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Utilization of Geospatial Technology in Enhancing Environmental Sustainability by Assessing Anthropological Effects on Erosion Development in Orumba North

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Abstract: This study investigates the assessment of soil erosion and human interactions on the landscape morphology in Orumba North LGA, Anambra State, Nigeria. Soil erosion, a significant global environmental problem, is exacerbated by both natural and anthropogenic factors. In Nigeria, particularly the southern states, gully erosion poses a severe threat to agricultural lands. This research aims to model the feedback mechanism between land use and soil erosion using geoinformation technology. The study utilised a mixed-method approach, integrating Remote Sensing and Geographic Information Science (GIS) with descriptive statistics. Landsat imagery from 1987, 2003, 2019 and 2024 was analysed using supervised classification to assess land use/land cover changes and erosion site development. The analysis reveals that human activities particularly intensive agriculture and sand excavation played a dominant role in the expansion and transformation of erosion sites in Orumba North LGA. From 1987 to 2003, substantial reclamation efforts led to the conversion of 7.32 sq. km of erosion sites to vegetation and 3.03 sq. km to farmlands, reflecting successful interventions. However, from 2003 to 2024, transitions were largely to farmlands, especially around the Nanka erosion site, indicating increased exploitation of erosion-prone areas and a decline in restoration activities. Minimal conversions to built-up areas and water bodies across all periods suggest limited urban and hydrological influence. These trends highlight the intensifying impact of land use pressures on erosion dynamics and the inconsistent effectiveness of reclamation efforts over time. The study highlights the ongoing challenge of gully erosion in the region and the influence of anthropogenic factors on its dynamics. The findings are significant for identifying areas susceptible to erosion and informing targeted mitigation strategies in Orumba North, Anambra State.

Keyword: *GIS, Gully Erosion, Land Use/Land Cover, Spatial Landscape, Anthropogenic.*

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I. INTRODUCTION

Soil erosion is one of the significant global environmental problems we are facing after flooding. The total amount of soils eroded yearly is recorded to be about 22-75 billion tons worldwide accumulating to approximately 40% of world agricultural land (Pimentel and Burgess, 2013; Hanyona, 2001). In 2010, the soil loss recorded in India was 5.334 billion tons yearly whereas in the previous year 2009, China suffered a combined soil and water losses which amounted to 3.75 million sq. /km, this is approximately about 38% of China total territory (Nwakanma, Dike, Dimkpa, and Obafemi, 2018; Pimentel and Burgess, 2013). In Nigeria, soil erosion is one of the most prevalent environmental problems endangering the few available agricultural lands. In the 1980s as recorded by Ofomata (1985) about 1% of Nigeria's land was ravaged by gully erosion and this has increased to a disturbing 6% in 2017 which is up to 6,000 sq./km of Nigeria's landmass (Nigeria Erosion and Watershed Management Project (NEWMAP), 2017). The Southern States of Nigeria has the highest occurrence and prevailing soil erosion problems. This region is affected by massive and expanding gully erosion which is an advanced stage of soil erosion. The southeastern region of Nigeria is prone to ravaging gullies mostly due to the geology and soil formation. The total land areas ravaged by the various stages of soil erosion has tripled over time from about 1.33% (1,021 sq./km) in 1976 to about 3.7% (2,820 sq./km) in 2006 and this is

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occurring when the population is increasing at over 2% per year (NEWMAP, 2017).

More than 75 % of the Earth's ice-free land shows evidence of alteration as a result of human residence and land use, with less than a quarter remaining as wildlands (Ellis and Ramankutty 2008). Globally most landscapes are blends of human activities with the expression of biodiversity; they are bio-cultural landscapes (Bridgewater and Arico 2002). This relationship between biological and cultural diversity has not been explored as biodiversity itself; this study of bio-cultural diversity involves a search for patterns across landscapes (Stepp et al. 2005). An intrinsic reciprocal relationship between culture and landscape structure exists: culture changes landscapes and culture are embodied by landscapes (Nassauer 1995). In the current contribution, the cultural component of landscapes is generalized to the large-scale spatial footprint of Man's actions, which refer to agriculture, urbanization, industrial development, road infrastructure and alteration of an original natural land cover by an anthropogenic type. This latter process is denoted as "anthropization" (Bogaert et al. 2011); the modification of landscapes by human action leads to anthropogenic landscapes, in which man-made features dominate and the original natural patch types often are reduced to a scattered pattern. A series of typical changes in landscape and biological characteristics during the conversion of natural lands to human-dominated landscapes has been reported (August et al. 2002). Hobbs and Hopkins (1990) in McIntyre and Hobbs (1999) expressed the range of human effects on landscapes in terms of the prevalent land use and using four levels: conservation of a more or less unmodified system, utilization of components of the system (forestry), replacement of the system by another type (agriculture), and complete destruction (urban development). Anthropogenic activities that require much space, which destroy and replace original land covers will consequently dominate human-driven landscape dynamics; they are considered exogenous disturbances (McIntyre and Hobbs 1999; Fischer and Lindenmayer 2007). This human impact on ecosystems and landscapes has led to the recognition of 18 "anthropogenic biomes", grouped in dense settlements, villages, croplands, rangelands and forested (Ellis and Ramankutty 2008). Landscape ecology focuses on landscape patterns (Bogaert et al. 2011; Bogaert and Andre 2013). Its central hypothesis is known as the pattern/process paradigm, which states that patterns and processes in landscapes are related in a way that landscape patterns condition those processes characterized by a spatial dimension, and that processes occurring in a landscape can modify landscape patterns (Turner 1989; Coulson et al. 1999; Noon and Dale 2002).

While erosion is a natural process, human activities have increased by 10 -40 times the rate at which erosion is occurring globally. Excessive (or accelerated) erosion causes both "on –site" and "off –site" problems. On –site impacts include decreases in agricultural productivity and (on natural landscapes) ecological collapse, both because of loss of the nutrient – rich upper soil layers. In some cases, the eventual end result is desertification. Human activities can significantly impact soil erosion, both by accelerating natural erosion processes and by altering the land in ways that increase erosion. Some common human activities that contribute to soil erosion include agriculture, forestry, urbanization and construction. These activities can alter the surface of the land, making it more susceptible to erosion by water, wind and other natural forces. Human activities can also increase erosion by disrupting natural land cover and vegetation, which can protect the soil from erosion. To minimize the negative impacts of soil erosion, it is important to carefully manage land use and to implement strategies that promote the conservation and restoration of natural land cover and vegetation.

II. RESEARCH METHODOLOGY

A. Study Area

Orumba North has the geographical coordinates that lie between Longitude 7°3′0″E to 7°18′0″E, and Latitude 6°0′0″N to 6°12′0″N. It has an estimated land area of 297.252 km^2. B The LGA is bounded by Awka South, Anaocha, Aguata, Orumba South and Enugu State. Orumba North is made up of ten towns, namely; Ozu, Ndiobani, Akpugo, Enugu Abo, Awgbu, Ndiowu, Ndikelionwu, Ogboji, Ufuma and Ajalli. (Figures 1 and 2).

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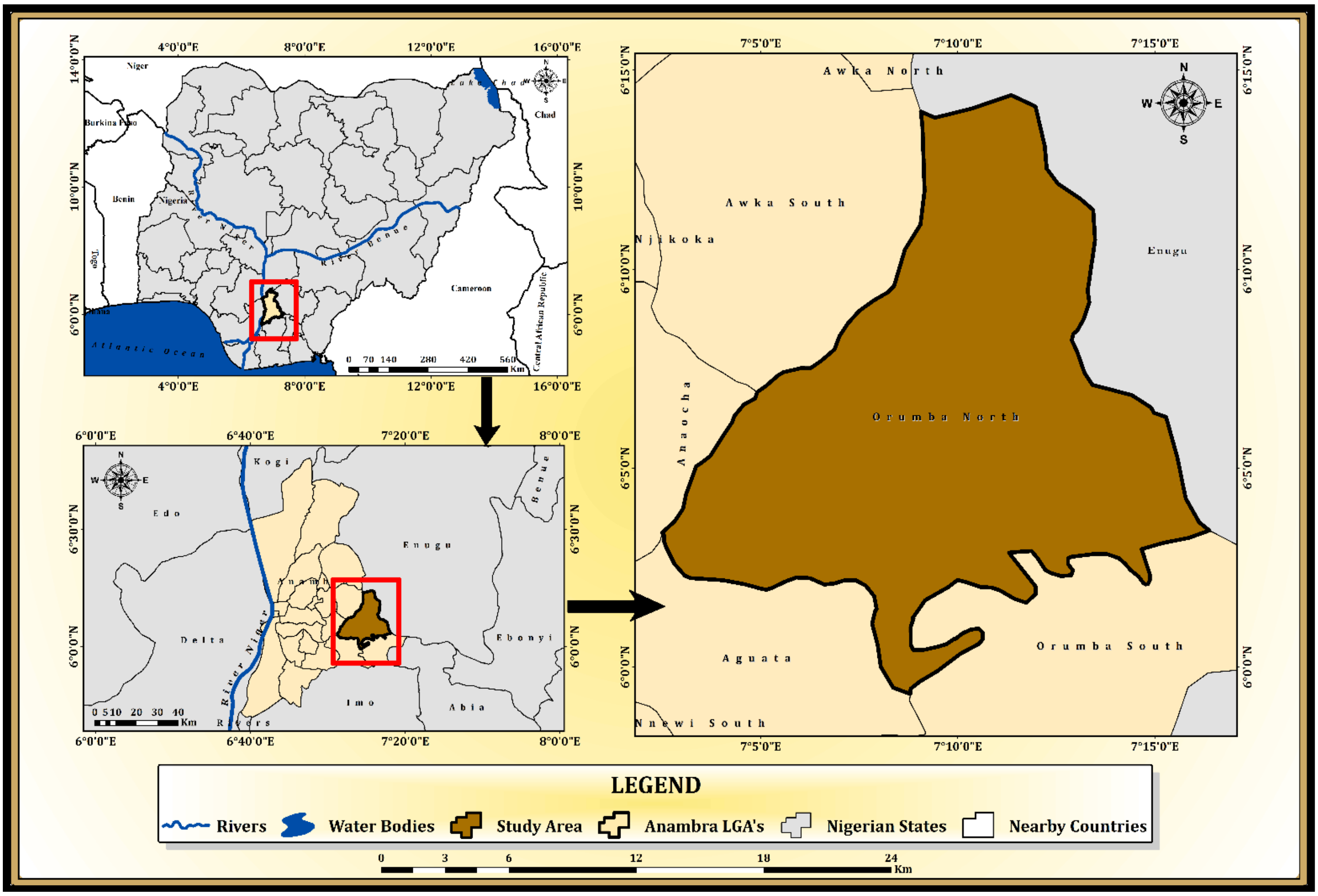

Fig 1 Map of Anambra State Showing Orumba North with an Inset of Map of Nigeria

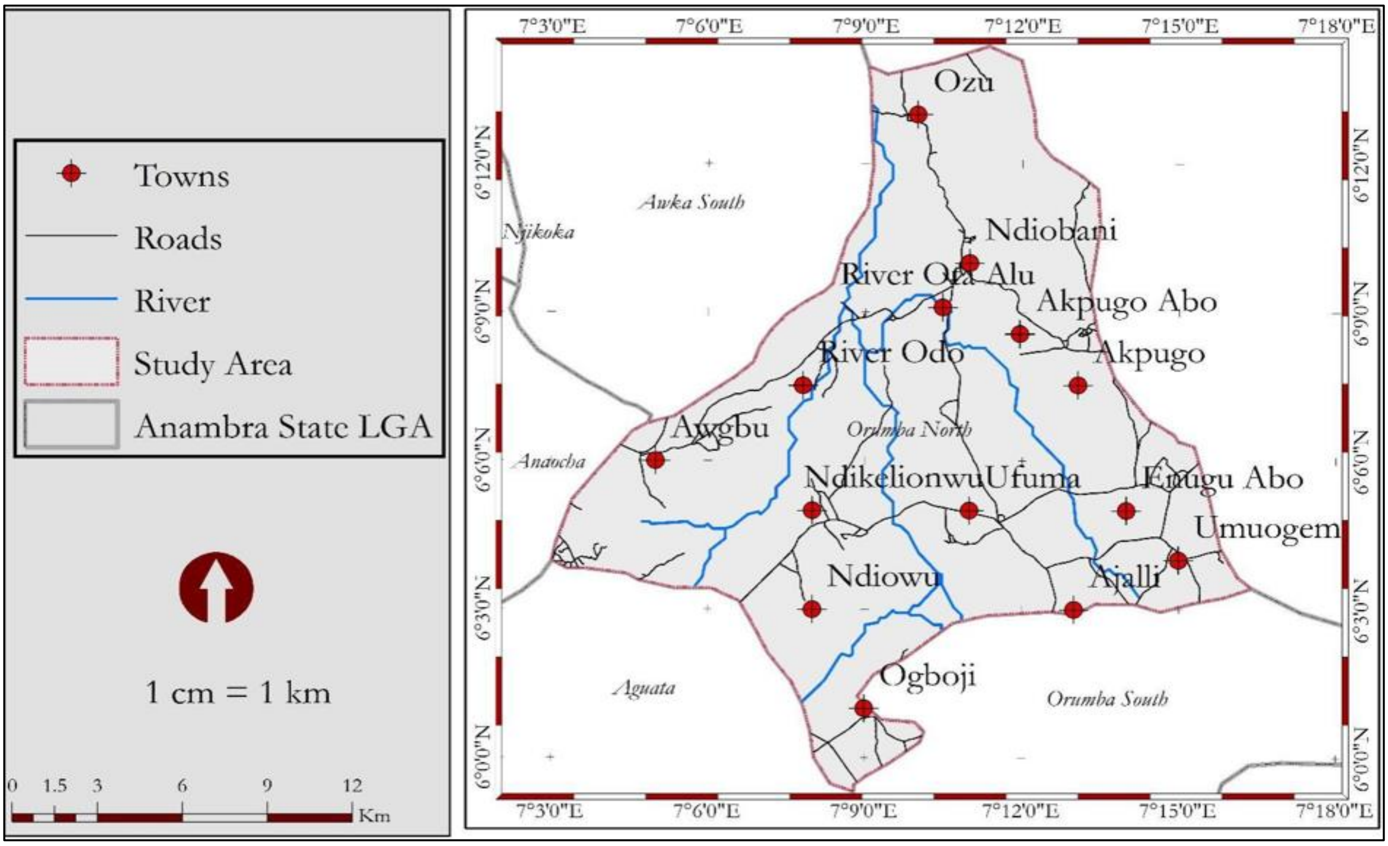

Fig 2 Map of Orumba North Showing Towns and Physical Features

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The geological setting in the study area is that of layered sequences in which a predominantly sandstone formation is underlain by a predominantly shale formation (Obiadi, et al., 2011). The study area is a significant part of Anambra River Basin stratigraphy and is basically a result of the paleohydrology of the region (Durham, et al., 2008). The main geological formation in the study area is the Ameki Formation, underlain by the dark grey plastic Imo Shale and overlain by the lignite-clay bearing Ogwashi-Asaba Formation. The main geologic units (soils) of the study area are derived from the Nanka Sand (Eocene), overlain by Ogwashi-Asaba, formation (Oligocene) and underlain by Imo Shale and as such comprise mainly of porous, red and brown sandy soils, and brown and pale clay soils (Obiadi, et al., 2011). Furthermore, Orumba North is a densely populated semi-urban town situated on an undulating terrain characterized by deep gully systems (Igwe, 2018). The last census of 2006, the local government area of study area was about 172,773 and when projected to 2019 using the geometric growth method of projection and a population growth rate of 2.1% in Anambra State gives a total population of 226,365 persons. The population density of 747.14/km2 (NPC, 2015). Also, the socio-economic activities in the study area involve slash-burn, grazing, firewood gathering, agriculture, commerce and construction.

B. Ecological Hazards

The main ecological hazards in the area are accelerated soil erosion and flooding. Extensive forest clearing, often by bush burning, and continuous cropping with little or no replenishment of soil nutrients, resulted in the disruption of the ecological equilibrium of the natural forest ecosystem. Such a situation in a region of loosely consolidated friable soils is prone to erosion giving rise to extensive gully formation. In the Nanka and Oko areas, which are underlain by the Nanka Sands, the gullies have attained spectacular and alarming proportions, turning the area into real 'badlands' (Obi and Okekeogbu, 2017). Many of the gullies are at the head streams of the rivers that flow down the cuestas. The head streams carve their valleys deep into the deeply weathered red earth, developing dendritic patterns of gullies. The greater part of the area is prone to severe sheet erosion. In the low plains of the Mamu River, heavy rains often result in excessive flooding, such that the undulations occupied by settlements are inundated for some months, resulting in some parts of the Local Government Area being cut off from others as their roads remain flooded for many weeks. The floods also cause serious damage to crops and other infrastructural amenities.

C. Data Sources

This research made use of secondary data. All the secondary data were collected from relevant websites. The secondary data for this study are satellite imagery and base maps from Google Earth. The main satellite imagery used are LANDSAT data, which provide medium spatial resolution. LANDSAT imageries are chosen for this study because they are available at no cost and have been found to be suitable in the study of environmental change. The satellite dataset used in this study will be geometrically referenced to the WGS 1984, UTM zone 32 projection systems. The administrative shapefile of the study area obtained from the grid3 website (www.grid3.org) which is an online repository for Nigeria Geospatial Data.

D. Data Acquisition, Preprocessing And Analysis

➢ *Landsat Data*

Three medium-resolution Landsat imageries of 1987 (TM) 2003 (ETM+), 2019 (OLI/TIRS), and 2024 (OLI/TIRS) will be used to derive Land use/Land Cover (LULC) changes over time and to assess the erosion sites development within the study area. The Thematic Mapper image will be downloaded for 27th December, 1987, the Enhanced Thematic Mapper plus (ETM+) image will be downloaded for 27th Dec. 2003 and the Operational Land Imager (OLI) for 28th Dec. 2019, and 24th Dec. 2024. The interval of +10 years is deliberately chosen by the researcher to ensure uniformity between the datasets and based on availability of data. The Landsat satellite data have 30m spatial resolutions, and the TM and ETM+ image has a spectral range of 0.45-2.35 micrometer (μm) with bands 1 to 7, while the Operational Land Imager (OLI) extends to band 12. These images will be obtained from the United States Geological Survey (USGS) website (https://earthexplorer.usgs.gov/) as standard products, i.e., geometrically and radiometrically corrected. To avoid the impact of seasonal variation, all images are selected from the same season in such a way that the cloud cover is less than 10%. The images were also of the same level of spatial resolution of 30m which makes it convenient for comparison of changes and patterns that occurred in the time under consideration.

E. Pre-Processing of LANDSAT Satellite Imagery

Comparative analysis using different Landsat data (i.e., ETM+, and OLI) can be challenging due to the instrumental errors related to the ache sensor, noise from several sources, and uncertainty in scale and geometric conditions. Preprocessing satellite imagery before conducting image classification and change detection is very vital to minimize those errors and to build a more thorough association between the obtained data and biophysical features on the ground. In this study, several sequential steps of data preprocessing were performed using TerrSet. These steps comprised radiometric, atmospheric, and geometric corrections in addition to sub-setting. Preprocessing also involved the selection of the appropriate band combinations to be used in image classification.

To reduce radiometric errors, images were calibrated using the radiometric correction tool in TerrSet, where raw data from the sensors (DNs) were converted to top-of-atmosphere reflectance. For atmospheric correction, a dark object subtraction model was applied in the current study as it is relatively the simplest and most widely used empirical method for classification and change detection applications. The images are projected to the Geographic Coordinate System, WGS 1984, and corrected for geometric errors from the sources. Then the images will be clipped to the study area administrative boundary to enhance accuracy.

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F. Supervised Image Classification

Image classification is an important remote sensing technique used to catalog all pixels in an image or raw remotely sensed data into a finite number of individual LULC classes to produce beneficial thematic maps and information. The image classification process is normally conducted to assign different spectral signatures from the dataset to several classes based on reflectance attributes of the diverse types of LULC. Different types of classification techniques exist, but based on reviewed literature it is observed that the Supervised Classification technique using the Maximum Likelihood classifier is the most widely used in remote sensing research. It is easy to implement, fast, enables clear interpretation of results, and is highly accurate.

False colour composite will be carried out by combining bands 5, 4 and 3 for 2003 Landsat ETM+, while bands 6, 5, 4 are used for 2019 and 2024 Landsat OLI-TIRS. Supervised classification using the Maximum Likelihood Algorithm is used to carry out the LULC change analysis. Random sample polygons are used to train the data.

G. Maximum Likelihood Classification Algorithm

Maximum likelihood classification assumes that the statistics for each class in each band are normally distributed and calculates the probability that a given pixel belongs to a specific class. Unless you select a probability threshold, all pixels are classified. Each pixel is assigned to the class that has the highest probability (that is, the maximum likelihood). If the highest probability is smaller than a threshold you specify, the pixel remains unclassified.

The maximum likelihood classification is performed by calculating the following discriminant functions for each pixel in the image (Richards, 1999):

$$gi(x) = 1np(\omega_i) - \frac{1}{2}1n|\Sigma_i| - \frac{1}{2}(x - m_i)^T \Sigma_i \quad -1(x - m_i) \text{..... (Eqn 1)}$$

Where:

i = class

x = n-dimensional data (where n is the number of bands)

$p(\omega_i)$ = probability that class ω_i occurs in the image and is assumed the same for all classes

$|\Sigma_i|$ = determinant of the covariance matrix of the data in class ω_i

Σ_i^{-1} = its inverse matrix

m_i = mean vector

III. RESULTS

This section examines the dynamic interactions between gully erosion sites and various land use and land cover (LULC) classes in Orumba North Local Government Area (LGA) from 1987 to 2024. The analysis, based on spatial data derived from satellite imagery, highlights the transition of erosion sites (E.S.) into different LULC categories over distinct time periods.

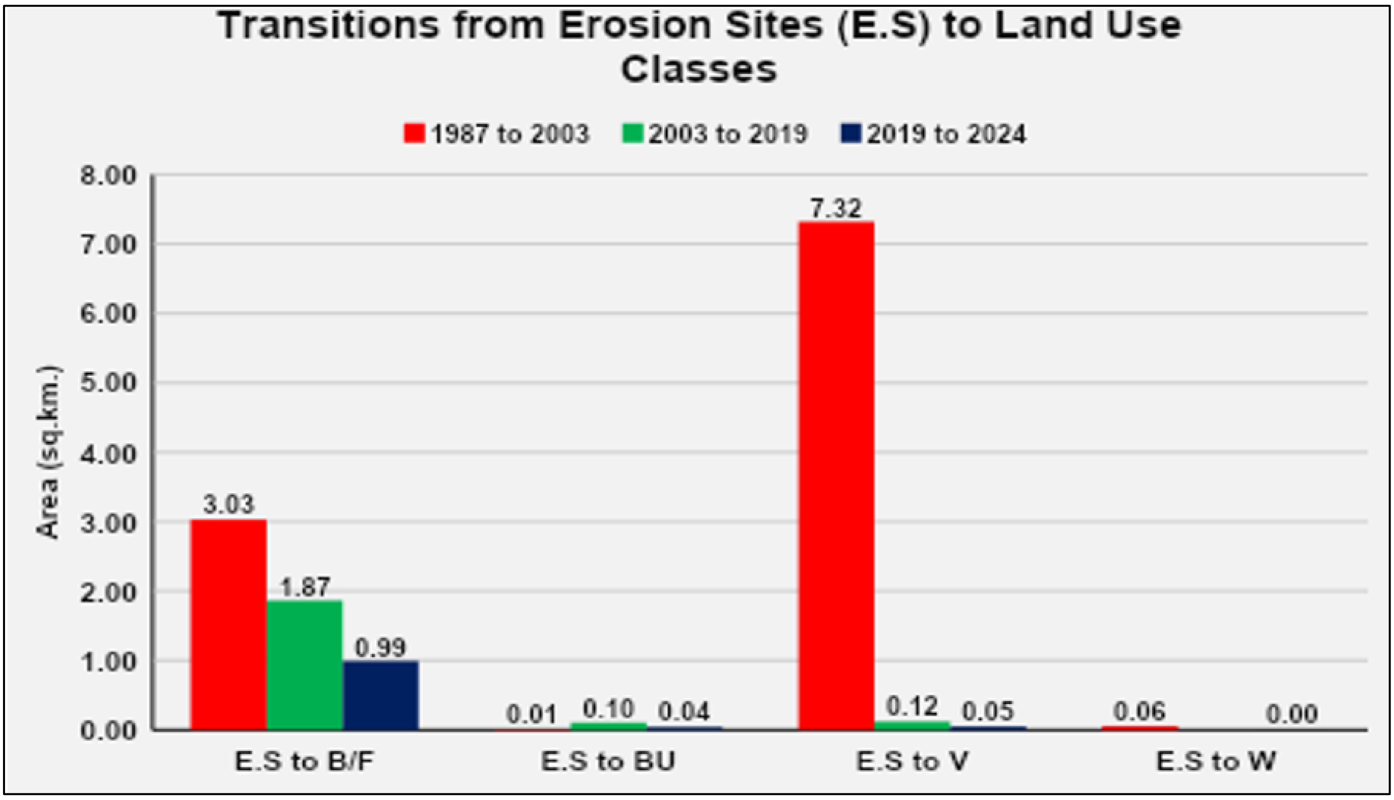

Fig 3 Erosion Sites Transition To LULC Classes From 1987 To 2024

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During this initial phase of 1987 to 2003, a notable conversion of erosion sites to barelands/farmlands (B/F) was observed, occurring at a rate of 3.03 sq.km. (figure 3), indicating a moderate conversion of eroded lands to agricultural or bare land uses during this initial period. This suggests early human intervention or natural succession favoring farmland establishment. Concurrently, an insignificant spatial extent of 0.01 sq.km. of erosion sites transitioned to built-up (BU) zones, suggesting negligible urban expansion onto eroded lands during this period. Critically, a significant transition occurred with the vegetation (V) class, as 7.32 sq.km. of areas identified as erosion lands in 1987 were subsequently converted to vegetative cover by 2003. This substantial shift indicates a successful reclamation of degraded lands from eroded soils during this period, primarily through their conversion into densely vegetated areas. A minor conversion of 0.06 sq.km. also occurred towards water bodies (W), which indicates limited hydrological influence on erosion development in the area during this period.

From 2003 to 2019, the highest rate of transition from erosion sites was observed towards barelands/farmlands, covering a spatial extent of 1.87 sq.km. This pattern is particularly evident in the transition map, where these conversions were predominantly concentrated in the southwestern region of the study area. This southwestern zone in the study area is notably home to the Nanka erosion site, a widely recognized and notorious gully erosion feature. Other transitions during this period included 0.10 sq.km. to built-up areas and 0.12 sq.km. to vegetation. No observed transition to water bodies was recorded.

Furthermore, from 2019 to 2024, the trend of erosion sites converting to barelands/farmlands persisted as the highest rate of transition, with a spatial extent loss of 0.99 sq.km. This consistent conversion pattern suggests that these eroded areas are frequently utilized for agricultural purposes, potentially due to the perceived quality of soil in washed-down erosion sites, where nutrients are likely to accumulate at lower levels. This phenomenon is further corroborated by observations indicating that most of these converted erosion sites to farmlands/barelands are situated in the area surrounding the Nanka erosion site. During this period, 0.04 sq.km. of erosion sites converted to built-up areas, 0.05 sq.km. to vegetation, and a minimal 0.004 sq.km. to water bodies.

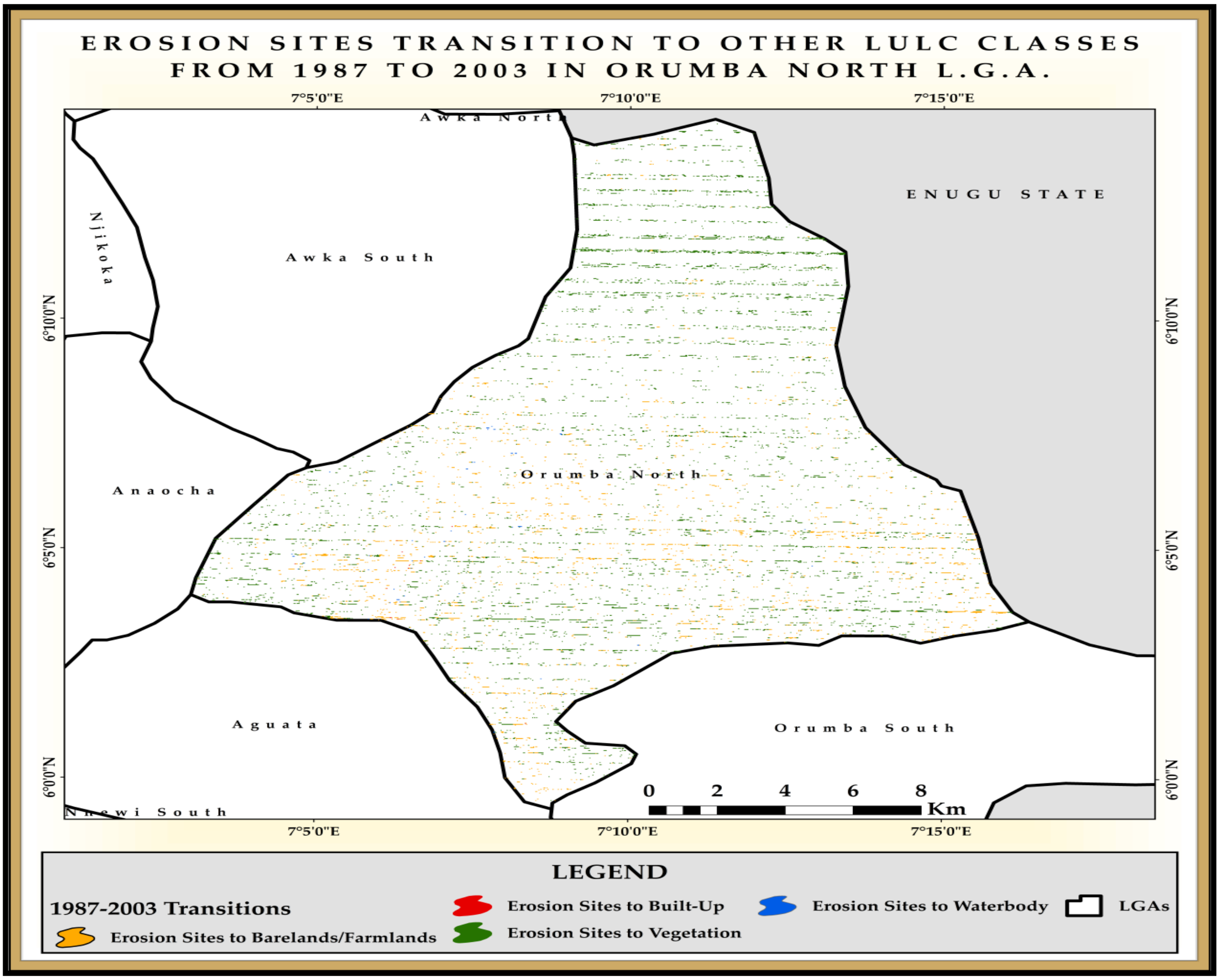

Fig 4 Transition Map to LULC Classes from 1987 To 2003

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The transition map (figure 4) reveals that from 1987 to 2003, the transition activities are spread across the entire Orumba North LGA, with a noted emphasis on the northern part experiencing the most changes compared to the southern part. This spatial variation may be attributed to differences in topography, soil composition, or human activity levels. The transition to vegetation is notably the most extensive due to the 7.32 sq. km reclamation effort, suggesting aggressive intervention projects were concentrated in multiple areas. The transition to barelands/farmlands (3.03 sq. km) appears more scattered, indicating widespread agricultural conversion from eroded lands, while builtup and waterbody transition zones are sparse, reflecting their minimal transitions.

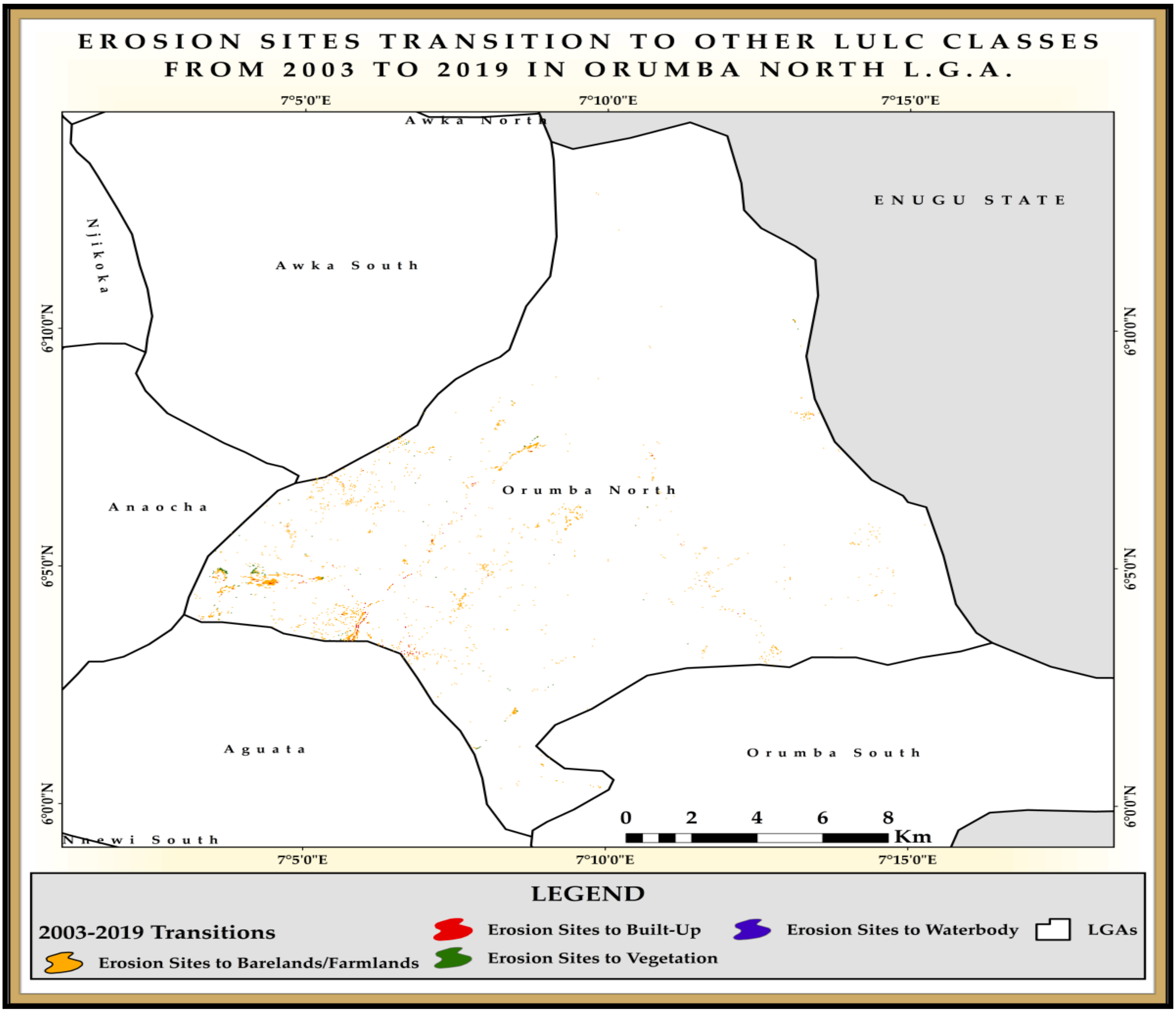

Fig 5 Transition Map to LULC Classes from 2003 To 2019

For 2003 to 2019 (Figure 5), the transition map shows a clustered distribution of transition activities, with a notable concentration in the southwestern zone of Orumba North LGA, where the notorious Nanka erosion site is located. The zones representing the 1.87 sq. km conversion to barelands/farmlands, dominates in this area, suggesting significant agricultural expansion or land conversion, likely driven by the presence of nutrient-rich soils at lower erosion levels. The zones of transition for built-up areas (0.10 sq. km) appear sparsely distributed, indicating limited urban development in relation to erosion sites, while the zones for vegetation (0.12 sq. km) are minimal, reflecting a decline in reclamation efforts compared to the 1987-2003 period. The absence of water-body transition aligns with the aforementioned statement of no observed conversion to water bodies during this period. The southwestern focus, particularly around the Nanka erosion site, underscores its role as a hotspot for erosion-related land-use changes. The map clustering suggests that human activities, such as farming and possibly sand excavation, are concentrated in this vulnerable zone, contributing to the dominance of barelands/farmlands transitions. The overall reduction in transition magnitude compared to the 1987-2003 period

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indicates a shift from reclamation to exploitation/stabilization of eroded lands.

Furthermore, from 2019 to 2024, erosion sites converted to barelands/farmlands at a spatial extent loss of 0.99 sq.km., once more the highest rate of transition amongst the classes during this period. This indicates that the erosion sites convert to farmlands for various reasons such as the quality of soil in washed down erosion sites, as nutrients are likely conglomerated at these lower levels of erosion sites. The transition map in figure 6 further corroborates this, as most of the converted erosion sites to farmlands/barelands are observed in the area surrounding the Nanka erosion site. The erosion sites converted to builtup areas at an extent of 0.04 sq.km., while converting to vegetation at 0.05 sq.km., and converting to water bodies at 0.004 sq.km.

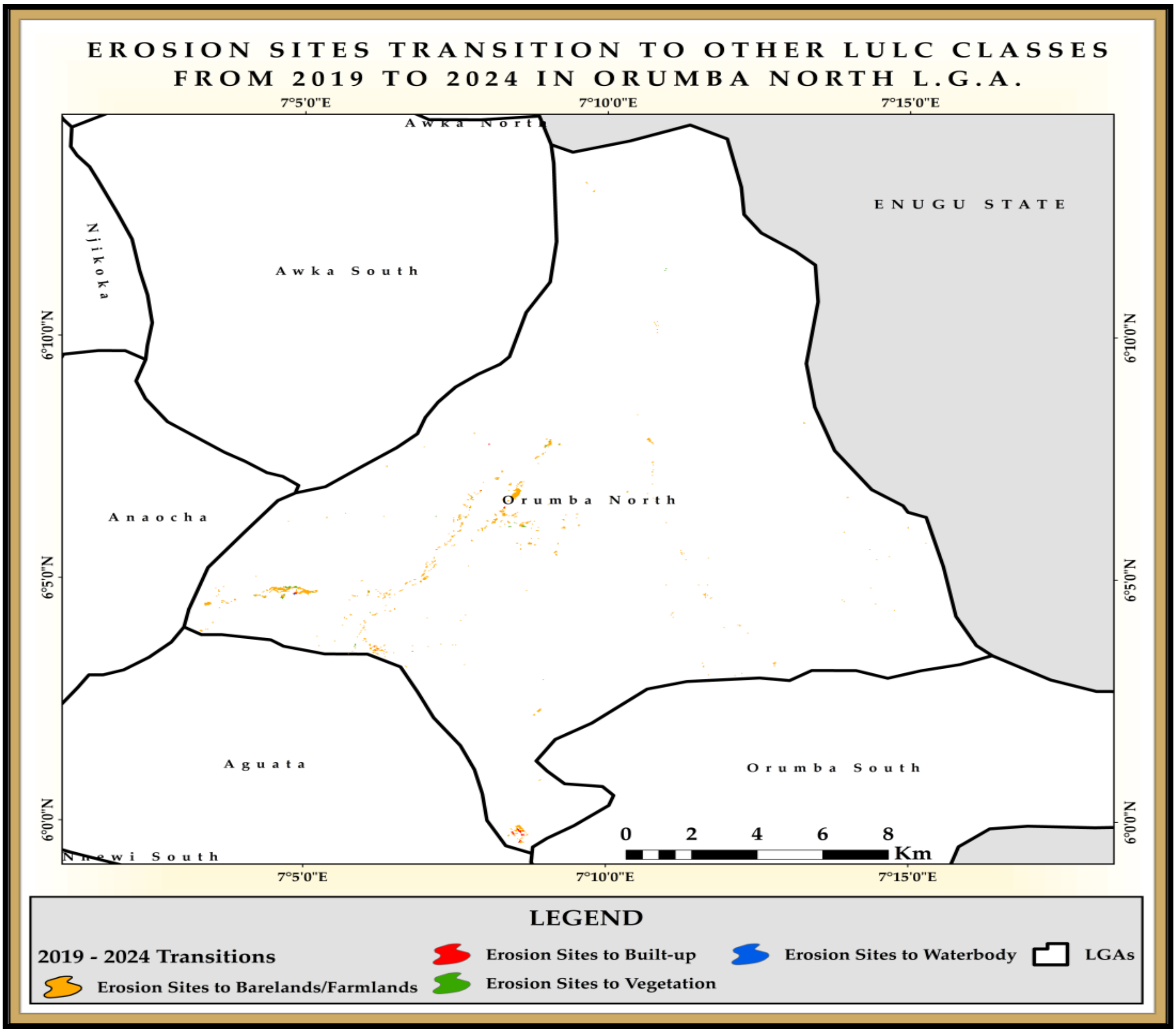

Fig 6 Transition Map to LULC Classes from 2019 To 2024

IV. DISCUSSION

The analysis underscores the pivotal and substantial role played by human activities in driving the development and progression of gully erosion throughout Orumba North LGA. During the initial phase from 1987 to 2003, a noteworthy transition of 3.03 sq. km of erosion sites into barelands/farmlands was observed, suggesting an early wave of agricultural expansion or a natural succession process occurring on previously eroded lands. This indicates the presence of initial human intervention or significant land-use pressure that influenced the landscape in relation to the erosion sites. The most remarkable and striking change during this period was the substantial conversion of 7.32 sq. km of erosion sites into vegetation, a clear reflection of aggressive and determined reclamation efforts, likely supported and facilitated by national and international bodies such as the World Bank. However, the extremely minimal transitions to built-up areas (0.01 sq. km) and water bodies

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(0.06 sq. km) suggest a limited degree of urban development or hydrological influence during this initial stage.

From 2003 to 2019, the highest rate of transition shifted prominently to barelands/farmlands, reaching a total of 1.87 sq. km, with a concentrated focus specifically observed in the southwestern zone surrounding the notorious Nanka erosion site. This shift indicates a growing and increasing reliance on the nutrient-rich soils found in eroded areas for agricultural purposes, potentially intensified by extensive farming practices or the effects of climate variability. Transitions to built-up areas (0.10 sq. km) and vegetation (0.12 sq. km) remained modest and relatively limited, with no recorded conversion to water bodies, suggesting a noticeable decline in reclamation efforts when compared to the robust initiatives of the 1987-2003 period. From 2019 to 2024, this trend persisted with a 0.99 sq. km loss to barelands/farmlands, further reinforcing the pattern of agricultural utilization particularly around the Nanka erosion site area, alongside minor and almost negligible transitions to built-up (0.04 sq. km), vegetation (0.05 sq. km), and water bodies (0.004 sq. km). These findings collectively underscore how human activities, particularly intensive agriculture and sand excavation, have both significantly exacerbated erosion by exploiting vulnerable and susceptible soils and profoundly influenced evolving land-use patterns, with varying and inconsistent success in reclamation efforts observed over the course of time.

V. CONCLUSION

This study concludes that gully erosion in Orumba North LGA is a human-induced and intensifying hazard that has significantly altered the landscape over the past three decades. While earlier years showed substantial reclamation successes, recent patterns indicate a reversal marked by rising erosion rates, particularly around the Nanka erosion complex. The results point to agricultural expansion, land misuse, and inadequate environmental management as the key drivers.

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