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Valuation of On-site Gully Erosion Control Benefits in Gombe Metropolis, Gombe State, Nigeria

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ABSTRACT

Soil erosion remains a significant environmental concern globally, with gully erosion identified as one of the most severe forms contributing to land degradation, particularly in rapidly urbanising areas like Gombe Metropolis, Nigeria. This study examines the economic benefits of gully erosion control measures implemented at two major sites within Gombe Metropolis, GSU-Mallam Inna-Kagarawal and FCE (T)-Jauro Abare-Jauro Kuna-M/Inna-Wuro Kesa-Tukulma. Using a combination of market-based, non-market-based, and value transfer economic valuation methods, the research quantifies the avoided damages and on-site benefits of erosion mitigation projects. Data were gathered through satellite image analysis, interviews with affected populations and officials, and document reviews. Findings reveal that while both sites demonstrated substantial on-site benefits, the FCE (T) gully site yielded significantly higher economic returns due to its scale and the number of communities affected. The total discounted benefit for the GSU site over 30 years was ₦2.61 billion, whereas the FCE (T) site generated a discounted benefit of ₦21.23 billion. The study highlights the importance of integrating comprehensive control strategies, including structural, biological, and socio-economic interventions, to enhance the sustainability and effectiveness of gully erosion mitigation efforts.

Keywords: Market-based valuation, gully erosion, on-site benefits, control benefits

INTRODUCTION

Soil erosion remains one of the world's most pressing environmental problems, threatening the sustainability of both plants and animals in the ecosystem. Over 65% of the soil on Earth is reported to have exhibited degradation phenomena due to soil erosion, salinity and desertification (Abegunde, 2003 as cited in Aliyu, 2017). The United Nations (UN) Convention to Combat Land Degradation (CLD) opines that soil erosion results in a reduction or loss of the biological and economic productivity and its impact on terrestrial ecosystems (Claassen, 2004). Erosion is one of the surface processes that sculpt the earth's landscape and constitutes a global environmental problem (Abdulfatah et al., 2014).

According to Romero-Diaz et al. (2019), gully erosion is one of the processes leading to land degradation in various environments. At different spatial and temporal scales, gully erosion causes considerable soil losses, damage to infrastructure and exports large amounts of sediment (Romero-Diaz et al., 2019). Gullies constitute water erosion and represent an environmental threat worldwide, affecting multiple functions of soil and land (Romero Diaz et al., 2019).

Gully erosion is a significant driver of land degradation globally, as is illustrated by the magnitude of soil erosion rates by gully erosion and the numerous countries that are severely affected (Romero-Diaz et al., 2019, as cited in Pathak et al., 2005; Brown, 1981; Castillo and Gómez, 2016). A gully, as defined by the Soil Conservation Society of America (1982) as cited in Romero Diaz et al (2019) is "a channel or miniature valley cut by concentrated runoff through which water commonly flows only during and immediately after heavy rains or during the melting of snow; it may be dendritic or branching or linear, rather long, narrow, and of uniform width". Kirkby and Bracken (2009) stated that "a gully is normally defined as deep channel on a hillside, generally cut by running water, and often not containing a perennial flow".

Gully erosion control measures are grouped into agronomic and engineering. Agronomical control provides the soil with physical protection against scour and slows down the velocity of flow by increasing the hydraulic resistance of the channel (Lal, 1988, cited in Amangabara, 2012). The engineering method involves structural design to control runoff and gully erosion in the field, where biological control practices alone are insufficient to reduce gully erosion to permissible levels. Therefore, for effective erosion control, a combination of these measures must be employed. Alternates may be approved for individual gully and sediment control plans. In general, they fall into the rather broad categories of structural practices and vegetative measures (GSWCC, 2000).

The incidents of gully have caused much concern to successive governments and other stakeholders in Gombe State, with concerted efforts to control them being taken each year. Various methods adopted by the government and residents of Gombe metropolis in gully erosion control include engineering, tree planting or vegetation, stone wall, sand bag and diversion of runoff. However, the control has not kept pace with the rate of gully expansion or growth, as some of these measures have been fully or partially successful. Others have failed, partly due to inadequate funds to adopt a holistic method of control that may involve a combination of both or single methods of engineering and mechanical, or vegetative and biological, as well as the stone/gabion method (Mbaya, 2017).

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In economic terms, erosion control measures can only be considered for implementation only when the cost of the control is not higher than the value of the erosion impact avoided, this means that the erosion meaning from the economic point of view may be somewhat dynamic than in the physical sense, but minor soil removal are still erosion in a physical geography point of view (Haydones, Peter, Barbara, and Phillips, 2008). Assessing the costs of erosion's negative impact may allow policymakers to implement various soil conservation measures. Furthermore, economic analysis of gully control allows for the implementation of the most effective gully control measure among various mitigation measures (Haydones et al., 2008).

In the literature dealing with the economics of erosion such as that provided by Haydones, *et al* (2008) the effects of erosion are generally subdivided into two broad categories, on-site effects (i.e. effects occurring on the properties where erosion takes place) and off-site effects (i.e. downstream effects, usually resulting from sediment deposition on other properties or in watercourses). Another distinction that is sometimes made is between direct effects (i.e. those arising on properties directly affected by erosion and deposition) and indirect effects (i.e. those arising from properties not directly affected, such as costs arising from erosion-induced disruption to transport arteries or in the flow of produce available to be processed). However, the distinction between temporary and longer-term effects is often not made because both types of effects are captured in a discounted cash flow or cost-benefit analysis over time.

On-site effects are those directly felt by the properties experiencing erosion. The off-site effects are those directly impinging on activities off-site, largely due to sedimentation and deposition. Indirect effects involve those affected entities as a consequence of a direct impact felt elsewhere, such as a processing plant that suffers reduced value added from changes in supply from primary producers, or similarly, other primary producers who rely on the affected properties for part of their business. Some variation in the characterisation of effects exists in the literature, depending on the nature of specific studies and the data available to them.

Study Area and Methodology

Study Area

Gombe Metropolis is located between latitudes 10^0 14'30" N to 10^0 20'30" N and longitudes 11^0 7'E and 11^0 14'E. It has some part of Akko LGA in the south and west, Yamaltu-Deba to the east, and Kwami to the north, as a metropolis. The metropolis occupied a total land mass of about $45Km^2$ (Aliyu 2024), see figure 1.

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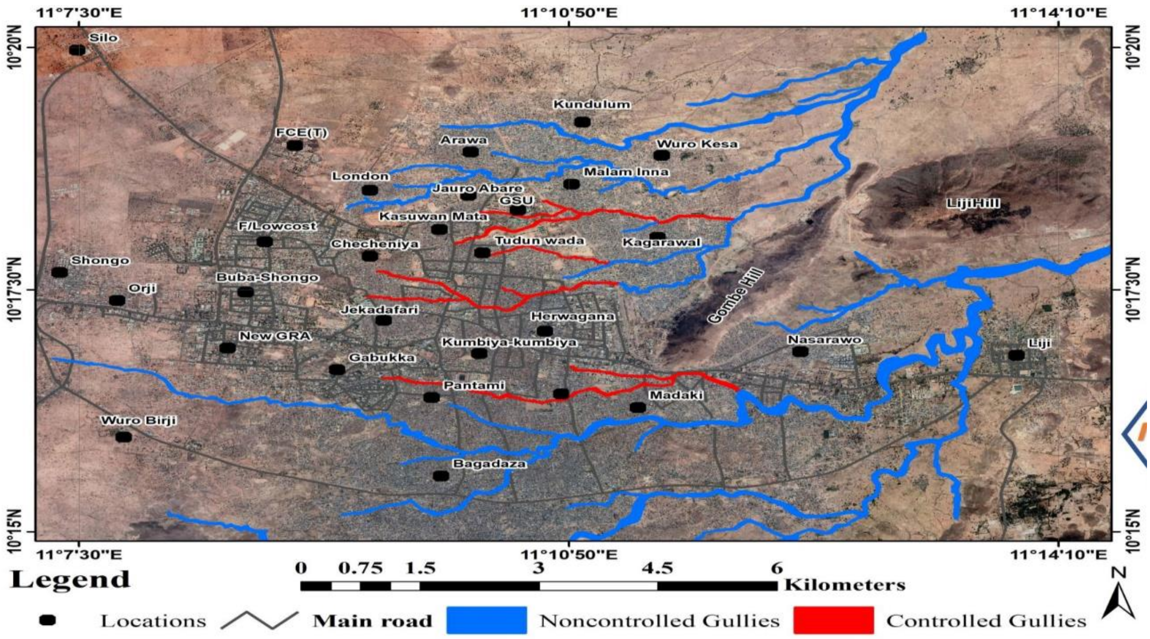

Figure 1: The Study Area. ***Source:*** Adopted from Aliyu (2024).

MATERIAL AND METHOD

Reconnaissance Survey

A reconnaissance survey was carried out first to get acquainted with the catchment, the gullies in the study area, and to observe some of the properties, including houses, economic trees and plots threatened by gullies.

Distribution of Gullies across the Study Area

Studies conducted by Aliyu (2024) in Gombe metropolis on gully erosion and assessment of gully situation in the metropolis, respectively, show that the total length of gullies within the metropolis was about 62,639M (62.64km) (Table 1).

Data Required

The data required for this study included data from field work and other primary and secondary sources. Data about the different benefits acquired as a result of the selected projects by project-affected persons were obtained, and the estimated cost of the benefits in terms of monetary value (Table 2).

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Table 1: Distribution of some Gully Erosion Sites in Gombe Metropolis

S/N	Name of Gullies	Length	Location
1	Gully Erosion site from Wuro Bajoga to Barunde Bridge with fingers.	7434m	Akko L.G.A
2	Gully Erosion site from F.C.E (Tech) staff sch. To railway line.	3580m	Gombe, Gombe L.G.A
3	Gully Erosion site from Checheniya to local govt. workshop Gombe	1500m	Gombe, Gombe L.G.A
4	Gully Erosion site from Railway line to Mallam inna boreholes.	3566m	Gombe, Gombe L.G.A
5	Gully Erosion site from Barunde Bridge to Bogo Stream.	2830m	Gombe, Gombe L.G.A
6	Gully Erosion site at Dawaki Qrts. Gombe.	450m	Gombe, Gombe L.G.A
7	Gully erosion site from mummy market to Kwanan Alheri.	2567m	Gombe, Gombe L.G.A
8	Gully erosion site at markazu science secondary.	1370m	Gombe, Gombe L.G.A
9	Shamaki/Tudunwada- -comprehensive to Railway line (phase2).	3563m	Gombe, Gombe L.G.A
10	Gully Erosion site from Orji housing estate to Shongo housing estate to CBN drain.	175m	Gombe, Gombe State.
11	Riyad qrts. Gully erosion site	711m	Riyad, Akko L.G.A,
12	Gully erosion site, second gate Gombe State University, Jauro Kuna Gombe.	800m	Gombe, Gombe State.
13	Gully erosion site from railway line Arawa B to WuroKesa.	1238m	Arawa B, Akko L.G.A
14	Gully erosion site from old Yola Road to Buhari model primary school (phase 1).	3650m	Gombe, Gombe L.G.A
15	Gully erosion site from Buhari model primary school to Bagadaza (phase 2).	2944m	Gombe, Gombe L.G.A
16	Gully Erosion site from Railway Line to Unguwa Uku.	5621m	Gombe L.G.A.
17	Gully Erosion site from Bishop's House to Buhari Estate.	550m	Gombe, Gombe L.G.A
18	London mai Dorawa to G.S. U	1,625	Gombe, Gombe L.G.A
19	Behind Joy Academy, Buba Shongo	502	Gombe, Gombe L.G.A
20	Makwalla Darazawa Junction- Sani Labaran House	605	Gombe, Gombe L.G.A
21	Mammy Market- Abubakar Umar Memorial Pri. Sch. Army Barrack	485	Gombe, Gombe L.G.A
22	FRSC Office New GRA- Tula Road, behind former quarters	2,246	Gombe, Gombe L.G.A
23	Herwagana Modibbo-Railway	1,920	Gombe, Gombe L.G.A
24	Kasuwan Shanu-Tudunwada Pri. Sch.	1,100	Gombe, Gombe L.G.A
25	Pantami-Barunde-Madaki-Doma phase II	1,250	Gombe, Gombe L.G.A
26	Nassarawo Phase A and B	957	Gombe, Gombe L.G.A
27	Wuro Bundu-Tumfure	560	Gombe, Gombe L.G.A
28	Pantami-Barunde-Madaki-Doma phase I	890	Gombe, Gombe L.G.A
29	Herwagana Primary School	250	Gombe, Gombe L.G.A
30	G.S.U-Mallam Inna-Kagarawal	7700	Gombe, Gombe L.G.A
	Total	**62,639M**	

Source: NEWMAP, Gombe State Office, (2021) & Fieldwork (2022).

Table 2: Summary of Data Required, Types and Sources

S/N	DATA REQUIRED	TYPES	SOURCES
1	Number of gullies, distribution and sections under control measures in the study area	Primary/researcher constructed data	Fieldwork, satellite image analysis, key informant interview, documented data.
2	On-site monetary value of the gully control benefits	Primary/researcher constructed data	Key informants interview, interaction with sampled PAPs, survey reports and publication

Source: Researcher constructed (2023).

Sources of Data

The sources of data for this study were derived from primary and documented sources, otherwise referred to as secondary sources of data. The primary data included data obtained from the gully control project sites, through classification and analysis of satellite images,

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in-depth and key informant interviews as well as interactive sessions with sampled project affected persons and other people living around the gully sites whose properties were directly or indirectly affected as a result of the control project and also with some officials of the State Ministry of Environment, the LGA Environment Department, the ACReSAL and officials of other relevant agencies.

Data Collection

The methods adopted for data collection for objectives i to v are as follows:

(a) ***Satellite image classification and Analysis:*** High-resolution satellite imagery and aerial photographs were identified and acquired for 2023. These images covered the area of interest, i.e Gombe Metropolis. The acquired images were georeferenced to align with the images to real-world geographic coordinates so that they were accurately overlaid on the GIS data. Controlled and non-controlled gullies were identified and differentiated using colours. Information obtained from this analysis includes two classified images; these are:

(i) Classified Image showing the distribution of gullies in Gombe Metropolis.

(ii) Classified Image showing sections of gullies that were controlled or uncontrolled in Gombe Metropolis.

(b) ***Interviews:*** In-depth interviews and interactions were conducted with the members of the communities affected by the project, especially the project-affected persons, at each of the project sites selected; 25% of the affected persons were randomly selected from the list of project-affected persons for the interview to avoid bias. Another set of interviews was conducted with officials of the relevant agencies responsible for the project, including the Ministry of Environment and ACReSAL staff. Two research assistants were employed and trained for the field work.

(c) ***Economic Valuation of Cost and Benefit:*** Economic valuation is a tool used to quantify the benefits of the gully erosion control project in monetary terms. Various methods have been developed to translate the value of the gully control project benefit into financial value. However, not all gully control benefits can be valued in monetary units (Xiang, 2018).

In general, economic valuation methods can be divided into three, namely, market-based, non-market-based valuation methods and value transfer (Xiang, 2018). It is important to note that the suitability of any of the methods mentioned above depends on the different costs and benefits of gully erosion projects under study. The market-based valuation method is based on existing market behaviour, including direct market valuation (e.g. direct market price) and indirect market valuation (e.g. avoided damage cost, replacement cost, travel cost). Non-market-based valuation methods are more applicable to valuing intangible benefits such as soil loss and nutrient loss that are associated with off-site effects compared to market-based valuation methods. The principle of the value transfer method is to estimate the benefits value based on the results of other valuation studies in similar conditions. Both market-based and non-market-based valuation methods, as well as value transfer, were used to evaluate different benefits and costs associated with the control projects.

Valuation of Benefits of the Control Project

In the valuation of the benefits of action against gully erosion, the costs of inaction represent the maximum level of benefit from action against land degradation (Mesfin, Singh, Apindi, Jane, Zinta and Gyde, 2015). The theoretical maximum benefits of action referred to the cost of inaction against the gully erosion problem in the area. The actual benefit of action, however, depends on the level of efficiency of the type of intervention or action in averting the gully erosion menace. Hence, the level of reduction in the associated lives and property losses. For example, different gully erosion control measures have different levels of efficiency in controlling gully erosion. It is also not possible to realise all of the costs of inaction into benefits at a time, because action or intervention requires both time and resources. Therefore, it is imperative to note that realistic assumptions will be used in estimating the benefits of action based on the market, non-market and value transfer valuation in calculating the cost-benefit analysis for this research work. Thus, for this study, the benefits of action were estimated as a fraction of the costs of inaction using the following equations according to Mesfin *et al.* (2015), where the fraction (λ) represents the rates by which the value of inaction was converted into benefits as follows:

$BA1 = n\lambda CIA1$……………………………………………. (3.1)

$BA2 = n\lambda CIA2$……………………………………………. (3.2)

Where:

BA1 = value of avoided physical properties lost.
BA2 = value of avoided economic trees lost.
λ = rate by which the factor causing the property lost is reduced at the time (t).
n = t-1 indicating that at the initial year of intervention n=0 and hence zero benefit.

Sampling Size and Sampling Techniques

Two gully sites were chosen for the economic valuation of gully control benefits. Note that these two gully project sites were selected because a standard resettlement action plan and other environmental and social standards policies, based on global practices, were incorporated into the projects. Therefore, to conduct economic valuation of the accrued benefits resulting from the gully control efforts, the following gully sites were also purposively selected:

1. GSU-Mallam Inna-Kagarawal Gully site. (known as the ***GSU Project site***)
2. FCE (T)-Juro Abare-Jauro Kuna-M/Inna-Wuro Kesa-Tukulma (known as ***FCE (T) Project Site***).

Out of the total number of projects, the number of affected persons for the two selected gully project sites was 120 persons for GSU and 324 persons for FCE (T) Gully sites, respectively. A simple random technique was used to select respondents from each gully erosion control project-affected community.

RESULTS AND DISCUSSION

On-site Benefit of Gully Erosion Control in the Study Area

The study also achieved objective four, which required the quantification or valuation of the on-site benefits of selected gully erosion control projects in the study area. Table 3 describes the variables associated with Resiliency Value or the losses avoided as a result of project implementation that are valued in monetary terms (Naira). Losses avoided in this case include direct physical damage and disruption, displacement, and human impacts, such as loss of life. Table 3 also presents the description and detailed results associated with the programmed elements of the project. These are the inherent social, economic, and environmental benefits associated with improvements being made to the Target Area communities. These are also estimated and valued in monetary terms.

On-site Benefits of GSU Gully Control

Table 3 identifies the benefits of the gully control project at GSU-Mallam Inna-Kagarawal. These benefits were identified through analysis of the project impacts and in-depth interviews with stakeholders and project-affected persons. Besides the projects, the community benefited from a series of sensitisation workshops on life skill aspects, such as waste management, waste-to-production, flood early warning system and Gender-Based Violence (GBV). Other benefits listed by the community included distribution of cash to old and vulnerable community members, as well as distribution of surface tanks to some community members for water harvesting. These benefits were quantified and valued in monetary units of Naira using the economic valuation method stated earlier. The result indicates that the direct physical damage to structures was valued at seventy-six million, nine hundred and forty-six thousand, six hundred and fourteen Naira (₦76,946,614) using the indirect market price and value transfer since it was an avoidable damage.

Economic trees were valued at two million, seven hundred and sixty-one thousand Naira (₦2,761,000). The social safety programme was valued at one million Naira (₦1,000,000) and three million Naira (₦3,000,000) for watershed management (Table 3). An employment opportunity offered by the project was not quantified in the benefit valuation because workers' employment was factored into the total contract sum, and many belong to both the contractor and the government.

Table 3 also shows that the direct value of the project is eighty-seven million, fifty-seven thousand six hundred and fourteen Naira (₦87,057,614) for the year, representing 19.51% of the total. This figure is low compared to that of FCE (T); this may be due to the length of FCE Gully, which is more than that of GSU Gully, as well as the number of communities the gully passes through, which are also more under FCE gully projects than that of GSU gully erosion control project. It relates to the future years of the expected project life span of 30 years to determine the discounted benefits value as shown in the formula; thus, (Bt X t) = total discounted benefit, where Bt = total benefit cost, while t = time horizon for the expected project lifespan.

(₦87,057,614 X 30years) = ₦2,611,728,420.

Therefore, this represents the total discounted benefit of the gully project.

On-site Benefits of FCE (T) Gully Control

The value of the FCE (T) project benefit in monetary value shown in Table 3 is three hundred and fifty-nine million one hundred and ninety-one thousand one hundred and fifty-seven Naira (N359, 191,157.00) for the year, representing 80.49% of the total. This was related to the future years of expected project life span of 30 years to determine the discounted benefits value; thus, (Bt X t) = total discounted benefit, where, Bt = total benefit cost, while t = time horizon for expected project lifespan.

(₦707,579,614 X 30years) = ₦21,227,388,420.00.

Therefore, this represents the total discounted benefit for the FCE-Arawa gully project.

The total discounted benefit value for the FCE gully erosion control project is higher than that of the GSU gully erosion control project, because the FCE gully is longer and passes through more communities; therefore, it has more properties and **a larger** number of PAPs to be resettled than the GSU gully erosion control project. The major finding here is that many structures, including houses, plots, and business premises, were demolished and residents compensated and resettled because of the control project. The members of the community benefited from interventions and sensitisation workshops to alleviate any effect that the control project might have caused. The implication was that some benefits that arose as a result of World Bank policy may not necessarily be available in other gully control projects embarked upon by the State government.

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Table 3: List of Benefits quantified and Included in NPV and BCR.

Gully	Benefit	Description	Calculated Benefit	Valuation Method	Benefit cost (N)	% Benefit
			Resiliency Value			
GSU-M/inna-Kag. 1	Direct Physical damage to buildings, shops, and plots/Displacement	The loss of valued structure as a result of the project which force for involuntary resettlement and subsequent destruction of the properties	Damaged plots Damaged houses Damage shops	In-direct/non-market/valve transfer	76,946,614	88.4
2	Destruction of economic trees	Loss of economic and other valuable trees during project execution	Damage economic trees	In-direct/non-market/valve transfer	2, 761,000	3.2
			Inherent Value			
3	Social safety intervention	Provision of safety net to vulnerable people around the GSU gully project area	Distribution of cash to vulnerable people	In-direct/non-market based	1,000,000	1.1
4	Watershed management	Protecting the channel from creating other rills as a result of water flowing from houses	Distribution of surface tanks for rain water harvesting and conservation	Direct/ market based	3,000,000	3.4
5	Formation of catchment school's environmental clubs	Support the establishment of environmental clubs in four different schools in the area	Distribution of materials to support the clubs	Direct/market based	450,000	0.5
6	Workshops/sensitization	Training and sensitization on different livelihood aspect	Waste management Flood Early warning systems Gender based violence	Market and non- market based	2,400,000	2.8
7	Environmental benefits	Benefits Environmental benefits will be gained from implementation of the project, which is designed to incorporate plantings of trees, provide	Air quality Climate regulation Control soil erosion	Indirect/non-market based	500,000	0.6

		connectivity between neighborhoods and the waterfront				
	Total				**87,057, 614**	**100**
		Resiliency Value				
FCE (T)-Arawa 1	Direct Physical damage to buildings, shops, and plots/Displacement	The loss of valued structure as a result of the project which force for involuntary resettlement and subsequent destruction of the properties	Damaged plots Damaged houses Damage shops	In-direct/non-market/valve transfer	691,976,914	98
2	Destruction of economic trees	Loss of economic and other valuable trees during project execution	Damage economic trees	In-direct/non-market/valve transfer	2,352,700	0.3
		Inherent Value				
3	Social safety intervention	Provision of safety net to vulnerable people around the GSU gully project area	Distribution of cash to vulnerable people	In-direct/non-market based	2,000,000	0.2
4	Watershed management	Protecting the channel from creating other rills as a result of water flowing from houses	Distribution of surface tanks for rain water harvesting and conservation	Direct/market based	5,000,000	0.7
5	Formation of catchment schools environmental clubs	Support the establishment of environmental clubs in four different schools in the area	Distribution of materials to support the clubs	Direct/market based	450,000	0.1
6	Workshops/sensitization	Training and sensitization on different livelihood aspect	On waste management Waste to production Flood Early warning systems Gender based violence	Market and non- market based	4,800,000	0.7
7	Environmental benefits	Benefits Environmental benefits will be gained from implementation	Air quality Climate regulation Control soil erosion	Indirect/non-market based	1000,000	0.1

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	of the project, which is designed to incorporate plantings of trees, provide connectivity between neighborhoods and the waterfront		
Total		**₦707,579,614**	**100**
Grand Total		**₦794,637,228**	

Source: Researchers' Construct (2023)

CONCLUSION

This study assessed the economic valuation of on-site benefits resulting from gully erosion control projects in Gombe Metropolis. Through a detailed analysis of two major intervention sites, it was established that erosion control efforts, particularly those supported by international best practices and comprehensive resettlement frameworks, can yield significant long-term economic benefits by mitigating damage to property, infrastructure, and the environment. The findings reveal that most of the uncontrolled or partially controlled gullies have increased in length within the said period. The GSU and FCE (T) sites illustrate that both projects were beneficial; the scale, design, and multi-community impact of the FCE (T) project led to a higher economic return. These findings underscore the need for holistic erosion control approaches that blend engineering and biological methods with community engagement and socio-economic support. Furthermore, economic valuation serves as a vital tool for policymakers in prioritising and funding erosion control initiatives, ensuring that the cost of intervention remains justified by the benefits accrued. Future gully control strategies in Gombe should incorporate standardised valuation frameworks to optimise impact and sustainability.

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