A Study of Land Use and Gully Erosion in Nekede Community, Owerri West, Imo State, Nigeria Using the GIS

Abstract

Land use and gully erosion incidence in Nekede community, Owerri Imo state was studied using some digital tools of the GIS and remote sensing. The Nigeria sat. 2 imagery sourced from the National Space Research and Development Agency (NASRDA) was acquired from the Landsat ETM sensor with a resolution of 30m. Landsat TM and ETM data obtained had cloud cover of less than 20%. The images were geo-referenced to a Universal Transverse Mercator (UTM) grid using the software to allow compatibility and comparison with other data sets. The Shuttle Radar Topography Mission (SRTM) 30m DEM of the study area was downloaded from the CIAT-CSI SRTM website. These data were projected to the UTM coordinates system and clipped to the extent of the study area. The Normalized Difference Vegetation Index (NDVI) was equally used to show some details since a ratio of red and near infra-red bands from a remotely-sensed image-greenness can be defined. Results are that the colour differences found in a large part of the south-west indicated built-up but were much earlier in time covered by dense forest cover which the inhabitants cleared in the process of urbanization and agricultural activities exposing the fragile soil to heavy rainfall and concentrated run off. The high speed of the surface runoff leads to rapid washing away of the soil and weakening the soil strata bringing in effect gullies. Land use zoning using digital GIS and remote sensing models in monitoring land use/cover changes following existing master plans was among others recommended.

Keywords; GIS, remote sensing, gully, land use, landsat, images.

Introduction

Soil erosion caused by wind or water has been documented from the earliest of times as a severe environmental hazard [(1)]. "Current estimates show that about seven percent of the world's topsoil is lost yearly to erosion in all ramifications. In fact, the World Resources Institute claims that Burkina Faso loses 25 tonnes of soil per hectare per year while Ethiopia loses 42 tonnes; Nepal 70, Deccan Plateau (India) 100, and the loess Plateau of North China 251 tonnes. Also, the soil survey of England and Wales reported that 44 percent of arable soils in the United Kingdom, an area once considered not under threat, are now at risk"[(2).] However, erosion in the form of gully threatens the world affecting most soils and land uses. As outlined above, examples of serious gully erosion events at various times are common in all areas of the world. The ever changing and fast evolving landscapes of past and present phases depict intense soil erosion in the form of gully, showing the impact of environmental change due mainly to interactions between geomorphological features, changes in land use and high climate-weather events. The extent of change in this time compared to the past decades implies that changes in land use processes and man-made activities are on the front burner. Increasing urban development with paved surfaces and iron roofing materials has increased the magnitudes of soil wash in the form of gullies with downstream consequences. The rural landscape is not left behind as residential structures with modern facilities now characterize these areas. Since the rural environments lack good capacity for organized sustainable planning and management as well as government attention in the third world nations, the rate of degradation to gullies has now become overwhelming.

"Land use changes as a prominent but consistent anthropogenic activity does not leave the environment without severe consequences. For example, the conversion of vast agricultural lands and forest areas to urban development shrinks the available land space for food and timber production, while soil wash, salinization, desertification processes, leaching and other types of degradation associated with improved agriculture and forest clearance negatively affect the quality of land resources and future agricultural productivity" [(2)].

It has also been projected that 20 million hectares of agriculturally viable land worldwide is now destroyed due to erosion annually. "In southern Nigeria, gully erosion is responsible for the destruction of transportation routes and communication systems, degradation of arable land, contamination of water supply, isolation of settlements and migration of communities. The area is associated with phases of high intensity rainfall which combine with non-cohesive soil structure to make erosion one of the most serious environmental hazards in the area. Dense gully networks now occupy many catchments in the region and new lines of flow have occurred in response to anthropogenic activities. Their occurrence has caused severe loss of soils particularly for agricultural productivity" [(3)].

Gully erosion which as a major type of soil erosion is one of the most prominent forms of soil erosion in south eastern Nigeria due mainly to the remarkable impressions they make which are part of the visible manifestations of the physical loss of land resulting in degradation and decline in agricultural productivity. Since the earth's environment undergoes routine changes due to land use and the activities of man; different land uses which accelerate the process of gully erosion and land degradation are land clearing, and forest clearance, urban development for residential, commercial, agricultural, recreational and educational uses; as well as the creation of fuel wood tracks that hasten the incidence of these processes. "However, natural resources development and management are of tremendous concern to mankind and the utility derivable from resources use and the deleterious effects and consequences of resources abuse are important for the continued existence of man and the survival of natural ecosystems. Environmental destruction sets in as the strength of a natural ecosystem to renew itself is held down always by frequent disturbance or perturbations posing a big threat to human survival and livelihood. Maps and measurements of degraded land can be derived directly from remotely sensed data by a variety of analytical procedures including statistical methods and interpretation by man". [16]

In Nigeria, the problem of gully erosion has become a problem for serious consideration since the early 1920. It has continued to attract under interest than before and has become a topic for spirited speeches by legislators, government functionaries at all levels, the academia and the general public [4]. According to [5] over 1,970 gully sites are in Imo and Abia states as [4] estimated about 2,500 active gullies in Imo state alone. These conflicting data call for serious concern in planning and budgeting for erosion risk management and control.

On the factors of gully erosion, there is no consensus as many researchers conclude that it is purely a water-related effect (surface runoff), while others believe only in the nature of soil as the major factor [5]. The impacts of groundwater and hydro-geotechnical factors as possible additional factors especially in the most delicate points where massive earth movement is the dominant mechanism have also been known that active gullies are found mostly at the discharge areas of groundwater systems and river banks as well as hillsides and road drainages [6]. Amazingly, despite the volume of literature on gully erosion; erosion is principally governed by two major processes of erodibility and erosivity. Erodibility suggests the nature of soil while erosivity adheres to the characteristics of the incoming force of detachment (wind or water). In that case therefore, for erosion to occur, the soil must be erodible while the incoming force of detachment erosive [7]. The intensity therefore of various land uses may worsen the process of soil detachment when the soils in the affected areas become less compact to resist loss. Land use change- forest clearance, urbanization, agriculture and other activities of man have changed the earth's surface structure. Such disturbance of the land impacts important ecosystem processes and services which can have wide-range and long-term negative results including gully erosion.

With these complexities, the study and management of gully erosion processes have become somewhat problematic leading to the development of numerous stochastic and process-based models with increasing emphasis on the use of Geographic Information System (GIS) and Satellite Remote Sensing (SRS).

Materials and Methods

1. Survey of the selected gully erosion sites was done physically while also making observations, visual analysis of outcrops, topography, slope and vegetation cover. The Mobile Topography application for Global Positioning System (GPS) with a

1.0 precision was used to obtain measurements of coordinates of the study area to give a range of latitude of $5^{o}18^{1}$ – $5^{o}39^{o}$N of the equator and longitude of $6^{o}51$ – $7^{o}08$E of the Greenwich [3].

2. The study area is Owerri West local government area Imo state, south eastern Nigeria which has an average altitude of about 300m above sea level covering about 1,200km^{2} of land area. The climate is of the humid tropical type with a mean annual rainfall of between 1,500mm and 2,200mm (60 to 80 inches) and a mean annual temperature range of between 27^{o} and 28^{o}C. Rainfall is mainly conventional, occurring in two major peaks i.e. July and October respectively[8] (see fig.1)

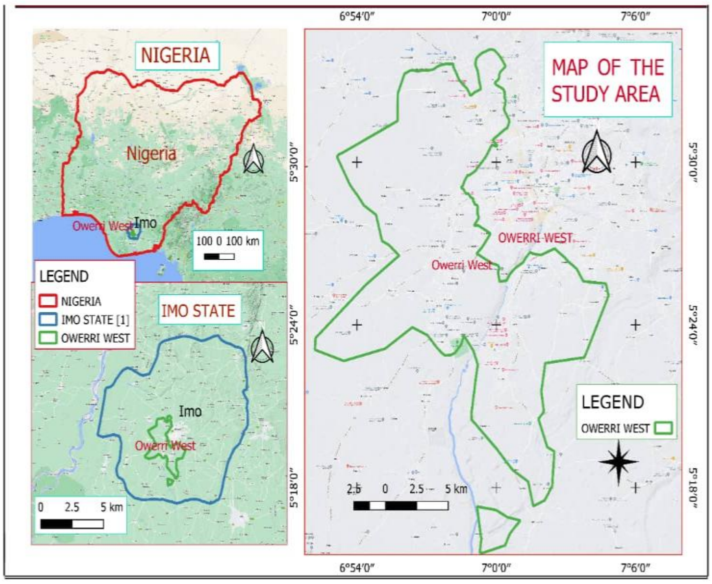

Fig. 1 Study Area

3. The Nigerian sat. 2 images obtained from the National Space Research and Development Agency (NASRDA) were acquired with a resolution of 30m. Landsat TM and ETM data obtained had cloud cover of less than 20%. The images were geo-referenced to all Universal Traverse Mercator (UTM) grids using the software to allow compatibility and comparison with other data sets.

Shuttle Rader Topography Mission (SRTM) 30m DEM of the study area was downloaded from the (IAT-CSI SRTM website (http://srtm.csi.cgiar.org). The data were projected to the UTM coordinate system and clipped to the extent of the study area. The raster consisted of 349 columns and 442 rows with a resolution of 90m per DEM cell implying that the landscape is approximately 20m to 181m – a vertical range of about 161m. The DEMs were visually assessed to observe their conformity to the field knowledge of the terrain shape and their consistency in showing the most prominent geomorphic features like drainage networks and ridges. One of the most important factors impacting soil erosion by water is typography. DEMs have been commonly used in a GIS for representing topography and for extracting topographical (slope, terrain) and hydrological (rainfall) features for various applications, including soil erosion studies.

The Normalized Difference Vegetation Index (NDVI) was equally applied to the study since by taking a ratio of red and near infra-red bands from a remotely-sensed image (an index of vegetation) 'greenness' can be defined. The NDVI is shown as;

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

$$= \frac{Band\ 5 - Band\ 4}{Band\ 5 + Band\ 4}$$

NIR = Near Infrared Band

The NDVI is probably the commonest ratio indices for vegetation. NDVI is correlated with many ecosystem attributes that are of interest to researchers and managers because makes it possible to compare images overtime to look for ecologically significant changes. The output of NDVI is a measure of vegetation richness of any environment. Values of NDVI can range from -1.0 to 1.0 but values less than zero typically do not have any ecological significance. Low NDVI values imply that there is a small difference between the red and near infra-red (NIR) signals. This happens when there is little photosynthetic activity or when there is just very little NIR light reflectance (that is, water reflects very little NIR light from the NDVI of +0.30 to -0.38) which shows unhealthy vegetation.

False colour images allow viewing of images captured in parts of the spectrum that would otherwise be invisible to the eyes such as infra-red or ultra-violet. The reflection of colour tones of different materials on the earth helps in distinguishing surface materials and their boundaries. In this work, there were three colour composite images with RGB; R=Red, G=Green and B=Blue bands of Landsat TM multispectral images respectively.

Results

The central region of the study area can be visibly spotted as spots shown by the blue colour with NDVI of -1.00 – 0.00. This colour can also be seen in a large part of the southwest area showing built-up. The areas were much earlier in time covered by dense forest which the inhabitants cleared in the process of urban development and agricultural activities exposing the fragile soil to heavy rainfall and corroborated by the findings of [6]. Also, the result is consistent with the fact that erosion of the soil is predicated on the incoming force of detachment [7]while[5] agrees that there is no consensus as many believe that it is purely a water-related effect (surface runoff). As others see it as nature of the soil, [3] states that the occurrence of this environmental hazard causes serious loss of soils affecting particularly agricultural productivity. The regions represented by colour green have the highest vegetation with an NDVI of 0.35 up to 1.00 (see fig. 2)

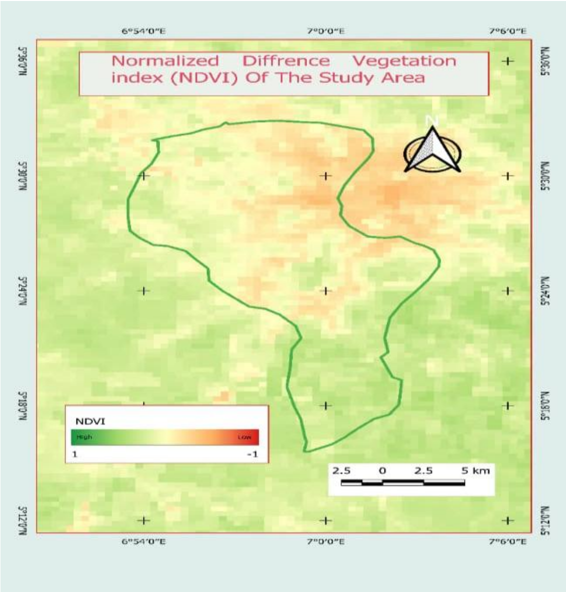

Fig 2. NDVI of the Area

Colour composite images show a natural and earth view of the study area and the images show the drainage pattern of the study area to be dendritic. Soil erosion (gullies) is more intensive on soils on which former growth has been negatively impacted to make way for infrastructural development, agriculture and other related land use activities. Those colour composites helped in exploring all the different areas on the map as shown on figures 3, 4 and 5. Generally, deep red hues indicate broad leaf and or healthier vegetation while lighter reds signify grasslands or sparsely vegetated areas. Densely populated urbanized areas are shown in light blue and blue represents water bodies.

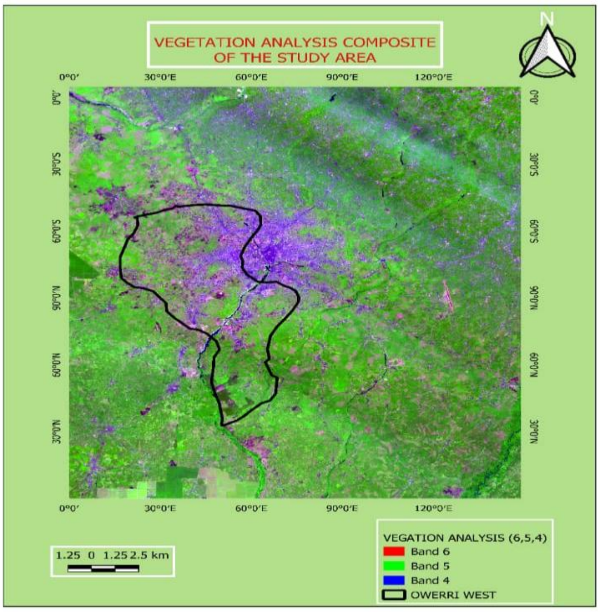

Fig.3 Vegetation analysis

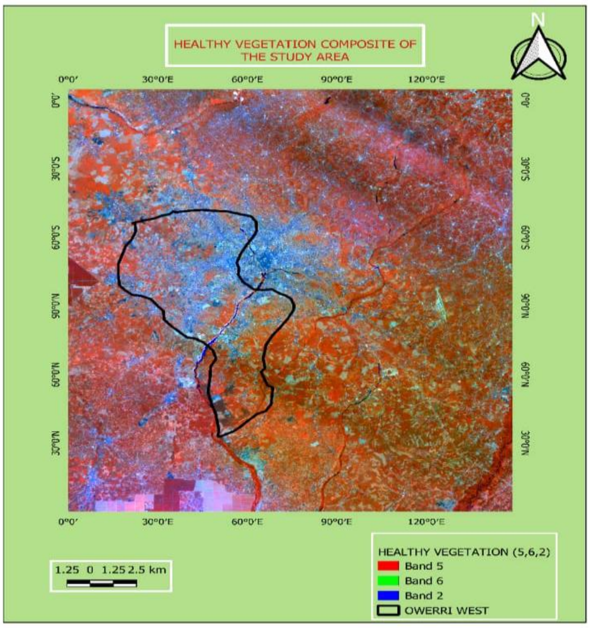

Fig. 4 Vegetation Composite

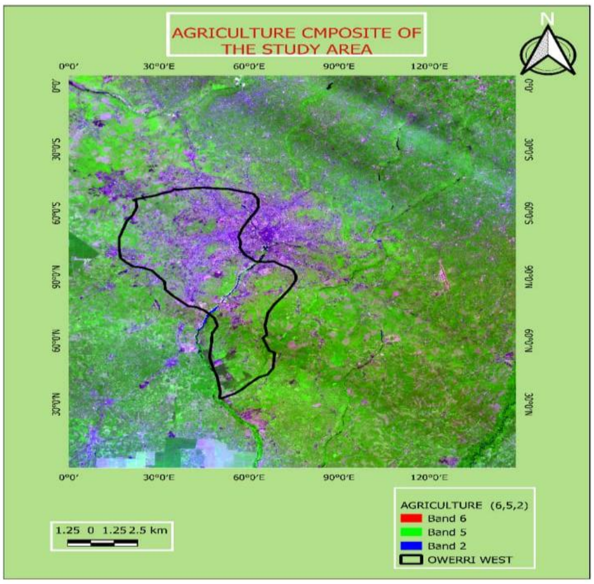

Fig. 5 Agriculture Composite

The DEM indicates that the slope surrounding the hills towards the top right of the image is somewhat steeper than that of the (green) southwest of the map. From the land cover information, huge parts of the landscape are covered by vegetation with slight indications of grasslands and sparsely vegetated areas. From the figure, the south-west region records a low elevation and large coverage with lowlands ranging from 48-90m above sea level. In the northwest, higher elevations were noticeable (90-140m) while at the extreme northeast corner; a peak of 140 – 180m was recorded. As the southwest region has this elevation, the elevation of the study area increased from the south-west to the north-east and it is characterised by low hills with steep slopes which when correlated with the intense rainfall, can be a causative factor of gully erosion in the area (fig.6).

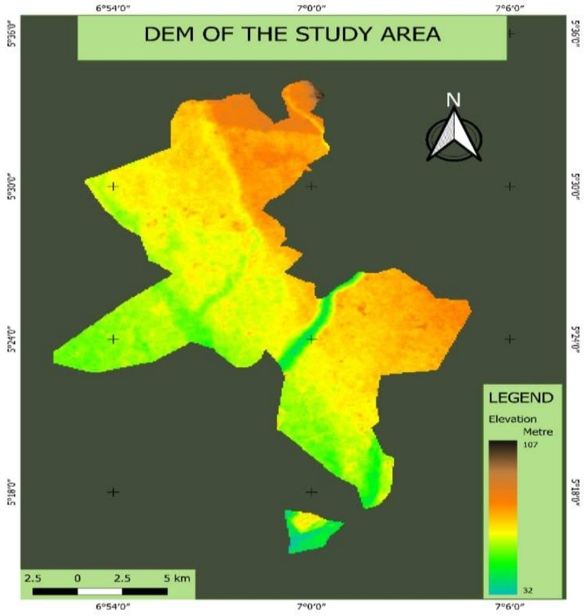

Fig.6 DEM

On terrain classification, the grey areas represent planar regions; blue areas represent channels and yellow ridges while occasional red cells that represent local peaks and green cells which represent passes in the landscape are evident (fig.7).

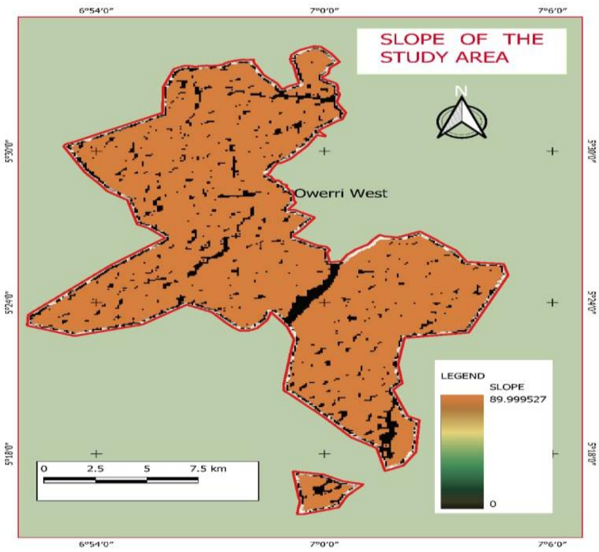

Fig.7 Slope

"Feature classifications like these are useful for several reasons. The pattern of channels appears somewhat similar to a drainage network thus giving an idea of where water would flow over the surface. Perhaps less obviously, the pattern of yellow cells gives an equivalent ridge network identifying portions of the landscape where water is likely to flow from". [16]

Discussion

Following this result, there is a strong link between land use changes and gully erosion in the study area. This fact is supported by studies from other researches across the world where for example, [10] observed that “changes in land use in East Africa have considerably transformed land cover to farmlands, grazing lands, human settlements and urban centres hence destroying the natural vegetation”. Also in a similar context, most of the areas in the Lower Tana River Forest Complex that were previously under forest cover were lost to crop production. This development/scenario which in most cases is unregulated goes on at an alarming rate which alters the natural ecosystem that opens up the environment to gully erosion.

[11] on their own equally revealed that changes in land use and land cover have always changed the landscape of the Mau forest complex which drastically reduce existing forest cover while another scenario was presented by [12] in the Lambwe valley of south western Kenya where human settlement increased land use and land cover changes. It is believed that these changes have worsened the scramble for the available land space. These situations spark off landscape transformations as numerous gullies begin to exist; losing great stretches of land to the hazard. In addition, [13] observed that vegetation cover decreased by 41.9 percent in 2015 including changes to other land uses in Bida Niger State Nigeria. In essence, it is expected that that the initiation of gully erosion due to land use and land cover activities will continue to remain a threat to livelihoods. These cases are worsened since practicable and sustainable land use and land cover inventory, assessment and management are not put in place through the machineries of government to check the hazards of gully erosion.

In the Jefferson County, Illinois, 59 percent of the land use is in agricultural production mainly corn and soybeans hence [14] observed that “about 7.4 percent of the agricultural land had an elevated risk of developing gully erosion. Among all the factors considered, the slope, land use, seasonal daily maximum precipitation and organic matter indicated the highest contribution in predicting the presence of gullies. It was also shown from results of other studies that spatiotemporal changes in land cover and precipitation were crucial in predicting gully formation in agricultural areas”. In the black soil region of north east China ([15] observed that “land use change associated with agricultural development has caused profound ecosystem change and is seen as the main driver of accelerated soil erosion in the region.

These research results from various therefore hold land use and land cover changes strong as the main factors that cause ecosystem and landscape alterations in the form of gullies".

Conclusion and Recommendations

The incidence of gully erosion has some digital correlation with topography, land use/land cover dynamics of the study area. Varying DEM and terrain characteristics reveal the extent of change of land use across the entire area.

Owerri being the administrative seat of government in Imo state is no doubt prone to different shades of land use transformations since demand for space is high due to population pressure. The sprawl to different parts of Owerri almost comes without the corresponding environmental impact assessment that will project future development trajectories and their associated consequences. Development and urban sprawl must keep pace with environmental protection sustainably if the ever increasing fragile landscape is to be maintained for posterity. The high events of runoff and climate-weather must be considered in all aspects of town and rural planning. Reliance on climate-weather predictions must be factored into the planning process as urbanization and development increase in intensity.

The study has also revealed that different colour bands of the GIS applications for different analytical tools made it clearer in assessing in real terms the intensities of development that will impact more on the landscape. All the same, man-made factors are major drivers of the land use changes-policy, urbanization, population pressure, economic and agriculture. As a rapidly urbanizing area due to population on mainland Owerri, land use zoning with digital applications of sprawl as well as a check on other human induced processes to gully erosion should be put in place against soil wash and degradation. Periodic assessment of changes in land use will further prepare for management options in the face of a rapidly degrading landscape due to gully erosion. Since erosion in the form of gullies is common in the south eastern part of Nigeria where the study area is situated, such factors as influences of geology, climate, slope, soil, vegetation and man must be considered while making developments now and in the future.

Author Contributions

Mr. Femi Martins Durumbah Obi coordinated and supervised the field work while identifying most gully sites and their accompanying land uses. Dr. Ejenma, Enyinnaya updated the literature, analysis, results, conclusions and recommendations in line with the phenomena on ground which helped in marrying the literature with GIS applications. Mr. Falana, Olufemi updated all maps using current GIS and RS applications for the study area. He further aided in the overall interpretation of the results of all digital applications.

Conflict of Interest

The authors have no conflict of interest.

Funding

This research did not receive any external funding.

Acknowledgement

The authors are grateful to Mr. Daniel Okocha who dutifully typed the final manuscript.

References

1. Poesen, J.W., Vandaele, K. and Van Wesmael, B. (2006). Contribution of gully erosion to sediment production on cultivated lands and rangelands. Erosion and sediment yield. Global and regional perspectives *(Proceedings of the Exeter Symposium)*.
2. Lubowski, R.N; Vesterby, M; Buchottz, S., Baez, A. and Robertz, M.J. (2006). Major uses of land in the United States, 2002. *Economic Information Bulletin* No. (EIB-14).
3. Kakembo, V., Xanga, W.W. and Rowntree, K. (2010). Topographic thresholds in gully development on the hill slopes of communal areas in Ngqushwa local municipality, Eastern Cape, South Africa. Catchment Research Group Rhodes University, South Africa.
4. Kalu, A.O. (2005). Soil erosion and landslide. 21st century environmental issues and challenges to rural development. *Unpublished paper in Waugh in Nigeria. Dept; of Urban and Regional Planning, Abia State University, Uturu.*
5. Onu, N.N. (2011). Training in geophysics: The challenges of oil exploration, gully erosion and water resources development. *18th Inaugural lecture of the Federal University of Technology, Owerri*
6. Igbokwe, J.I., Ojiako, J.C. and Nnodu, V.C. (2003). Monitoring *characterization and controlling of flood water erosion using Remote Sensing Techniques. Proceedings of the Technical Session of the 38th annual conference of The Nigerian Institution of Surveyors, Lokoja, Nigeria* pp.73-79
7. Ejenma, E. (2009). Spatio-temporal analysis of environmental hazards in Abia state. *Being an unpublished doctoral proposal submitted to the Dept. of Geography and Environment Management, University of Port Harcourt, Rivers State.*
8. Iwegbu, N.E. (2017). Assessment of gully erosion in Nekede Community, OwerriWest, Imo state using GIS and remote sensing. *Being unpublished HND project, Dept. of Environmental Management Technology, Federal College of Land Resources Technology, Owerri Imo state, Nigeria.*
9. Nnaji, A.O. (2009). Climatology and meteorology. A pocket note. Owerri Nigeria, Bill Fred Publishers.

10. Maitima, J.M., Mugatha, S.M., Reid, R.S., Gachimbi, L.N., Majule, A., Lyaruru, H., Pomery, D., Mathai, S. and Mugisha, S. (2009). The linkages between land use change and land degradation and biodiversity across East Africa. *African Journal of Environmental Sciences and Technology*, 3(10):310-325

11. Ayuyo, I.O. and Sweta, L. (2014). Land cover and land use mapping and change detection of Mau complex in Kenya using Geospatial methods. *International Journal of Science and Research.* 3(3):767-778.

12. Njoka, T. .J., Muriuki, G.N., Reid, R.S. and Nyariki, D.M. (20030. The use of sociological access land use change. A case study of Lambwe valley Kenya. *Journal of Social Science*, 7:181-185.

13. Mahmud, H.L. and Umaru, E.T. (2018). Impact of gully erosion on land use/land cover in Bida town Niger State, Nigeria. *International Journal of Geography and Environmental Management*, vol.4 no. 2

14. Stein, M., Han, J., Guzman, J. and Chu, M. (2022). Gully erosion susceptibility considering spatiotemporal environmental variables: Midwest U.S. region. *Journal of Hydrology: Regional Studies*. DOI:10.1016/j.ejrh.2022.101196.

15. Li, M., Li, T., Zhu, L., Meadows, M.E., Zhu, W. and Zhang, S. (2021). Effect of land use change on gully erosion density in the black soil region of north east China from 1965 to 2015: a case study of the Kedong County. *Frontiers of Environmental Science*, vol. 9/652933. DOI.10.3389

16. UJA E, EQUERE U, POPOOLA J. REMOTE SENSING, A TOOL FOR EROSION STUDY: A CASE STUDY OF NEKEDE AND ITS ENVIRONS. REMOTE SENSING. 2019 Dec;5(12).