly over the land, it can cause significant erosion, especially if the soil is loose or poorly structured. The slope of the land also plays a crucial role, as steeper slopes can lead to faster and more powerful water runoff, increasing the risk of erosion and soil loss. This is particularly concerning for farms built on steep hillsides, where soil erosion and washouts can be devastating.

Vegetation, including cover crops, can help mitigate the impact of water on farm fields by reducing soil erosion (Hartwig & Ammon, 2002; Dabney et al., 2001). Selective tillage practices can also play a crucial role (Lal, 2007). While traditional tillage helps prepare fields for planting, control weeds, and retain moisture, research suggests that minimizing mechanical disturbance can be more beneficial for preserving soil health and reducing erosion (Huggins & Reganold, 2008). By adopting a less-is-more approach, farmers can help protect their soil from erosion and promote long-term sustainability.

2.4 Forms of Water Erosion

Water, although essential for life and agriculture, can be remarkably destructive. Even the impact of a single raindrop can alter soil structure, highlighting water's potential for erosion.

Below are four common types of water erosion.

2.4.1 Sheet Erosion

Sheet erosion, also known as interrill erosion, occurs when rainfall detaches soil particles that are then transported away in a thin layer of surface runoff (Dlamini et al., 2011). Sheet erosion involves the uniform removal of a thin layer of topsoil across a large area, such as a hillside, often going unnoticed until significant soil loss has occurred. Sheet erosion can be hard to detect initially, but it leads to significant soil loss by removing fine particles rich in nutrients and organic matter, often becoming apparent only when damage is severe or soil is deposited elsewhere.

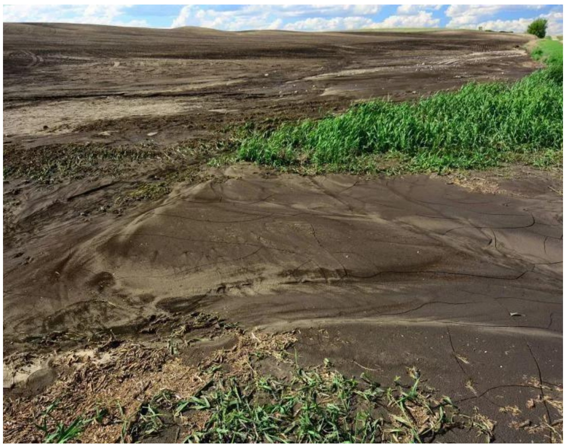

Plate 2.1: Sheet erosion on plowed native prairie in Stutsman County, North Dakota (*Rick Bohn/USFWS)*

Sheet erosion occurs when raindrop impact and shallow surface runoff detach and transport soil particles, leading to the loss of fertile soil, particularly in agricultural areas, and posing a threat to sustainable ecosystems through environmental degradation (Wight & Lovely, 1982;

Wang et al., 2018). Sheet erosion is influenced by rainfall characteristics like kinetic energy, duration, intensity, and pattern, as well as hydrodynamic factors such as shear stress, stream power, and unit stream power (Fox & Bryan, 2000; Parsons & Stone, 2006).

2.4.2 Rill Erosion

Rill erosion happens when concentrated runoff water creates small channels, or rills, on a slope, typically up to 0.3 meters deep. When these channels exceed 0.3 meters in depth, they are classified as gullies, marking a transition to gully erosion. Rill erosion is characterized by small, concentrated flow channels, typically up to 30 cm deep, where the primary cause of erosion is the concentrated flow, with minimal impact from individual raindrops (Govers et al., 2007; Sun et al., 2013). Rill erosion can sometimes be mitigated, either naturally fading away over time or being smoothed over through tilling in agricultural settings.

Plate 2.2: Rill erosion at a housing development site in Ankeny, Iowa (*Lynn Betts/USDA NRCS)*

Rills are most active in areas with high water erosion rates, typically on disturbed upland areas. They have shallow flow depths (usually a few centimeters or less) and steep slopes, resulting in unique hydraulic characteristics distinct from larger streams and rivers. Once rills form, surface flow concentrates, increasing velocity and shear force. This concentrated flow has a much greater capacity to detach and transport soil particles than rainfall alone, leading to a sudden surge in erosion. Rill erosion is often the most severe type of water erosion on slopes and can mark the transition to gully erosion (Auerswald et al., 2009; Chen et al., 2013).

2.4.3 Stream-Bank Erosion

Bank erosion is the gradual wearing away of riverbanks and stream banks due to intense water movement, often worsened by human activities like removing vegetation or overgrazing. This can lead to significant land loss and displacement, as seen in southwestern Bangladesh, where riverbank erosion severely impacts farming communities and displaces thousands annually. Bank erosion refers specifically to the wearing away of riverbanks, distinct from scour, which affects the riverbed. Bank erosion can be measured by inserting metal rods into the bank and tracking changes in the bank surface over time. (Gordon N. D., 2004)

Plate 2.3: Bank erosion in Sunamganj, Bangladesh | Malcolm Dickson/Water Alternatives, CC-BY-NC 4.0

Stream bank erosion is primarily caused by the destruction of vegetation on riverbanks, often due to human activities like clearing, overgrazing, cultivation, or vehicle traffic, as well as the removal of sand and gravel from the stream bed.

2.4.4 Tunnel Erosion

Tunnel erosion occurs when water infiltrates through soil cracks or decayed root holes, dispersing and carrying away subsoil particles, creating tunnels. As the tunnels enlarge, the surface soil may eventually collapse, forming gullies. This process accelerates if an outlet for water flow is present. Sodic soils with dispersible subsoils, like Sodosols, are particularly vulnerable to tunnel erosion due to their tendency to break down in water.

Plate 2.4: *Tunnel erosion in Marburg, Queensland (Wikipedia)*

2.4.5 Gully Erosion

Gully erosion occurs when soil is washed away, creating deep channels or grooves, often due to heavy rainfall on unprotected land or through human-made drainage lines. Farmers may temporarily address this by filling the grooves with fresh soil. Gully erosion occurs when concentrated runoff detaches and transports soil particles, often forming a waterfall-like effect. As water plunges over the gully head, it gains energy, eroding the subsoil through splashback, causing the gully to progressively move upslope. Gullies form in areas with concentrated runoff, such as watercourses or areas with advanced rill erosion. This type of erosion is visible, impacts soil productivity, and can damage infrastructure like roads and buildings. Gully depth typically ranges from less than 2 meters, limited by underlying rock, to 10-15 meters in deep alluvial and colluvial soils.

Gully erosion is a significant environmental issue that occurs when rushing surface water erodes deep channels, removing and transporting soil. This process not only alters the surrounding landscape but also accelerates sedimentation in rivers and dams, ultimately affecting water quality and ecosystem balance. Understanding the variables that influence gully erosion is crucial for effective management and mitigation. Gully erosion impacts the environment in two primary ways: it erodes the surface, diminishing soil quality and leading to high sediment production, and it escalates surface discharge while decreasing groundwater recharge. By addressing the factors that contribute to gully erosion, we can work towards preserving soil health, maintaining water quality, and protecting ecosystems (Belayneh et al., 2020; Ghorbanzadeh, Blaschke, et al., 2020; Hancock & Evans, 2010).

Plate 2.5: A highly eroded gully

Gully erosion in South-Eastern Nigeria has severely increased, with affected areas tripling from 1.33% (1,021 km^2) in 1976 to 3.7% (2,820 km^2) in 2006. This is likely due to sandy soils being overwhelmed by runoff, resulting in deep gullies that can damage infrastructure and homes (Gordon N. D., 2004). The South East region of Nigeria is prone to erosion, largely due to heavy rainfall and flooding, which is exacerbated by climate change (Nwajide, 2013). This has resulted in significant damage to farms, homes, and buildings.

In this study, we shall be evaluating and controlling this gully erosion using gabion structures.

2.4.5a Causes of Gully Erosion

Gullies are primarily caused by surface runoff, which erodes the land and creates deep channels. These gullies can expand with each rainfall, eventually forming dozens or hundreds of feet deep ravines. Natural factors contributing to gully formation include heavy rainfall, poor soil infiltration, and unfavorable catchment shapes (*NSW Environment & Heritage, 2018).*

In South-Eastern Nigeria, gully formation is accelerated due to the prevalent soil types, namely sandy clay and loamy sand, which have high sand content. These soils allow water to flow through easily due to their porous nature, making them prone to erosion. The lack of cohesion and nutrient retention in sandy soils hinders plant growth, which would otherwise help stabilize the soil. Without root systems to hold the soil in place, erosion becomes more likely. To mitigate soil depletion, fertilization and irrigation are crucial considerations for crop cultivation in this region (Kayode O. T et al., 2018).

Nigeria's climate significantly contributes to gully formation, particularly in dry areas where intense rainfall leads to flooding. The aggressive nature of the rainfall, characterized by large raindrops and high volumes of water, overwhelms the soil's capacity, causing erosion. Human activities, however, play a more substantial role in gully formation, including:

1. Poor road design and construction, especially inadequate drainage termination, which disperses water flow and erodes the soil.

2. Poor waste management practices, such as dumping refuse into drains, causing blockages and flooding.

3. Unsustainable land use practices, like improper sand mining and tilling, which loosen topsoil and create pathways for runoff.

The gully erosion crisis in Nigeria's southern region has far-reaching consequences, affecting the entire nation. As gullies expand, homes and structures collapse, posing a significant threat. If left unchecked, the region risks being transformed into a badland, rendering it uninhabitable and unsuitable for human activity.

2.4.5b Control of Gully Erosion

Vegetation is a highly effective long-term solution for controlling gully erosion. While engineered structures can provide immediate stabilization, vegetation offers a self-sustaining and potentially improving solution over time. Engineered structures, such as those made of concrete or wood, may be necessary to complement revegetation efforts, but they require careful design, maintenance, and specialized expertise to ensure their effectiveness and prevent failure.

When deciding on gully control measures, consider the following factors:

1. Cause of the gully: Address the root cause to ensure long-term effectiveness.

2. Impact of the gully: Weigh the costs and benefits of control measures against the consequences of inaction.

3. Catchment size: Larger catchments often require more complex solutions.

4. Soil type: Fertile soils support vegetation growth, while poor soils may require additional measures.

5. Gully components: Identify the most actively eroding areas (head, floor, or sides) and consider gully morphology.

6. Runoff diversion potential: Explore options to divert runoff to a safe disposal area, reducing gully erosion.

By considering these factors, effective and sustainable gully control measures can be developed.

2.5 Gabion Structures

Gabions are wire mesh containers filled with rocks, concrete, or soil, used to create sturdy structures for erosion control. Gabions are cylindrical structures filled with earth or stones, used in construction projects like dams, dikes, and erosion control measures. They're a versatile and effective solution for stabilizing soil and managing water flow. They come in various shapes and sizes, depending on the application, and are assembled on-site. Gabions are a versatile solution for stabilizing soil and preventing erosion in various environments. Gabions have a long history, dating back thousands of years to ancient Egypt and China. Initially made from plant materials, they had limited durability. The introduction of wire mesh in the late 19th century (around 1879) revolutionized gabion construction, enabling the creation of more durable and long-lasting structures. Today, gabions are widely used globally for various applications, including erosion control, bank stabilization, and retaining walls (Gary E. F. and Craig F., 2012).

Gabions come in three basic forms: the gabion basket, gabion mattress, and sack gabion. All three types consist of wire mesh baskets filled with cobble or small boulder material, typically rock but sometimes other materials like bricks. These baskets are used to maintain stability and protect streambanks and beds. Gabion baskets and mattresses differ in thickness and size, while sack gabions are mesh sacks filled with rocks. Gabions allow smaller rocks to work together to resist erosion, making them effective for protecting stream beds and banks. Gabion mattresses are shallower (0.5-1.5 ft) and specifically designed for erosion protection. Gabion baskets are typically thicker (1.5-3 ft) and cover smaller areas, making them suitable for applications like bank protection, slope stabilization, and constructing structures to withstand erosive forces. They are used in various situations where soil needs protection from water, such as drop structures and pipe outlets.

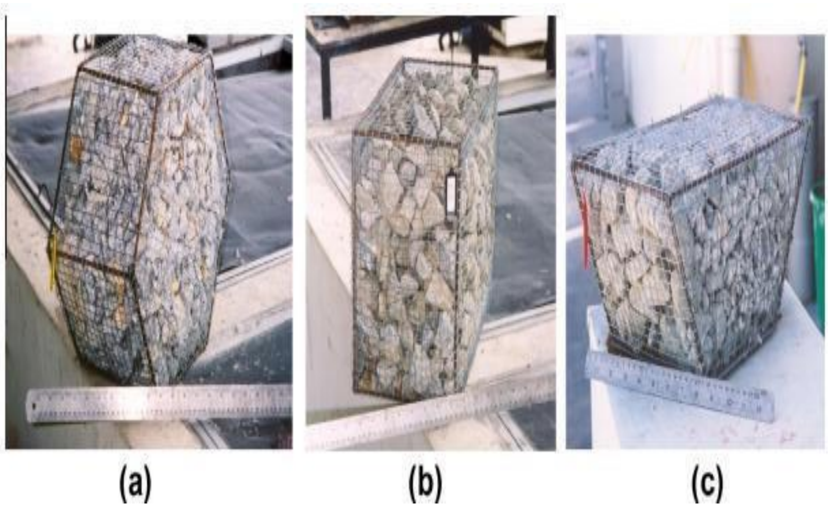

Plate 2.6: (a) Hexagonal, (b) rectangular, and (c) semi-rectangular shape of gabions.

Gabion baskets are typically made from galvanized wire mesh, which can be welded or woven, and sometimes coated with plastic for added protection. Newer materials like Tensar, a heavy-duty polymer, are also being used as alternatives to wire mesh. However, if the mesh fails due to corrosion, damage, or vandalism, the rock fill can be lost, compromising the structure's effectiveness (Gary E. F. and Craig F., 2012).

Gabions are particularly useful in situations where the available rock size is too small to withstand the erosive forces at a project site. This can be due to the high cost of transporting larger stones from remote locations or a desire for a smoother appearance compared to riprap. One advantage of gabions is that they require about one-third the thickness of material compared to riprap designs. However, riprap is often preferred due to its simplicity and low labor requirements for placement (Gary E. F. and Craig F., 2012).

The design and installation of gabions are supported by established science and research. Dr. Stephen T. Maynord of the U.S. Army Engineer Research and Development Center has developed design guidance, including a software package called CHANLPRO. Two common methods for determining gabion stability in stream channels are critical shear stress calculation and critical velocity calculation, providing a solid foundation for gabion design and implementation (Gary E. F. and Craig F., 2012).

The debate between welded wire baskets and woven wire baskets has been ongoing, with manufacturers and experts weighing in on their durability and effectiveness. While both types have their proponents, project results suggest that both welded and woven wire baskets can perform satisfactorily, indicating that either option can be viable depending on the specific project requirements and conditions.

Gabions can support aquatic life by providing rocky substrates for various organisms. However, establishing vegetation can be challenging unless the rock voids are filled with soil, allowing plants to take root and thrive. Large woody vegetation in gabions can cause damage as roots grow or when plants are uprooted, potentially breaking the baskets. While vegetation can enhance aesthetics and ecology, it's often recommended to limit growth to grasses and smaller plants, rather than large woody vegetation, to maintain the structure's integrity. A balance between ecological benefits and structural stability is key (Gary E. F. and Craig F., 2012).

2.6 Use of Gabion Structures for Water Conservation

Gabion structures are innovative and eco-friendly solutions for water conservation. These structures are made of wire mesh baskets filled with rocks or stones and are used to prevent soil erosion, stabilize slopes, and manage water flow. Gabions help prevent soil erosion by reducing the velocity of water flow and allowing sediment to settle, thereby preventing further erosion (Brown, 2015).

The flexibility of gabions makes them suitable for areas with unstable ground or moving water. They can settle and deform without losing their efficiency, making them ideal for riverbank stabilization and slope protection. Gabions also allow vegetation to grow through the structure, further stabilizing the soil and promoting biodiversity (Terzaghi, 1950).

In water conservation, gabions can be used for river training, canal lining, dam construction, and flood control. They can line canals and prevent erosion, reducing water loss and ensuring efficient water supply. Gabions can also be used in dam construction to prevent erosion and ensure stability. By slowing down water flow and preventing erosion, gabions can help control flooding and promote sustainable water management (Punmia et al., 2005).

The design of gabion structures requires careful consideration of the wire mesh and rock fill materials. The materials should be selected based on the water flow and soil conditions. The structure should be designed to withstand water currents and soil settlement, ensuring its stability and effectiveness (Das, 2013).

2.7 Review of Previous Work Done

The design and assessment of gabion structures for gully erosion control and water conservation have been extensively studied in various contexts. A review of existing literature provides valuable insights into the effectiveness, benefits, and limitations of gabion structures in different environments. This section reviews related works on gabion structures, highlighting their applications, design considerations, and impact on the environment. The review aims to synthesize existing knowledge and identify research gaps, providing a foundation for further investigation into the use of gabion structures for gully erosion control and water conservation.

Ahmad et al. (2018) investigated the effectiveness of gabion structures in controlling gully erosion in a watershed in Pakistan. The study used a combination of field observations and remote sensing techniques to monitor gully erosion and sediment yield. The results showed that gabion structures reduced sediment yield by 70% and runoff by 50%, demonstrating their potential as a sustainable solution for gully erosion control. The authors recommended the use of gabion structures in conjunction with other conservation practices to achieve optimal results.

A study to assess the stability of gabion structures in a gully erosion-prone area in India was conducted by Kumar et al. (2019). The study used numerical modeling to simulate the behavior of gabion structures under different flow conditions, including varying flow rates and depths. The results showed that gabion structures were stable under low to moderate flow conditions but failed under high flow conditions, highlighting the need for careful design and installation. The authors recommended further research on the design and construction of gabion structures to improve their stability.

Liu et al. (2020) evaluated the impact of gabion structures on water quality in a river system in China. The study monitored water quality parameters, including pH, turbidity, and nutrient concentrations, upstream and downstream of gabion structures. The results showed that gabion structures improved water quality by reducing sediment and nutrient loads, demonstrating their potential as a best management practice for water quality improvement. The authors recommended the use of gabion structures in conjunction with other conservation practices to achieve optimal results.

Moges et al. (2017) investigated the effectiveness of gabion structures in controlling gully erosion in a watershed in Ethiopia. The study used a combination of field observations and remote sensing techniques to monitor gully erosion and sediment yield. The results showed that gabion structures reduced gully erosion by 80% and improved soil conservation, demonstrating their potential as a sustainable solution for gully erosion control. The authors recommended the use of gabion structures in conjunction with other conservation practices to achieve optimal results.

A study to assess the economic benefits of gabion structures for gully erosion control in a watershed in Bangladesh was conducted by Nahar et al. (2019). The study used a cost-benefit analysis to evaluate the economic viability of gabion structures. The results showed that gabion structures were economically viable and provided a benefit-cost ratio of 2.5, demonstrating their potential as a cost-effective solution for gully erosion control. The authors recommended the use of gabion structures as a sustainable solution for gully erosion control.

The impact of gabion structures on aquatic ecosystems in a river system in India was investigated by Patel et al. (2018). The study monitored aquatic habitats and biodiversity upstream and downstream of gabion structures. The results showed that gabion structures improved aquatic habitats and biodiversity, demonstrating their potential as a sustainable solution for aquatic ecosystem conservation. The authors recommended the use of gabion structures in conjunction with other conservation practices to achieve optimal results.

Rahman et al. (2020) evaluated the effectiveness of gabion structures in controlling gully erosion in a watershed in Malaysia. The study used a combination of field observations and remote sensing techniques to monitor gully erosion and sediment yield. The results showed that gabion structures reduced sediment yield by 60% and runoff by 40%, demonstrating their potential as a sustainable solution for gully erosion control. The authors recommended the use of gabion structures in conjunction with other conservation practices to achieve optimal results.

Singh et al. (2019) conducted a study to assess the stability of gabion structures under different flow conditions. The study used numerical modeling to simulate the behavior of gabion structures and found that gabion structures were stable under low to moderate flow conditions. The authors recommended further research on the design and construction of gabion structures to improve their stability.

Tfwala et al. (2018) investigated the impact of gabion structures on soil conservation in a watershed in South Africa. The study monitored soil erosion and sediment yield upstream and downstream of gabion structures. The results showed that gabion structures improved soil conservation and reduced erosion, demonstrating their potential as a sustainable solution for soil conservation. The authors recommended the use of gabion structures in conjunction with other conservation practices to achieve optimal results.

The effectiveness of gabion structures in controlling gully erosion in a watershed in China was evaluated by Wu et al. (2020). The study used a combination of field observations and remote sensing techniques to monitor gully erosion and sediment yield. The results showed that gabion structures reduced gully erosion by 90% and improved water quality, demonstrating their potential as a sustainable solution for gully erosion control and water conservation. The authors recommended the use of gabion structures as a best management practice for gabion structures as sustainable solution for gully erosion control and water conservation.

Liu et al. (2019) reviewed gully erosion control practices in Northeast China, highlighting the effectiveness of various structures and bioengineering techniques. The study identified drop structures, soil check dams, masonry check dams, gabion check dams, and wicker check dams as effective measures. Bioengineering techniques, such as continuous live wicker and plant enclosures, were also found to be highly effective in controlling gully erosion. The authors noted that the application of these practices depends on topography, gully size, and local economy, and highlighted the importance of selecting suitable techniques for specific contexts.

Poesen (2011) identified key challenges in gully erosion research, underscoring the need for further investigation into gully initiation and development processes, interactions with other soil degradation processes, and effective prevention and control measures. The study emphasized that addressing these knowledge gaps is crucial for predicting gully erosion's impact on environmental change, sediment yield, and landscape evolution, ultimately informing sustainable land management strategies.

Nyssen et al. (2014) investigated the impact of gabion check dams on gully erosion in Ethiopia, finding that they reduced sediment yield and stabilized gully channels. The study recommended integrating gabion structures with vegetation and other conservation practices to enhance their effectiveness and promote sustainable land management.

Meerkerk et al. (2009) studied the effects of gabion structures on gully erosion and sediment yield, finding that they reduced erosion rates and improved landscape stability. The study recommended combining gabion structures with other conservation practices, such as vegetation and terracing, to achieve optimal results and promote sustainable land use.

Li et al. (2015) reviewed the use of gabion structures in soil conservation, highlighting their effectiveness in controlling gully erosion and stabilizing slopes. They noted that gabion structures can be particularly effective in areas with high rainfall intensity and steep slopes.

The study emphasized the need for careful planning, design, and maintenance to ensure the long-term stability of gabion structures.

the effectiveness of gabion structures in gully erosion control was examined by Castillo et al. (2019). The result of the findings showed that they significantly reduced erosion rates and improved soil stability. The study highlighted the importance of proper design, installation, and maintenance of gabion structures to ensure their long-term effectiveness. They also noted that gabion structures can be an eco-friendly and cost-effective solution.

Igwe et al. (2018) reviewed the use of landscape design in controlling gully erosion, highlighting the effectiveness of vegetative approaches, such as planting woody trees and grasses, and structural approaches, like gabion structures. They noted that combining both approaches can enhance soil stability, reduce erosion rates, and promote ecosystem services. The study recommends careful planning and implementation to achieve optimal results.

2.8 Research Gap

A significant research gap exists in the comparative evaluation of gabion structures with other gully erosion control measures, such as bioengineering approaches and engineered structures, in terms of effectiveness, cost, and environmental impact. While gabion structures are widely used, few studies have compared their erosion control effectiveness, cost-benefit tradeoffs, and environmental impacts with those of alternative control measures, particularly in the context of Benin City, Nigeria. This study aims to address this gap by investigating the relative performance of gabion structures compared to other control measures, providing insights into their design, installation, and maintenance requirements for optimal effectiveness and sustainability.

CHAPTER THREE

METHODOLOGY

3.1 Description of Study Area

The study area, which is represented by an aerial view map, is located in Federal College Road, Benin City, and coversspecific places inhabiting residential population. The (catchment)area covers an area of 28.82km^2 as shown in Figure 3.1. The coordinates are 6.4305ºN °N, 5.5932ºE °E, and contain inhabitants who are mainly residents of the city who live or work there. The area contains socio-economic infrastructures that generate a lot ofhuman activities around the area. It lies within the Ikpoba River basin, and most of the rainfall in this area flows and ultimately discharges into the Ikpoba River in Benin City, as revealed through on-site inspection. Annual precipitation in Benin City is around 190mm and has 274.89 rainy days (75.31% of theyear). The yearly average temperature of Benin City is 29.75°C (Floyd et al., 2015).

Plate 3.1: Federal College Road, Benin City (Google Earth Pro).

3.2 Site Reconnaissance Survey

Site inspection of the study area was conducted to assess the best area where the prepared gabion structures are to be installed. The purpose of the survey was to visually inspect the site and identify erosion characteristics in the area, including the extent of erosion, soil type, and water flow patterns. During the investigation, the survey aimed to determine the most critical areas of erosion and identify the most suitable locations for installing the prepared gabion baskets to be installed for the control of gully erosion and to conserve water resources effectively.

3.3 Gabion Baskets Preparation Parameters

In the preparation and installation of the gabion baskets, different parameters were considered and ascertained. These parameters include:

3.3.1 Rate of Streamflow (Q)

To accurately determine the force intensity of water flow in the selected area, the quantity of discharge was estimated. This helped to prepare the gabion baskets adequately with sufficient stability to withstand erosion.

The total discharge of the catchment was calculated using the Rational formula method, as shown in equation 3.1

$$Q = \frac{CIA}{360} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (3.1)$$

Were,

Q = Total discharge (in m^3/s)

C = dimensionless runoff coefficient;

I = rainfall intensity for a given return period. (Return period is the average number of years within which a given rainfall event will be expected to occur at least once.)

A = area of catchment (ha).

Table 3.1 shows the value of different coefficients for different area types

Table 3.1 Runoff Coefficients for Rational Formula

Type of Drainage Area	Runoff Coefficient, C*
Concrete or Asphalt Pavement	0.8 – 0.9
Commercial and Industrial	0.7 – 0.9
Gravel Roadways and Shoulders	0.5 – 0.7
Residential – Urban	0.5 – 0.7
Residential – Suburban	0.3 – 0.5
Undeveloped	0.1 – 0.3
Berms	0.1 – 0.3
Agricultural – Cultivated Fields	0.15 – 0.4
Agricultural – Pastures	0.1 – 0.4
Agricultural – Forested Areas	0.1 – 0.4

3.3.2 Stone Size Selection for Gabion Basket

To avoid the presence of voids within the stones in the gabion baskets and ensure the ability of the gabions to withstand water pressure, stones of 85mm (3.35inches) minimum sizes were selected for use. This stone size was adopted to help prevent erosion, ensure structural integrity, and promote long-term durability of the gabion basket. Gravels as well as broken concrete blocks were used.

3.3.3 Size of Mesh Openings

A suitable type of gabion basket with a mesh opening of 60mm x 80mm was used. Research has recognized two common types of gabion types, viz:

- Type 60: 60mm x 80mm mesh opening
- Type 80: 80mm x 100mm mesh opening

The Type 60 was employed in this study, as it has a smaller mesh opening, which can provide better stability and retention of fill material, especially for smaller aggregate sizes. Figure 3.2 shows the mesh opening used

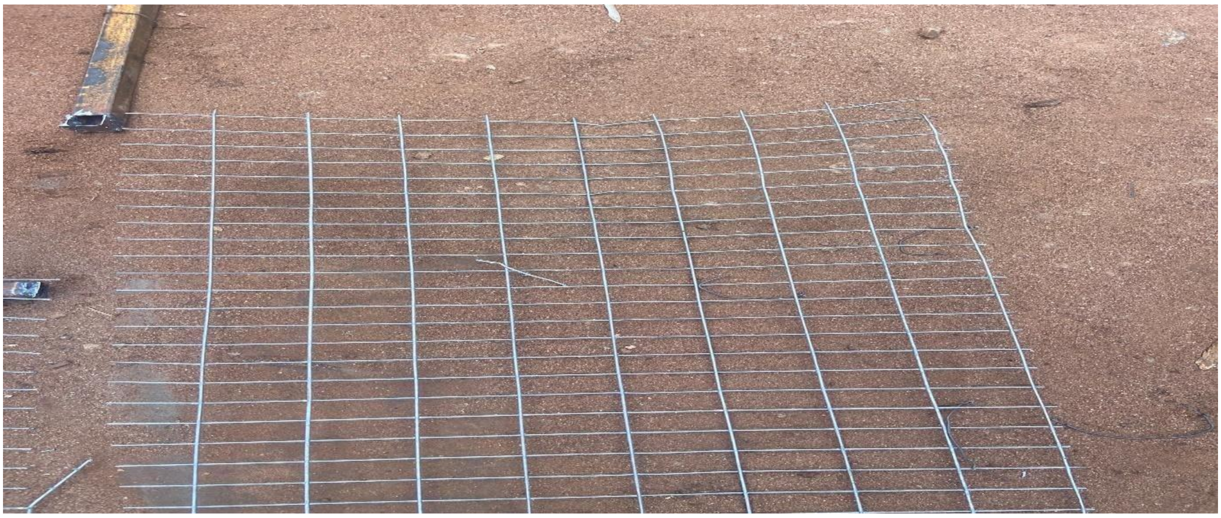

Plate 3.2: Mesh Opening

3.4 Design of Gabion Basket

The gabion basket used for this study was specially fabricated to withstand field/site conditions. The design considered factors such as strength, compaction, ease of filling, stability, and resistance to deformation during loading.

The basket was rectangular in shape, with overall dimensions of 800mm by 700mm by 800mm (length by width by height). It was constructed using galvanized steel wire mesh of 3mm diameter and mesh opening of 60mm by 60mm. The wire mesh was cut to size and joined at the edges by arc welding, forming a rigid rectangular box with an open surface.

The stone fill material consisted of crushed granite with particle sizes ranging from 50mm to 100mm, which were uniformly placed to minimize voids and ensure interlocking.

The gabion basket was fabricated by a local welder in Ekosodin, Benin City, based on the design specifications provided to him.

The design was considered adequate to withstand the applied loading during the testing while maintaining structural integrity and proper drainage characteristics.

Plate 1 shows the fabricated gabion basket used in this study.

3.5 Gabion Basket Making Procedure

The following procedures were followed for the gabion production process:

3.5.1 Assembly

First, the acquired folded gabion units were opened and unfolded to their original shape from the initial bundle and placed on a hard, rigid surface. Then, to form an open box shape, the front, back, and end panels were lifted to a vertical position, ensuring both sides are of equal height. The end panels were folded and secured to cover the basket, and all edges and diaphragms were tied or fastened using a binding wire.

The assembly of the gabion basket was typically done at a welding workshop and then transported to the installation location.

3.5.2 Fastening

To ensure a tight and secure connection of the gabion baskets, the edges of the baskets were tied using sufficient binding wire, as shown in Figure 3.3.

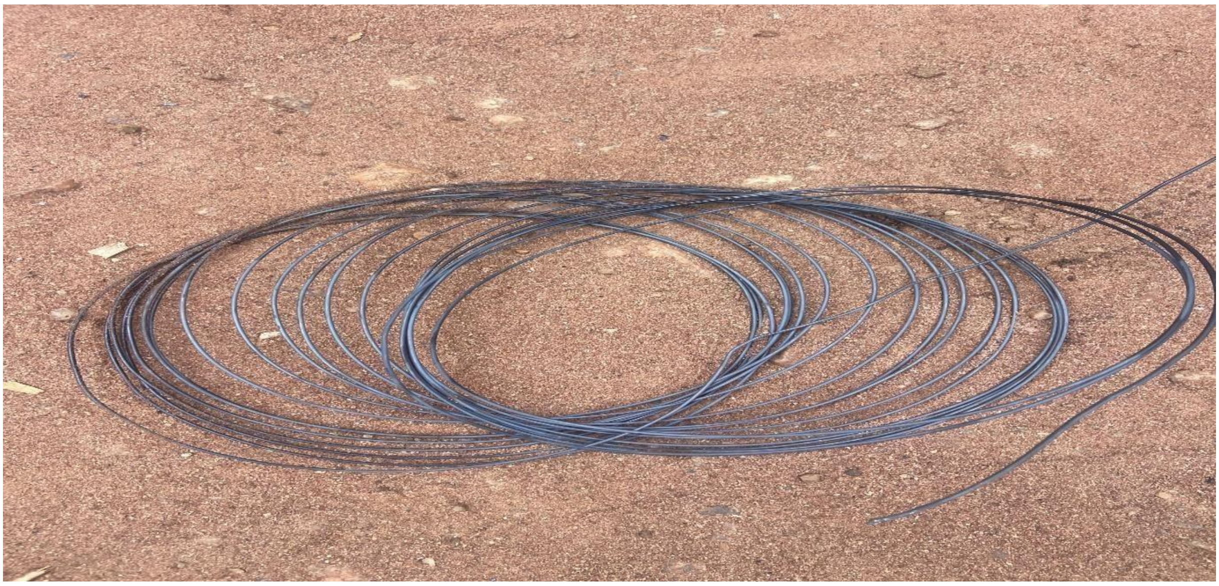

Plate 3.3: Binding Wire for Fastening

3.5.3 Foundation Preparation

The foundation where the gabion baskets were to be placed was prepared to ensure a smooth surface, free from irregularities, loose material, and vegetation, with the location and slope elevation following the project drawings, as shown in Figure 3.4. Available filter fabrics were used to prevent soil and bed material movement under the gabion basket. Bedding and gabions were only placed once the foundation work was completed.

Plate 3.4: Foundation Preparation

3.5.4 Installation, Filling, and Closing of Baskets

After assembly, the gabion baskets were placed in their proper location and connected, ensuring they are aligned before filling with stones. The edges of empty cells were connected with binding wire to form a continuously connected unit. All adjacent gabions were securely laced together to prevent structural failure. For riverbank protection, the baskets were placed with their width perpendicular to the slope, except in small ditches. In sharp curve areas, baskets may be cut diagonally and overlapped to achieve the proper shape. Once assembled, the baskets were placed on adequate bedding material and filled with stones of appropriate size, according to project specifications. The stones were hard, durable, and able to withstand water pressure throughout the structure's lifespan. Stones were placed by hand. Care was taken to avoid damaging the wire coating, and small stones were used to fill gaps between larger stones. The stones were placed compactly within the basket, forming a uniform top surface.

3.6 Performance Evaluation

After the installation of the gabions, visual inspections of the location were done after a month interval to monitor the performance and effectiveness of the structure in erosion control and water conservation. Signs of settlement, deformation, or damage were checked for, and the gabion structure was verified if it meets its intended design purpose.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results of Site Inspection

The site inspection findings revealed erosion characteristics, including the extent of erosion, soil type, and water flow patterns, with photographic evidence and field notes documenting site conditions. Critical areas of erosion were identified based on terrain, water flow, and soil loss, with the upstream section being most vulnerable. Suitable locations for gabion installation were selected based on proximity to critical areas, soil stability, and water flow patterns to effectively control gully erosion. The installation of gabion structures is expected to reduce soil loss, prevent further erosion, and conserve water resources. Some of the photographs from the inspection are shown in Plates A1 and A2 in the appendix.

4.2 : Discharge Estimation

To estimate the discharge across the entire study area, the area was measured using a steel tape, and the discharge was calculated using equation 3.1

$$Q = \frac{CIA}{360} \qquad (3.1)$$

Where,

Q = Total Discharge in m^3/s

C = Dimensionless runoff coefficient

I = Rainfall intensity for a given return period. (Return period is the average number of years within which a given rainfall event will be expected to occur at least once.)

A = Area of catchment (ha).

According to standard, C = 0.4 (Table 3.1)

Oyegoke et al. (2017) provided the peak rainfall intensity for Benin City from empirical derivation as 164.9 mm/hour.

I = 164.9mm/hr.

$A = Area\,of\,Catchment = Length\,of\,catchment(L) \times Width\,of\,catchment(W)$

After the measurement of the portion of the area under study, the following outcome was obtained

Length of area under study, L = 420m

Width of area under study, W = 316.1m

$$A = 420 \times 316.1 = 132762m^2 = (132762 \times 0.0001)ha$$

$$A = 13.2762ha$$

Therefore,

$$Q = \frac{0.4 \times 164.9 \times 13.2762}{360}$$

$$Q = 4.865m^3/s$$

The discharge above is the quantity of water that flows over the study area during rainfall.

The calculated discharge value of $4.865m^3/s$ is a critical parameter in designing and evaluating the effectiveness of the gabion structure for erosion control in the study area. This value represents an estimated quantity of water flow that the structure must withstand, informing design parameters such as gabion basket size, rock size, and structure placement. By considering this discharge value, the gabion structure was designed to effectivelymanage water flow, prevent erosion, and provide long-term stability to the area.

4.3 : Speed and Depth of Water Flow Before and After Gabion Installation

Recall,

$Q = 4.865m^3/s$

4.3.1 : Before Installation

Width = 4.43m

Measured Depth of water flow = 0.71m

$$Area = width \times depth$$

$$= 4.43 \times 0.71$$

$$= 3.15m^2$$

$$velocity = \frac{Discharge}{Area}$$

$$= \frac{4.865}{3.15}$$

$$v = 1.54m/s$$

4.3.2 : After Installation

Width = 6.73m

Measured Depth of water flow = 0.52m

$$Area = width \times depth$$

$$= 6.73 \times 0.52$$

$$= 3.50m^2$$

$$velocity = \frac{Discharge}{Area}$$

$$= \frac{4.865}{3.50}$$

$$v = 1.39m/s$$

Table 4.1 presents the results gotten and recorded before and after the installation of the gabion structure at the study site using the depth and speed of flow as the main parameters to access the impact of the gabion structure on the water flow.

Parameters	Before Installation	After Installation
Depth (m)	0.71	0.52
Speed (m/s)	1.54	1.39

Table 4.1: Results of Speed and Depth of Water Flow Before and After Gabion Installation

According to Table 4.1 above, the installation of the gabion structure resulted in a notable reduction in both depth and speed of water flow. Specifically, the depth decreased from 0.71m to 0.52m, while the speed reduced from 1.54m/s to 1.39m/s. This decrease in flow energy is expected to help mitigate gully erosion by reducing the erosive power of the water. The results suggest that the gabion is effective in stabilizing the gully and preventing further erosion, thereby achieving its intended purpose of controlling gully erosion.

4.4: One-Month Performance Evaluation Results of Gabion Structure for Erosion Control

4.4.1: Appraisal Design Description

The gabion was installed, and after one month, during which a maximum rainfall was recorded, the assessment of the gabion's performance was conducted. The observation location area was separated into three main regions: upstream of the structure (direction from which water flows), the structure itself, and downstream of the structure (direction to which the water flows). Most of the outcomes for various performance evaluation parameters, such as the nature of the gabion basket, gabion rocks, settlement, deflection, wire mesh, and recommendation for repair, were given judgment values – either good, fair, or poor were entered. The states of the gabion structure after 30 days are shown in plates B1 and B2 in the appendix, and the results are analyzed in the following sections.

4.4.2: Analysis of Results

4.4.2 a: Operational Factors

At the time of this project, water flow was maximum, as peak rainfall was recorded; however, observations of operational factors like water levels and flow patterns could not be assessed as a result of the short period of observation. Meanwhile, the structure had experienced a few subsequent runoffs before inspection, allowing for observations of high-water marks and debris gathering, as well as the piling of the topsoil around the installed gabion. There was also the presence of domestic waste materials, such as nylon papers and plastic materials, trapped around the structure. Debris buildup and sand accumulation from erosion somewhat impacted the state and performance of the installed gabion after 30 days. Branches and wood pieces were commonly found trapped in baskets, on the weir, block, and side slopes, potentially causing deformation and dislodgement. Vegetation, including weeds, was also prevalent, with moss potentially reducing the roughness coefficient and energy dissipation. The accumulation of debris and vegetation, as well as the piling of sand around the basket, altered flow patterns, affecting the structure's overall performance.

4.4.2 b: Structure Response

The structure showed no significant settlement, but where settlement occurred, it was minor and primarily at the weir and counter weir. This may be due to the short period of rainfall allowed before the evaluation. Also, deformation was invisible. This could be as a result of the short period of performance that the structure was subjected to. Additionally, minor erosion and siltation were observed at certain parts of the structure.

4.4.2 c: Appraisal Conditions

A comparative rating system (good, fair, or poor) was used to assess key structural elements. Although subjective, this approach provided a reasonable evaluation based on the observations. The structure's operating environment and period of operation significantly influenced these assessments, as age was not a major factor since the structure was barely a month old.

The gabion baskets received ratings from fair to good, with very few deformities noted at impact blocks and weirs. Wire mesh conditions varied from fair to good. Gabion rock conditions also ranged from fair to good, with the fair rating due to minor displacement or oversized rocks.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

The study assessed the effectiveness of gabion retaining structures in mitigating gully erosion within the Federal College Road area of Benin City, Edo State, Nigeria. Findings from the site inspection showed that erosion was most severe in the upper part of the site, mainly due to the slope, soil type, and concentrated surface runoff. The calculated discharge value of 4.865 m^3/s served as an important design factor, ensuring that the gabion structures were properly sized, well-packed, and positioned to handle the expected water flow.

After installation, there was a clear reduction in both the depth and speed of water flow—from 0.71 m to 0.52 m in depth and from 1.54 m/s to 1.39 m/s in speed. This reduction shows that the gabion structure effectively lowered the energy of flowing water and reduced its ability to cause erosion, helping to stabilize the gully and prevent further soil loss.

A one-month performance check showed that the gabions remained stable, with only minor settlement and no major deformation. Some silt buildup, vegetation growth, as well as debris and domestic waste accumulation were noticed, but did not significantly affect performance. The main parts of the gabion—baskets, rocks, and wire mesh—were rated between *fair* and *good*, showing satisfactory short-term results.

Therefore, the gabion retaining structures successfully reduced gully erosion by lowering water flow speed, stabilizing the soil, and conserving water. Although the evaluation covered a short period with light rainfall, the results indicate that gabions are reliable, durable, and cost-effective for erosion control.

5.2 RECOMMENDATIONS

Based on the findings of this study, the following recommendations are made to enhance the performance, durability, and long-term effectiveness of gabion retaining structures in gully erosion control:

i. Since this study covered only one month, a longer monitoring period—covering both dry and rainy seasons—should be undertaken to fully assess the gabion's long-term performance. Data from extended monitoring will help in refining design standards and predicting maintenance intervals for similar projects.

ii. Domestic waste and debris, such as plastic materials and branches, should be regularly removed from the gabion site. Their accumulation can block water flow, alter drainage patterns, and increase pressure on the structure, potentially causing damage over time. Community awareness programs on proper waste disposal near drainage and gully areas should also be encouraged.

iii. The gabion structures should be inspected periodically, especially after heavy rainfall events, to detect early signs of deformation, wire breakage, or rock displacement. Timely maintenance, such as tightening the wire mesh, replacing displaced rocks, and clearing trapped debris, will help sustain the structural integrity and efficiency of the gabion over time.

iv. Local community members should be engaged in the maintenance and protection of gabion structures. Training programs can be organized to teach simple repair techniques and monitoring practices. This will promote sustainability and reduce maintenance costs.

v. It was observed that there was a sand build-up around the structure at the upstream part. Therefore, planting suitable grass and shrubs around the gabion structure is recommended to complement its mechanical strength. Vegetation will help bind the soil, reduce surface runoff, and enhance slope stability. The combination of gabions and vegetation (bioengineering) provides a more sustainable and eco-friendly erosion control approach.

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APPENDIX

GABION BASKET PICTURES AND SITE PICTURES

Plate 1: Designed gabion basket

Plate A1 **Plate A2**

Plates A1 and A2: Different sections showing the erosion extent of the selected area.

Plate B1

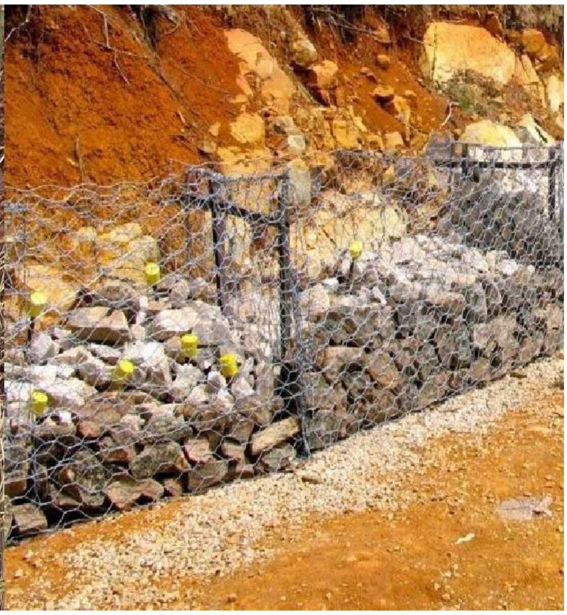

Plate B2

Plates B1 and B2: State of gabion structure after 30 days.