Mapping and Controlling Gully Erosion in Enugu State: NEWMAP's Integrated Approach of Utilizing GIS, Awareness Programs, and Stakeholders' Engagement

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Abstract: The World Bank and other international agencies have identified gully erosion as a major threat in Nigeria's Southeast, notably Enugu State. The Geographic Information System, or GIS, has been involved in recorded attempts to deal with this calamity as a bold way of providing trustworthy and long-term remedies to gully destruction. The researcher obtained the information, materials, and techniques via onsite research, interviews, high-resolution imagery from satellites, a digital elevation model (DEM), as well as ArcGIS 10.3 software as a component part of a Geographic Information Systems (GIS) consultancy service that was offered to Enugu State NEWMAP by REDDFOX Nigeria Limited supervised by the writer of the article, who worked as the consultants' overseeing officer in facilitating the approval process of the consultancy service. During the procedure, a total of 508 potential gully erosion sites were identified, with 51 of them finally being recognized. The detailed results were divided into two parts: (a) map products and (b) GIS products. The map deliverables included composite maps that showed all erosion sites, highways, and communities; land cover; erosion risk; flood vulnerability; digital soil maps; and topographic and watershed maps. The GIS deliverables, on the other hand, came in the form of a folder containing ArcGIS 10.3 software. The folder contains composite site data as well as separate site subfolders. The erosion site data composites were further classified into four types: maps, composite shapefiles, database documents, and database quarry platforms. All of this was given a personal touch through awareness-raising, stakeholder dialogue, and involvement. Based on the preceding, this method is deemed an effective and unique method for detecting gully erosion sites, their distributions, causes, and consequences within the research region. A multi- and cross-sectoral Environmental Management Information System (EMIS) is advocated as a model for monitoring and management for the sake of sustainability.

Keywords: Gully erosion, GIS, Mapping gullies, NEWMAP, Consultation

1. INTRODUCTION

Projects have come and gone in the country, with varying degrees of success. What is more essential, however, is the legacy of worldwide best practices techniques for handling comparable challenges, particularly in the areas of environmental and catastrophe risk management. This novel GIS technique was used during the full implementation of the Nigeria Erosion and Watershed Management Project (NEWMAP). These are demonstrated by the identification of gully erosion locations, the delineation of project intervention sites, the Resettlement Action Plan (RAP), the Environmental and Social Management Plan (ESMP), and the Environmental and Social Impact Assessment (ESIA) studies. Needs assessment, livelihood restoration, engineering design and operation, maintenance, and monitoring are among the others. The objective of this study is thus to detail NEWMAP's novel strategy in order to facilitate replication in solving comparable environmental concerns in Nigeria. The objectives listed below can help you reach this aim.

Objectives

The study's specific objectives are to: i. examine the distribution of gullies in the study area using GIS; ii. Identify the causes of gully erosion and identify areas affected by gully erosion; iii. Assess the impacts of gully erosion on the development of the area; iv. Investigate the uniqueness of the NEWMAP erosion control approach; and v. determine effective and sustainable control measures in light of recommendations for improved replication.

2. REVIEW OF RELATED LITERATURE

GIS has been characterised in a variety of ways by various writers and authorities, including wide and limited perspectives. Dale (1991) defined GIS as "a computer-based technology that aids in the management, manipulation, analysis, and display of spatial (mapped) data in the decision-making process." ESRI (1910) characterised GIS in a nutshell as "an organised collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyse, and display all forms of geographically referenced information." Based on these broad and specific interpretations, GIS can be broadly defined as a computerized system that utilizes software applications to effectively capture, store, verify, integrate, manipulate, analyze, update, and visually represent spatially referenced data. This technology can be further classified into six main categories based on their intended functionality and type: Professional GIS, Desktop GIS, Handheld GIS, Component GIS, GIS Viewers, and Internet GIS (Akinmoladun, 2003) as outlined below:

Professional GIS – high-end, fully functional systems with facilities for data collection and editing, database administration, advanced image processing and analysis module. Some of the examples are: ERDAS (Earth Resources and Analysis System), ESRI's Arc Info, ELAS (Earth Laboratory Analysis System). This type is very expensive and its use is restricted to technically E

Desktop GIS – The most popular and frequently used that focus on data use rather than data collection with excellent tools for making reports, charts and map production. Their examples include: MapInfo Professional, Clark University's Idrisi and ESRI's ArcView.

Component GIS – Used by software developers to create focused applications. They are usually toolkits of GIS functions which are used by programmers to build full GIS systems. Their examples are MapInfo, MapX and ESRI's MapObjects.

Handheld GIS – Lightweight systems designed for mobile and field use. They have many of the same capabilities as the desktop system. They are capable of supporting display, queries, and simple data analysis. The examples are ESRI's ArcPad and Small world Scout.

GIS Viewers – have limited functional and are restricted to query, simple mapping and display. They are special in helping software vendor to establish market, share and disseminate specific vendor terminologies and data formats as de facto standards. It is usually distributed free.

Internet GIS – Most patronized but limited to simple display and queries. Majority of the vendors often exploit the unique characteristics of the **World Wide Web (www)** by developing GIS technology that integrates **Hyper Text Transmission Protocol (http)** for communication. The examples include MapInfo Extreme and ESRI's ArcIMS.

There has been an increased awareness and wider acceptance of GIS in the field of land surveying and urban planning as a tool to manage the urban areas, especially in developed countries. In like manner, GIS (Geographic Information Systems) are commonly used as planning and analysis tools in developing countries (Forrester et al, 2002).

The importance of gathering all necessary spatially-referenced data in a computer compatible form is paramount to any GIS. Four common methods of acquiring data into a digital mapping system, namely photogrammetric, remote sensing, ground survey methods, and cartographic digitization. Equally important is to understand that the data collected must have been measured with sufficient accuracy, encoded, structured and labelled with appropriate descriptive codes and attributes to enable it to be used in the available system (Nwilo, 1998; Akinmoladun, 2003). GIS application has been found to be very useful in addressing environmental issues particularly gully erosion and other land degradation. Extant studies have shown that formation and impacts of gullies are among the greatest environmental disasters in Southeastern Nigeria. Natural factors including the nature of the soil, topography, erosivity and erodibility make these areas susceptible to gully erosion while most of the gullies are linked to human activities especially through improper development and poor land management (Ezezika and Adetona, 2011; Nwilo et al, 2011; ENS- NEWMAP, 2014). The studies equally noted that the impacts have greatly been observed and felt in displacement of people, damage to land and agricultural produce, destruction of houses, roads/transport and other infrastructures. Going by the complexity of gully erosion devastation, failure of many decades of budgeting efforts through ecological fund and local strategies, it is obvious that a new technological approach of integrated form is required. This involves integration of sensitization of people in the causes and effect of gully erosion, public participation and application of GIS in identification and addressing the gullies.

Sensitization, according to Un-Habitat (2001) refers to the process of giving regular briefings and trainings to stakeholders at different levels, to create a better understanding of the participatory process and to "sensitize" them to the kind of changes in planning and management which are promoted through the process.

Causes of Gully Erosion

Gully formation can be attributed to a range of factors, including natural causes as well as human activities that have a significant impact. In South-Eastern Nigeria, the soil types are particularly prone to water erosion, making them highly susceptible to gully formation. Once a gully begins to form, it tends to expand rapidly, making it challenging to control. This is primarily due to several factors:

1. Soil Nature and Weather Elements: The characteristics of the soil, combined with adverse weather conditions, contribute to the rapid expansion of gullies. Certain soil types in the region are more vulnerable to erosion, exacerbating the problem.

2. Improper Road Drainage Design and Construction: Inadequate planning and construction of road drainage systems can contribute to gully formation. When roads lack effective drainage mechanisms, water accumulates and exacerbates erosion, leading to gully development.

3. Inadequate Road Drainage Maintenance: Insufficient maintenance of road drainage infrastructure can worsen gully formation. If drainage systems are not regularly cleared and maintained, they become less effective in channeling water away, allowing erosion to intensify.

4. Delayed Gully Control Measures: Failure to promptly address gully formation can result in its rapid expansion. Timely implementation of gully control measures is crucial to prevent further erosion and minimize the damage caused.

5. Poor Solid Waste Management: In urban and sub-urban areas, inadequate solid waste management practices can contribute to gully formation. Improper disposal of waste can lead to the clogging of already insufficient drainage systems, impeding water flow and exacerbating erosion.

6. Destructive Land Use Practices: Unsustainable land use practices also contribute to gully formation. Activities such as removing protective vegetation cover, disturbing fragile soil, and encroaching upon carbon-rich areas and biodiversity hotspots can destabilize the landscape, making it more susceptible to erosion.

It is important to note that these causes of gully formation have been documented in various studies, including those conducted by Eze (2023), Ezezika and Adetola (2011), Nwilo et al. (2011), and ENS-NEWMAP (2016).

Impacts of Gully Erosion and GIS Application in the Development of the Study Area

The physical and socioeconomic consequences of gully erosion in the area and throughout Sub-Saharan Africa is increasing, and regulating this trend has become a nightmare. As a result, erosion has a severe impact on many people's lives and damages infrastructure critical to economic growth and poverty reduction (ENS- NEWMAP, 2016 and FPMU-NEWMAP, Undated). Every level of the intervention has been touched and the success story has been outstandingly recorded thanks to the novel GIS strategy and its associated awareness sensitization and stakeholders' engagement and participation.

Public (Stakeholders) Consultations and Participation

Consultations with key stakeholders in a project is given special attention and discussed accordingly. This is emphasized throughout the life cycle of every project as a means to allay grievances, enhance positive impacts, mitigate negative impacts, and ensure project buy-in and sustainability. According to ENS-NEWMAP ESMP (2014), ENS-NEWMAP RAP (2014) and ENS- ESIA (2019) Final Reports, the following issues are given emphasis and peculiar attention during preparation of consultation process:

- Provision of sufficient and timely information about the proposed project to the Project Affected Persons (PAPs);
- Utilization of stakeholders engagement opportunities to influence project design in a very positive direction;
- Creation of engagement opportunities to ensure that no major potential impact is overlooked;
- Identification of issues of concern to stakeholders early enough in the project implementation process;
- Reduction of conflict through the early identification of contentious issues and findings for proper attention;
- Proper management of expectations and misconceptions regarding the project;
- Secure local and traditional knowledge and information to ensure attainment of ESIA standard process;
- Sensitization of Ministries, Departments and Agencies (MDAs), Non-governmental Organizations (NGO) and Community Based Organizations (CBOs) about the project and solicit their views and discuss their share of the responsibilities for the smooth functioning of the overall project operations; and
- Creation of a sense of project ownership and adequate involvement in the minds of stakeholders for full participation and sustainable development. Consultation Plan – The objectives of the consultation process are to:
- establish and sustain a consultation process for the entire life cycle of the project aimed at shaping and informing the public of the nature, scope and feedback on the project intervention;

- form and inform the development of an integrated framework for addressing issues relating to socio-economic displacement triggered by the project; and
- create a base for dialogue among the project team and various stakeholders so that the benefits of the project will last on diverse perspectives even beyond the intervention's life span.

Vulnerable Group Involvement –
At the course of initiating action on consultation, the vulnerable groups are identified as a matter of priority. These groups include:

- Children;
- Aged (old men and women); and
- Physically challenged persons.

Stakeholders' Consultation Meetings – The concerns raised during these meetings, including requests from the stakeholders are summarized and documented preferably in tables.

3. ENUGU STATE NEWMAP - THE STUDY AREA

The Government of Nigeria implemented the multi-sectoral and multi-level Nigeria Erosion and Watershed Management Project (NEWMAP), which was financed by the World Bank (WB), Global Environment Facility (JEF), the Special Climate Change Fund (SCCF), and the Government of Nigeria. NEWMAP financed activities implemented by States and activities implemented by the Federal Government. The project's effectiveness was September 16, 2013; while it was eventually brought to closure on June 30, 2022. It started with 7 states, namely Anambra, Abia, Cross River, Edo, Enugu, Ebonyi, and Imo. The number increased to a total of 23 states by the close of the programme. It was programme designed to address very complex gullies and related soil degradation that obviously out-weighed the capacities of the concerned communities. It is an intervention of sustainable modelled international best practices meant not only to handle the degradation but also to build capacities of the stakeholders and improve the livelihood of the affected persons. The Project Development Objective (PDO) of the NEWMAP is to reducing vulnerability to soil erosion in targeted sub-catchments. It aims to improve erosion management and gully rehabilitation; increase incomes for rural households from improved agricultural and forest practices through the use of conservation agriculture, agroforestry, natural regeneration, etc.; and gain efficiency in public administration and public spending through improved knowledge base, analytical tools, multi-sectoral coordination and stakeholder dialogue. The project includes four main components, namely:

Component1: Investment in Targeted Areas to support on-the-ground interventions that address, prevent and reverse land degradation.

Component2: Institutional Development and Information Systems for Erosion Management and Watershed Planning to address longer term sustainability by strengthening the enabling federal and states MDAs on environment with a view to addressing erosion and watershed degradation problems in a comprehensive manner across sectors and states.

Component 3: Climate Change and Disaster Preparedness

Component 4: Project management to support the government at federal and state levels to implement this project.

Enugu State is in Southeast of Nigeria.

Background Information on Enugu State

Enugu State was established on August 27, 1991, with Enugu as its capital. The state takes its name from the capital city, which began as a modest coal mining town in 1912 and developed to become the capital of Nigeria's erstwhile Eastern Region. The state has seventeen (17) local government areas (LGAs), five of which are mostly urban. Enugu State had a population of 3,267,837 people in the 2006 national census, with 1,596,042 men and 1,671,795 females (National Bureau of Statistics, 2010) with a total area of 7,638km2. Figure 3.1 depicts an administrative map of Enugu state.

Relief and Drainage

All of the formations have a basic north-south direction, and several noteworthy landforms and associated features have been fashioned out of them. The Nsukka-Okigwe cuesta, located in Enugu State, is distinguished by two main features: the Enugu and Awgu escarpments and the Udi-Nsukka Plateau. The scarp face of the cuesta landforms is created by tough sandstones of the Lower Coal Measures, while the softer upper slopes and crest are produced by less resistant false-bedded sandstones.

The escarpments in the area exhibit significant indentations caused by deep river valleys, while intense gully erosion is prominent at the upper reaches of most streams. The Nsukka Plateau gently slopes towards the lowlands along the Niger and Imo rivers. The plateau is expansive, measuring approximately 48km in width in the Nsukka region and

16km in the Udi and Awgu areas. In addition to residual hills, the plateau features a low density of drainage and wide, flat-bottomed dry valleys. These dry valleys are believed to be former river valleys that have since dried up due to infiltration into the false-bedded sandstones. Climate change can also contribute to the presence of dry valleys. However, in the case of the progressive migration of the Enugu escarpment, the migration of the water table caused by gullying and ravination may be an alternative explanation. Enugu State is primarily drained by the Anambra-Mamu River System, which flows westward. This river system covers extensive areas of the Uzo-Uwani Local Government Area in the northwest and Awgu in the southwest. During the majority of the rainy season, the Uzo-Uwani lowlands, in particular, experience complete flooding. The hindered drainage of the soil in these flooded areas creates a favourable environment for specialized agricultural practices.

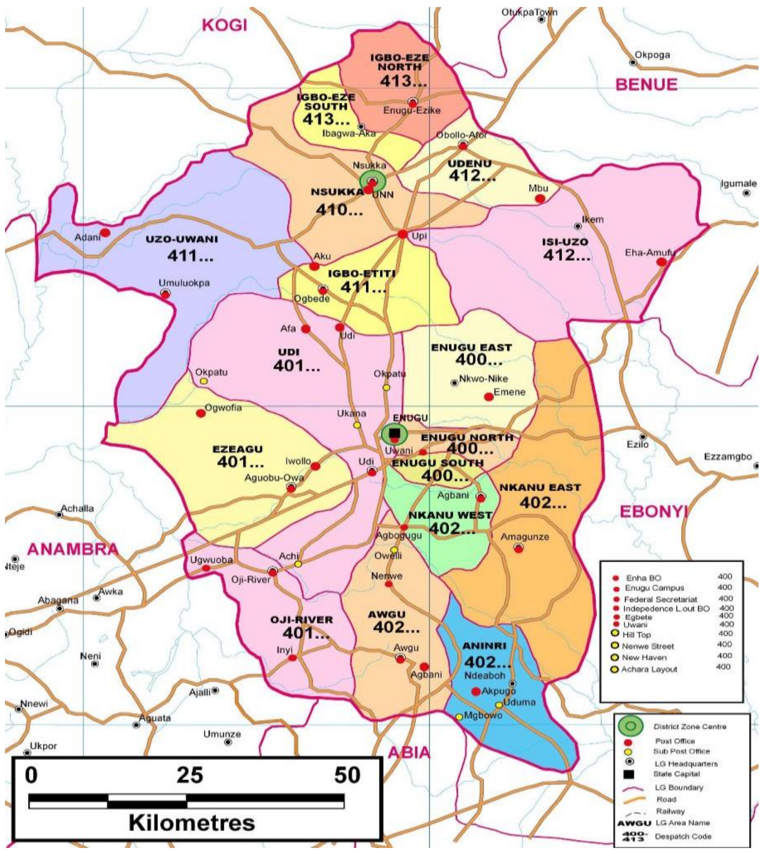

Figure 3.1: Administrative Map of Enugu State
Source: Enugu NEWMAP GIS-Based Baseline Mapping and IWMS Consultancy Service (2016)

Soils and Soil Erosion
The soils are composed of shallow and rocky lithosols found on the steep slopes of the cuesta and often left uncultivated, ferrallitic soils (also known as red earth or acid sands) located on the plateau, and flood plain hydromorphic soils.Soil erosion, caused by both natural and man-made factors, is widespread in many sections of the state. It can be seen as rills along roadside embankments, sheet wash through complexes and farmlands, and gullying in distinct channels and zones, sometimes rather spectacular. The biggest gullies are centred on the borders of extremely friable sandstones that erode readily and produce gullying even on slopes as low as 5°.

Vegetation of the State
The vegetation atop Awgu's highlands and extending through its rocky promontories to connect with Udi's undulating hills is of the semitropical rainforest kind. It is generally green, and in the Nsukka region, it is supplemented with typical grassland vegetation. The Niger-Anambra Basin has fresh water swamp forests.

Climate of the Area
In the mountainous and environmentally transitional region of Nsukka, the climate is fairly pleasant and especially equable. The average monthly temperature from February to April is around 33°C, while the yearly rainfall fluctuates

between 152 and 203cm. Rainfall is nearly exclusively seasonal, with the majority of it occurring between May and October.

Ecological Problems

There are several environmental issues. Aside from soil degradation, there is the risk of extreme sandiness in the Ezeagu-Udi corridor, as well as rain-fed major flooding in the Uzo-Uwani area. Deforestation is a man-made danger that has harmed the state's ecological balance and agricultural potential. Figures 1 and 2 depict erosion incidences in Ajali, Udi, and Ezeagu LGAs, respectively.

4. METHODOLOGY

Our project strategy is based on cutting-edge technology and methodologies such as remote sensing imaging and GIS, as well as awareness raising, stakeholder engagement, and involvement. This is summarised in figure 4.0, which depicts the flowchart of the technique used. Aside from the chart process, the consulting firm's operations were supplemented by on-site observation, ground trothing, interview, and survey design. The business was particularly hired for this exercise, and the author was the GIS specialist who oversaw and was reported to the consultants, who in turn reported to the Project Coordinator and the World Bank. Hardware and software used as well as several high speed computers and accessories with sufficient storage space and the high processing speed required to execute and support the digital image processing and analysis operations were all engaged. The following software sets were used:

(i) ArcGIS (ArcInfo Licensee);
(ii) Erdas Imagine;
(iii) ENVI;
(iv) eCognition;
(v) Global Mapper, etc
(vi) ArcHydro Tools for Terrain analysis.

Field Work Process Applied in the Study

The process involves on-site observation, data collection, satellite image acquisition and processing, output production stages and database production for erosion and integrated watershed management system. See flowchart of the methodology in figure 2 for details.

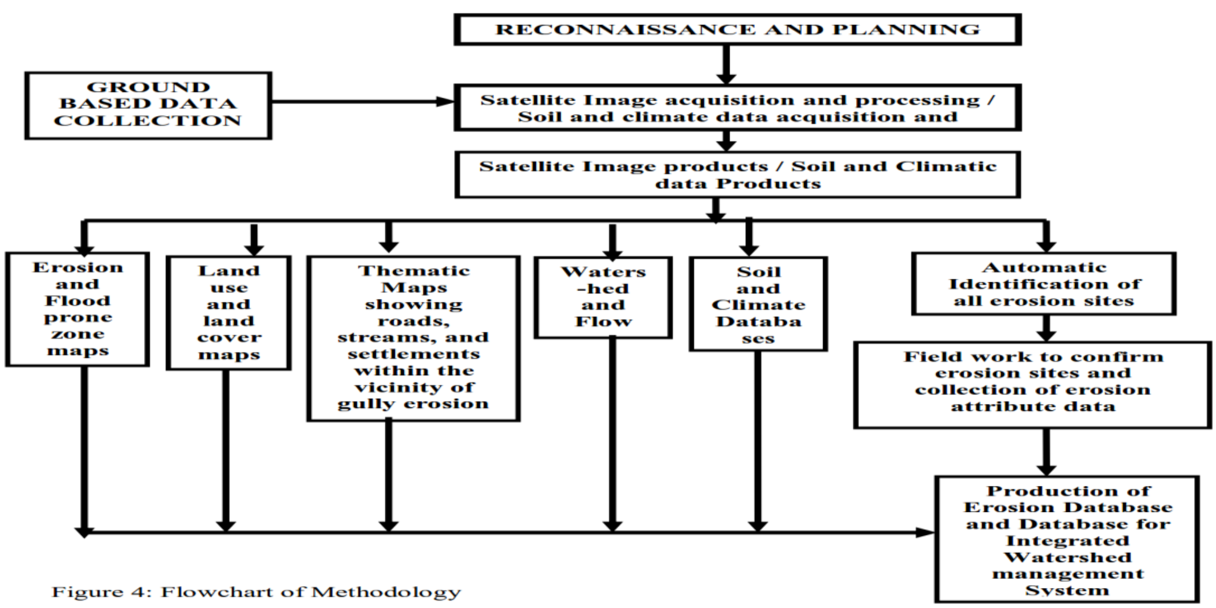

Figure 4: Flowchart of Methodology

Source: Enugu NEWMAP GIS-Based Baseline Mapping and IWMS Consultancy Service (2016)

5. DATA PRESENTATION: IDENTIFICATION AND MAPPING OF ALL EROSION SITES AND GROUND TROTHING

There are two aspects of this activity:

(i) Semi-Automatic identification of erosion sites by satellite image processing and ground trothing; and
(ii) Field measurement campaign to verify likely gully erosion site and to carry out measurement as well as collect vital information about the erosion sites.

Semi-Automatic Identification of Erosion Sites Using Satellite Images

Feature extraction was carried out in eCognition software that uses an object-oriented approach for semi-automated image analysis. The coordinate of eleven (11) gully erosion sites obtained from the NEWMAP Enugu were also used as training sites. The Gray Level Co-occurrence Matrix (GLCMs) was used to significantly enhance the efficiency of image classification. Direction was significant to distinguishing gullies from non-gully features. Gullies are generally directed along the slope following the flow direction, while features such as freshly ploughed land, which has spectral and textural properties similar to gullied area, usually run slope parallel (at least within the study area where tillage operations are non-mechanical. To quantify such features and distinguish them from gullies a set of rotation-variant GLCMs metrics (contrast and correlation) was calculated based on the flow direction. The outcome includes a lot of false positive which would be verified by the field measurement team. A total of 508 likely gully sites were indicated by the software for the whole of Enugu State. Figure 5.1 shows the spread of the likely erosion sites as produced through Enugu NEWMAP GIS-Based Mapping and Integrated Watershed Management System (IWMS).

Field Measurement Campaign to the Erosion Sites

With hand held GPS set on the navigation mode, the field measurement team visited all likely gully erosion sites. This was executed local government by local government. In addition, the field measurement team solicited the assistance of the local government personnel as well as local communities in physically identifying the erosion sites. Formal letters to the local government authorities were obtained from NEWMAP Enugu before embarking in this exercise. Information collected include.

(i) Site location and coordinates;
(ii) Nature and causes of erosion;
(iii) Infrastructures under threat;
(iv) Environment description;
(v) Impact on communities;
(vi) Approximate length of erosion site;
(vii) Approximate width of erosion site;
(viii) Average depth of erosion site;
(ix) Highest depth of erosion site;
(x) Lowest depth of erosion site;
(xi) Estimated area of erosion site; and
(xii) Estimated volume of erosion site.

At the end of the field campaign, the final number of erosion sites identified was 51. Details are presented in Sections 4 and 5 of this report. Appendix H list the center point coordinates (Longitude and Latitude) of all the 51 erosion sites.

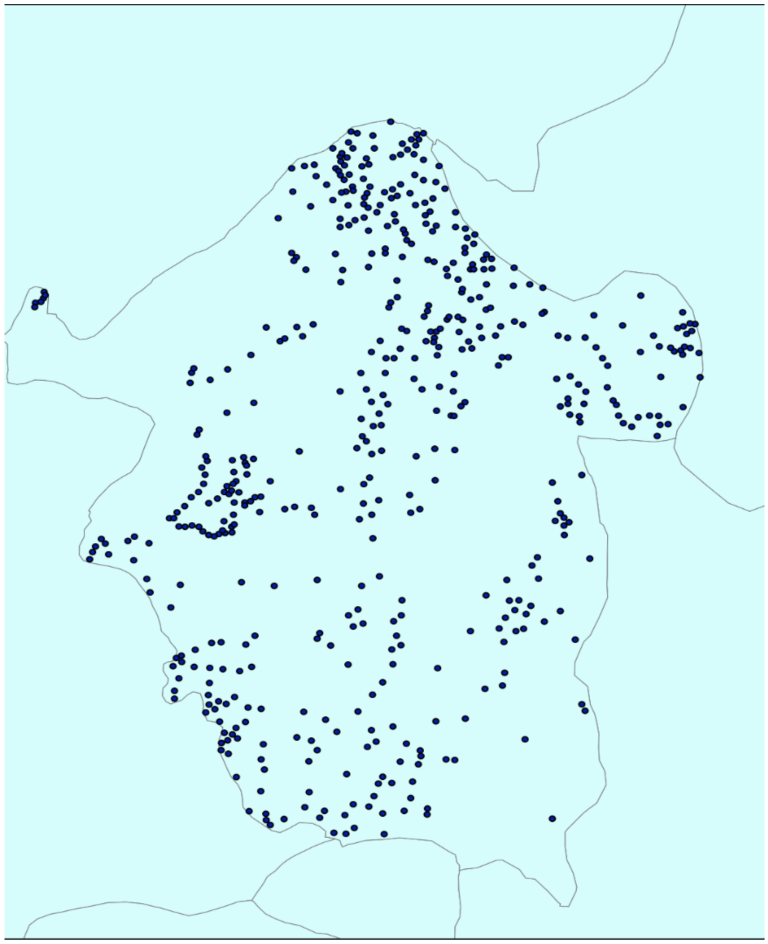

Figure 5: Spread of 508 likely Gully Erosion Sites in Enugu State
Source: Enugu NEWMAP GIS-Based Baseline Mapping and IWMS Consultancy Service (2016)

The SPOT 2.5m imagery is a natural color composite. The colors of natural features such as water bodies and vegetation appear as they are on ground and the image is fairly close to reality. However, due to insufficient contrast between and among many objects on the imagery, some features were not easily distinguished due to their very similar spectral signatures. The enhancement operation performed basically consisted in splitting the multispectral SPOT image composite into individual RGB channels and then re-compositing these bands by changing their grouping. Selecting the appropriate band combination to use in the composite had a huge impact on increasing the contrast between features to aid easy detection and classification by our remote sensing system.

Development of the Integrated Watershed Management System (IWMS) for the Project

A database management system has been developed and implemented in a GIS environment for the IWMS. The developed system is capable of performing data storage, management, retrieval, analysis, query and maintenance of all information captured for each erosion site at the watershed level. Digital data such as flood/erosion sites, thematic layers, land use land cover, soil properties, administrative boundaries, road network, hydrology, utilities, structures at risk, etc. at different layers, with their attribute data were all integrated into the GIS Database.

Most importantly, all the information gathered about each erosion site were included in the database. These include but are not limited to:

(i) Erosion location;
(ii) Possible causes of erosion;
(iii) Nature of erosion;
(iv) Infrastructure threatened by erosion;
(v) Description of environment/vegetation around erosion;

(vi) Sketch of erosion site including infrastructures close to erosion;
(vii) Coordinates of erosion site;
(viii) Coordinates of infrastructures close to erosion;
(ix) Communities impacted;
(x) Approximate length of erosion site;
(xi) Approximate width of erosion site;
(xii) Average depth of erosion site;
(xiii) Highest depth of erosion site;
(xiv) Lowest depth of erosion site;
(xv) Estimated area of erosion site;
(xvi) Estimated volume of erosion site; and
(xvii) Photograph(s) taken.

6. DISCUSSION OF RESULTS

The entire results are made up of two components: (i) Map products and (ii) GIS products

Map Products

The following map documents were produced as available in the table below with their relevant scales:

Table 6.1: List of Map Products from the Mapping Project

S/N	Map Products	Scales	No of Sheets
1	Composite map showing all erosion sites, roads settlements, towns, etc	1:400,000	1
2	Land cover Map of Enugu State	1:750,000	1
3	Watershed Map (Composite) of Enugu State		1
4	Erosion Risk Map (Composite) of Enugu State		1
5	Flood Vulnerability Map (Composite) of Enugu State		1
6	Digital Soil Map of Enugu State showing Erosion Sites and Soil Drainage		1
7	Digital Soil Map of Enugu State showing Erosion Sites and Soil Texture		1
8	Digital Soil Map of Enugu State showing Erosion Sites and Soil Suitability for Mechanized Agriculture		1
9	Digital Soil Map of Enugu State showing Erosion Sites and Description of various Soil pH		1
10	Digital Soil Map of Enugu State showing Erosion Sites and Different Geological Zones represented by Soil Types	1:150,000	1
11	Topographic Maps of Enugu State (Natural Resources Inventory)		20
12	Watershed Maps of Enugu State		20
13	Erosion Risk Maps of Enugu State		20
14	Flood Vulnerability Maps of Enugu State	1:50,000	20
15	Individual Erosion Sites Maps (1 Map each for the 51 Erosion Sites)	varies	357

Source: Enugu NEWMAP GIS-Based Baseline Mapping and IWMS Consultancy Service (2016)

Composite Map Products

The composite map of all erosion sites shows all the 51 erosion sites labeled from ENE 01 to ENE 51. It also shows the state and local government boundaries, settlements, towns and villages, roads and pathways as well as water bodies. This is presented in figure 6.

Sustainability Model of the GIS /EMIS Integrated Approach

The sustainability of this integrated approach gives birth to the author's Environmental Management Information System (EMIS) model for sustainable erosion control and monitoring as presented in Figure 6.3. EMIS has been described by UN-Habitat (2001) as covering the gathering of relevant information for a participatory urban environmental planning and management process. Such information is stored in archives, databases and in maps. Again, the information generated and maintained through such a system is usually up-to-date as it allows for continuous input of data generated through an agreed standard, involving public and popular participation. The Habitat maintains that the main outputs of an EMIS are attractive and colorful maps and therefore a Geographical Information System (GIS) is a suitable tool for the EMIS.

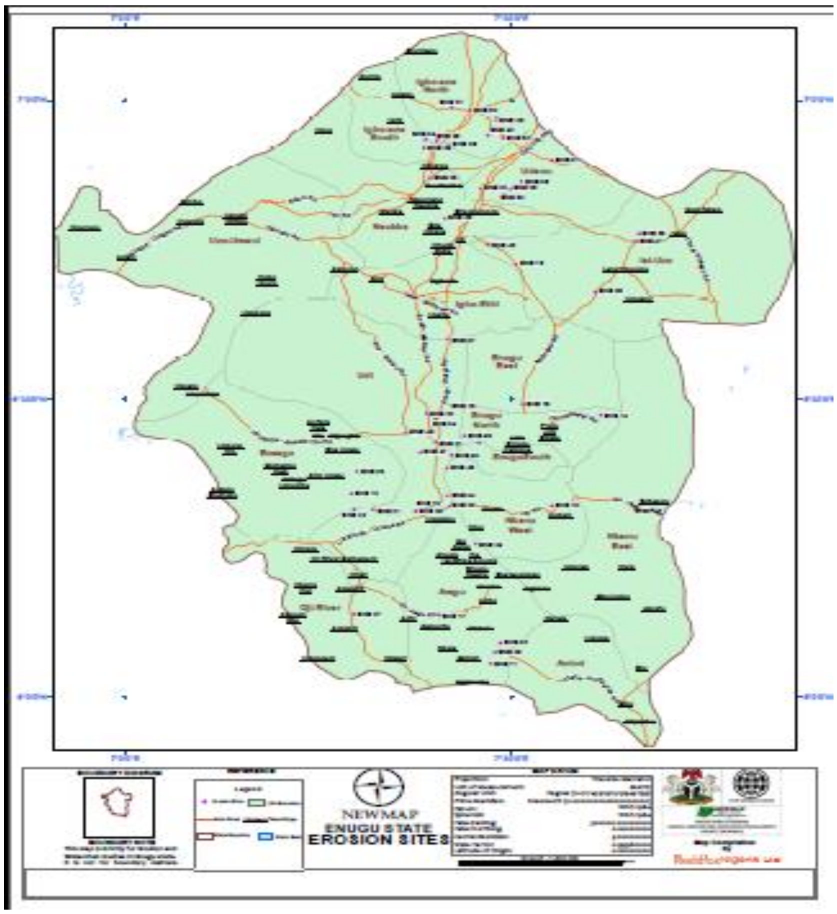

Figure 6.2: The Composite Map showing all the 51 Erosion Sites (ENE 01 to ENE 51)
Source: Enugu NEWMAP GIS-Based Baseline Mapping and IWMS Consultancy Service (2016)

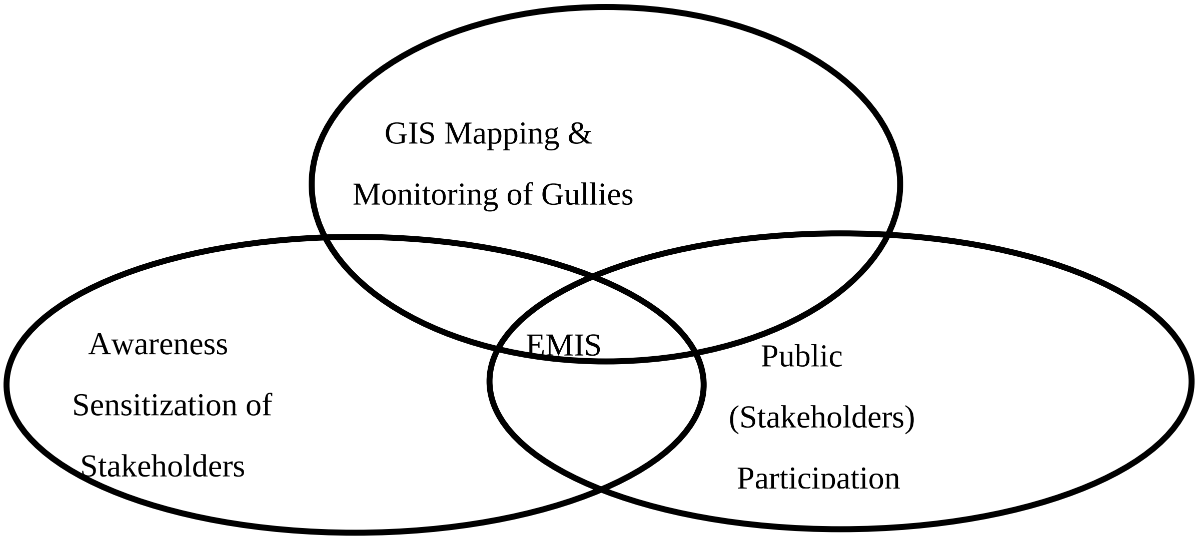

Figure 6.3: The Authors' Model of EMIS for Sustainable Integrated Erosion Control and Monitoring

GIS Products

The GIS work is all contained in a folder called NEWMAP Erosion Project in ArcGIS 10.3 Software. This folder consists of the following subfolders:

(i) Composite Site Data; and (ii) Individual Site.

Composite Site Data

This consists of erosion sites data as composites. It is further split into three:

(i) Maps;
(ii) Composite Shapefiles;
(iii) Database Documents;
(iv) Database Query Platform.

Maps

It consists of the following documents in pdf and jpg formats:

(i) Flood vulnerability map;
(ii) Watershed map;
(iii) Map of all the erosion sites;
(iv) Land cover map.

Composite Shapefiles

This consists of all map and database data needed for smooth running of the database platform. It includes:

(i) Watershed shapefiles;
(ii) Land use shapefiles;
(iii) Flood shapefiles;
(iv) Erosion sites;
(v) Table Geodatabase, etc.

Database Documents

It consists of the following documents:

(i) Database of all sites in Excel; and
(ii) Database of sites arranged according to their order of decreasing threat level.

Database Query Platform

There is a query platform for the composite data. It is called "Composite Queries Platform". This is a platform that consists of different queries on the database. The highlight of the queries as "**general queries"** are as follows:

(i) Queries on Erosion Sites in the different local government areas;
(ii) Queries on width, length, of erosion sites;

(iii) Queries on the possible cause of erosion sites;
(iv) Query to call up catchment polygons around erosion sites;
(v) Queries to call up Land uses around erosion sites; and
(vi) Queries to call up flow directions around erosion sites.
(vii) Buttons to call up the two tables mentioned above are provided. The table will be added to the platform and kept in the Table of Content. When right-click on it and select open, then one can view its contents.

CONCLUSION AND RECOMMENDATION

The integrated approach of GIS mapping and control supported with awareness sensitization and public participation are innovative method of environmental risk management of international best practice standard worthy of replication.

Conclusion

This is essential as a useful tool for achieving the overall aim of Enugu NEWMAP which is to restore degraded lands caused by erosion and reduce long-term erosion vulnerability in targeted areas in Enugu State. The approach of baseline mapping and creation of Integrated Watershed Management System (IWMS) aids the knowledge of gully erosion sites, land resources, hydrology and watershed of the areas of interest in Enugu State. Ultimately, the integration of all the information into a GIS database is an invaluable strategy suitable for erosion monitoring, management and control.

Recommendation

It is recommended that efforts be made by NEWMAP to maintain and sustain these huge datasets, build enough capacity and institutionalize the process of its application for optimal benefit of erosion and disaster identification, monitoring and control in Enugu. To ensure that all these will not end up with NEWMAP implementation, the following steps are essential:

(i) Establishment and maintenance Environmental Management Information System (EMIS) – Ministries, Departments and Agencies that are involved in the services of the built environment should not only be digitized but establish state of the art GIS unit. Above all, there should be unified operation of EMIS. In this way, EMIS is essential as a tool of better urban management, because it ensures that data is collected and analyzed in a participatory and gender responsive way (UNEP and UN- Habitat, 2000). EMIS was further defined as a participatory tool for urban environmental planning and management, concentrating on the interaction between environment and development activities; while GIS helps to store and manage large amount of spatially referenced data and therefore helps a better understanding of the activities on the earth's surface.
(ii) The GIS approach developed should be institutionalized for gully erosion and other environmental risk disasters' monitoring, control and data/information sharing for the purpose of achieving better environmental management.
(iii) GIS as an essential tool should be made more functional through integrated approach of its combination with awareness sensitization and stakeholders' consultation and participation as established in the study.
(iv) NEWMAP should be institutionalized into an agency in the state even at the closure of the international agencies' funding of the project.

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