© 2017 IJSRSET | Volume 3 | Issue 1 | Print ISSN: 2395-1990 | Online ISSN : 2394-4099
Themed Section: Engineering and Technology

Soil Erosion Vulnerability Mapping and Implication on Vegetation in Parts of Oshun River Basin, Nigeria

Samuel A. Samson[1*], Ayansina Ayanlade[2], Omowunmi Alabi[3], Abayomi Taofiq Alaga[4], Mustapha Olayemi Oloko-oba[5], Samson A. Ogunyemi [6,] Rahmon A. Badru [7]

[1,4,5,6 ,7] Cooperative Information Network, National Space Research and Development Agency, Obafemi Awolowo University Campus, Ile-Ife, Nigeria
[2]Department of Geography, Obafemi Awolowo University, Ile-Ife, Nigeria
[3]African Regional Centre for Space Science and Technology Education in English (ARCSSTE-E), Obafemi Awolowo University Campus, Ile-Ife, Nigeria.
Corresponding author: Samuel Samson (samidoy@yahoo.ca)

ABSTRACT

Soil erosion caused by water has been identified as a threat washing away top soil nutrients needed for healthy plant growth. It is thus required to identify and map areas vulnerable to erosion for effective conservation of the natural resources and maintain vegetation health. This research thus analysed soil erosion vulnerability and its implication on vegetation in parts of Oshun river basin, Nigeria. Data used for this research included: Tropical Rainfall Measuring Mission (TRMM), LandSat Image, Soil Map, Topographic Map, Small Unmanned Aerial Vehicle and Global Positioning System. All the dataset were integrated into GIS enabled software where Multi-criteria Analysis was used to map soil erosion vulnerability. Normalized Difference Vegetation Index was used to assess basin vegetation. The result showed that 86.38% of the basin soil is moderately vulnerable and soil under dense vegetation are less vulnerable to erosion.

Keywords: Erosion, GIS, NDVI, Vegetation, Vulnerability

I. INTRODUCTION

Soil erosion is a natural and dynamic process that occurs when the force of wind, raindrops or runoff on the soil surface exceeds the cohesive agent that binds the soil together [10]. It can also be defined as a systematic washing away of soil plant nutrients from the land surface by the various agents of denudation which occurs in several parts of Nigeria under different soil, climatic and geological formations, although the degree of occurrence varies considerably from one part of the country to the other [20].

Soil erosion caused by water is a serious problem in many parts of the world which causes most of the degradation of agricultural lands [1]. In Nigeria, soil erosion is a major environmental problem [20]. where most of the natural vegetal cover has been degraded. The soil profile as a whole and topsoil thickness maintained under undisturbed natural vegetative can be regarded as being in a steady state [9]. Thus, there is hardly any such soil under undisturbed vegetation with exception of the forest reserves in Nigeria. Anthropogenic activities of man on soil and natural vegetal cover leads to exposing the soil to agents that accelerate soil erosion and deterioration, depending on the existence of other favorable conditions.

Soil erosion is a major environmental threat to the sustainability and productive capacity of agriculture causing soil infertility and resulting to productivity decline [12;13;19].

Nigeria is witnessing increase in prices of foodstuff and low food crop production coupled with rise in demand as population keeps increasing [5;8;23]. However, this calls for efficient and sustainable soil management knowledge as it has major impacts, both positive and negative, on the properties of the soil that govern its productivity [4].

Studies on soil erosion have been carried out in many parts of the world. In Nigeria, such studies include those of Ibitoye and Adegboyega [15]; Igwe [11]; Ogwo [21]; Fasinmirin [7]. In addition to these is the work of the ministry of agriculture and food security, ministries of Agriculture and environment in Nigeria. In the study conducted so far in this area, the authors were not aware of studies on soil erosion vulnerability mapping at basin scale.

It was discovered that none of the studies has been able to map soil erosion vulnerability areas at basin scale.

Therefore, this study will identify and map areas vulnerable to soil erosion caused by water and assess vegetation health over the basin using Normalized Difference Vegetative Index (NDVI)

A. Study Area

The study area covers some sub-basins in Oshun-Ogun River Basin. The upper part of the basins originates from Kwara and Oyo from the east and drains into middle and lower part of the basins in Osun. The geographical location of the sub-basins is between Longitudes 4o 23’5” E to 4o53’ 51” E and Latitudes 7o 44’39” N to 8o 11’45” N (Figure 1). Some major settlements in the basin include Offa, Erin-Ile, Ikirun, Okuku, Ilobu Erin Osun, part of Ede and Oshogbo. The land area of the basin is about 146621.2 hectares while the basin makes part of Oshun River Basin [22]. The Oshun River basin is characterized with basically two seasons: dry and wet seasons where the dry season runs for November to March and the wet season is between April to October. The mean annual rainfall ranges from 900mm to 2000mm with estimated potential evapotranspiration ranging between 1600 and 1900mm per annum. The major forested vegetation region is to the south with shrub land tending towards the north. Agricultural farmland is found in most zones suitable for cultivation within the basin.

The soil is predominantly Lixsols luvisols with few percentages of Fluvisol along the major streams. The soil permeability ranges from deep to very shallow to moderately deep well drained soils.

The relief is constituted with low to gently undulation with gradient from north east to the south. The Erin Dam receives its source from the Ile Hills with an elevation of about 625m above the mean sea level. The major rivers in the basin include Otin River, Ogun River, Alako River and Erin River.

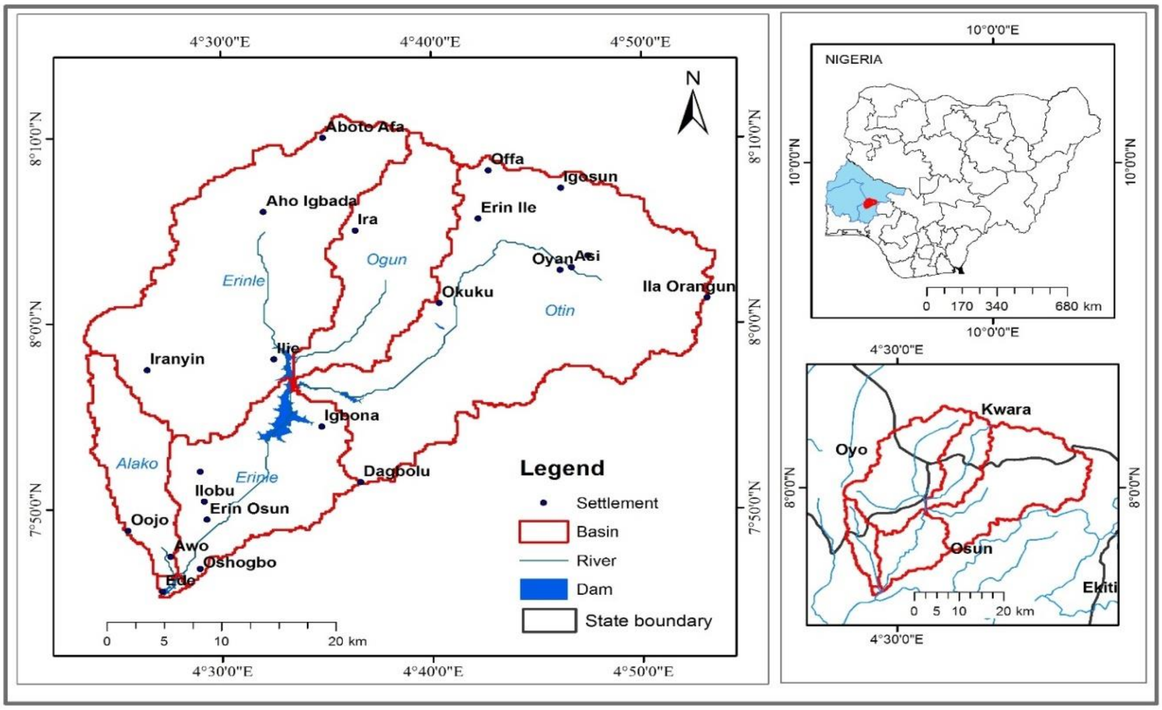

Figure 1: Study Area Map of the Basins

II. METHODS AND MATERIAL

A. Material

The data used for this study include satellite and analogue achieved data. Satellite data includes the use of LandSat 8 OLI Imagery for the year 2015, Tropical Rainfall Measuring Mission (TRMM) for the year 1998 – 2015 and Shuttle Radar Topographic Mission – Digital Elevation Model (SRTM-DEM v3, 1 ARC SEC). The analogue archived data includes six Topographic Sheets of the scale 1:50,000 and Soil map. Other data were generated from ground truthing were Aerial Photograph was acquired using small Unmanned Aerial Vehicle (sUAV) and Ground Control Points was established with hand held Gobal Positioning System(GPS) for training the remote sensing data analyses and validation of result.

B. Methods

To delineate the study area, the Shuttle Radar Topography Mission Digital Elevation Model (SRTM DEM v3, 1-Arc Sec) covering the study was extracted. Subsequently, the basin was delineated using ArcSWAT extension tool in ArcGIS 10.3. The delineated basin was exported as a shapefile into a working folder from which it was imported and added to the different software as a layer. Furthermore, the region of interest (ROI) basin was used to subset all the participatory spatial dataset and images used for the project.

The LandSat 8 OLI imagery was imported in Geo-tiff file format into ERDAS 9.2 software and layer stacked. The generated basin marking the ROI was used to subset the satellite images while bands 5(NIR), 4(Red) and 3 (Green) combination was used to generate the False Colour Composite (FCC) of the individual image. Band combination is efficient when using LandSat and other similar image data to study Land use/Land cover especially if it has to do with vegetation, farmland, water body, wetland, bare surface and built-up.

Studying soil erosion at basin scale needs data prepared from primary and secondary sources. In this work, the thematic layer of interest includes: contour, drainage network, soil textural layer, landuse/landcover, rainfall, relief and NDVI.

Topographic and soil map containing the required thematic dataset were scanned, geo-referenced and subset using the delineated ROI. Personal geo-database was created in which all thematic layers were added as feature classes (point, line and polygon) and subsequently digitized using on-screen process. Other surface terrain information generated was Triangulated Irregular Network (TIN) derived from contour for 3D visualization and slope map. In addition, sub-watersheds, stream order and other drainage frequency was generated from the drainage map. The land use/land cover was generated from the maximum likelihood classification of the FCC image covering the study area.

It is important for hydrologists to understand the spatial distribution of the amount and rate of precipitation [3]. As an input to a hydrological model, the accurate measurement of rainfall is essential for hydrological cycle research [27]. The Tropical Rainfall Measuring Mission (TRMM) dataset was preferred to in-situ meteorological dataset due to the availability of more than one station present across the study area. Hence, the estimated data was further integrated into GIS supported environment where Inverse Distance Interpolation (IDW) was applied. The IDW assumes that rainfall at a measured point compared to an unmeasured point is inversely proportional to the distance between the two points [26]. Thus, an exponent of one was used for the inverse distance relationship. The IDW method was deployed in GIS enabled software to obtain the mean annual.

Model building and analysis for mapping potential soil erosion vulnerable areas within the basins was achieved using multi-criteria analysis. The aim of soil erosion potential model is to map out the vulnerability through pixel or grid based, weighing analysis of influential factors of erosion and simplify working with them in the utilized GIS and statistical software. The pixel model approach was used which is a weighting process or weighted sum model (WSM), in which weights for each layer assigned according to its significance in promoting or reducing soil erosion.

Furthermore, each layer was classified into a number of classes with each having its own specific weight (Table 3.2). The layer of interest for building the model includes: rainfall, slope, soil texture, drainage frequency and land use. These layers were assigned weights in accordance to their contribution to soil erosion which must sum up to one (1). The assigned weight was multiplied by its constant class where it is given index values. Furthermore, the critical index for each pixel was obtained by the addition of all the computed results of the spatially overlying pixels for the five (5) participatory layers. The assignment class weight and selection of participatory layers was achieved through pairwise computation techniques [2], field work evaluation, literature review and expert judgment [14;18;24]. Geographic Information System (GIS) supported weighted overlay function was used to produce the soil erosion vulnerability map.

The implication of soil erosion on vegetal cover was assessed using NDVI map of the study area. Spatial analyst tool was used to extract NDVI pixel value intercepting the various level of vulnerability for statistical report and assessment.

Table 1.0 : Multi-criteria Decision Analysis Modelling Table.

Name of the Attribute (j)	Logic behind the attribute	Attribute Weightage (wj) (Rwj = 1)
Slope	Steep slope usually poses greater erosion potentiality	0.2
Soil Texture	Coarse texture indicates more propensity to soil erosion	0.23
Landuse	Soil under dense vegetal cover are less susceptible to erosion	0.22
Rainfall	More raindrop leads to more erosion	0.2
Stream frequency	High drainage segment found over relatively elevated and sloppy area leads to more soil being transported	0.15

III. RESULTS AND DISCUSSION

A. Soil Erosion Vulnerability

Using weighted linear combination model to map the soil erosion vulnerability areas of the basin, the five (5) factors used for the study includes:

1. Slope

Slope drives erosion in a positive direction and plays one of the dominant role [25]. Steep land has more potential to water erosion than flat land in the sense that erosive forces scour detached transport and deposit soil particles in a distance place. Therefore, land cover with slope > 300 are considered to be steep to very steep, 10-300 are strongly sloping and less than 100 are flat to gently sloping [6]. The study area is characterized with varying degrees of slope ranging from flat to gentle to very steep sloping topography. Region around longitude 4045’E and latitude 80 N are regions with very steep slope. Erin Osun and its environ is categorized under steep slope and more than 50% of the basin area are flat to gentle sloping (Figure 2).

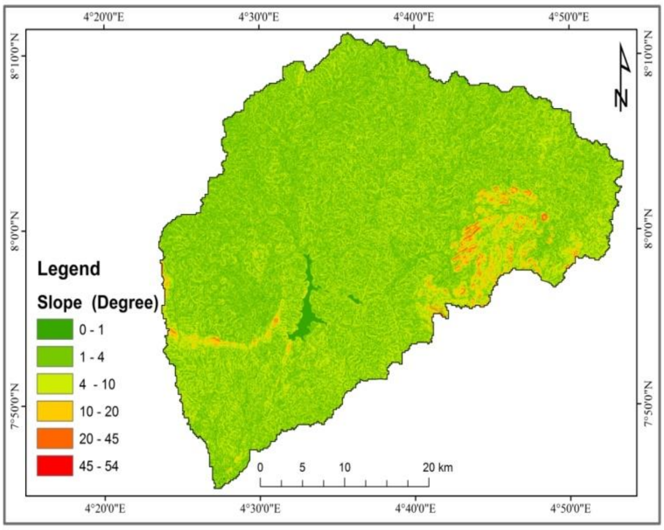

Figure 2 : Slope Map

2. Soil

The susceptibility of soil to water erosion is the function of its erodibility influenced by its physical and chemical properties. Hence, soil texture inherently determines erodibility and cohesiveness of soil. Loam soil is highly susceptible to water erosion in the study area (Figure 3). Larger percentage of the soil in the study area is sandy to loamy sand which inspires the weightage value of 0.23.

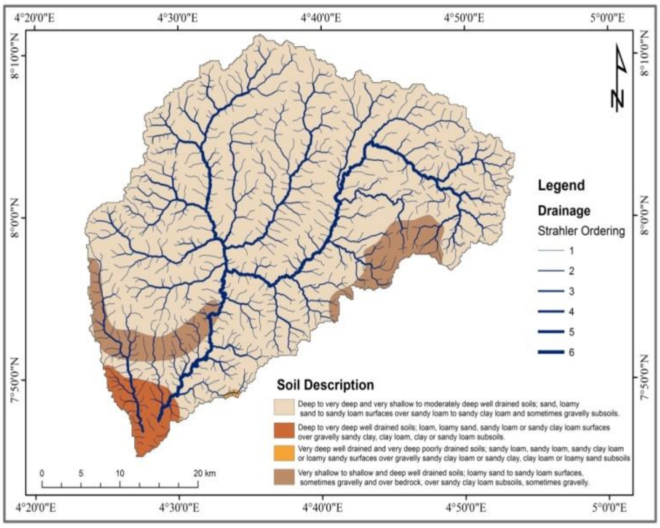

Figure 3 : Soil Map Extracted from Nigeria Soil Map .3. Landuse

Land use refers to the current use of the land, whether for agricultural or non-agricultural purposes. Vegetation and land use plays a major influence in the rate of soil erosion. Land cover such as waterbody and rock outcrops has the least potential to soil erosion. Vegetation intercept raindrops and influences infiltration of water. This increases surface soil organic matter, thereby reducing soil erodibility. Vegetation cover also slows down soil erosion process while surfaces like open land agricultural land are more prone to soil erosion by water. Figure 4 shows the land use/land cover of the basin.

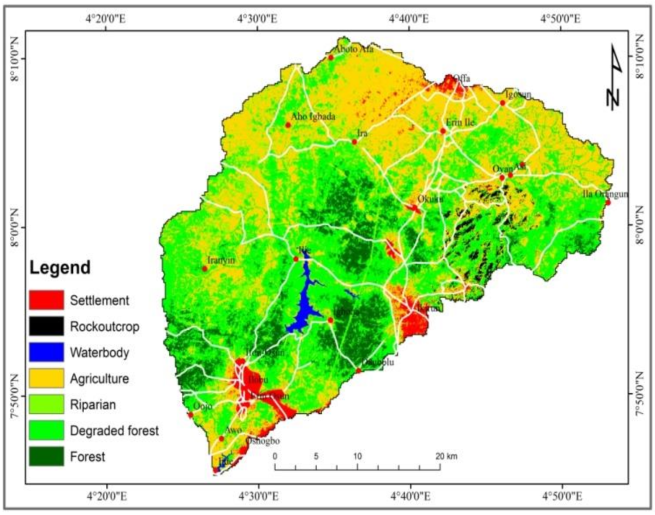

Figure 4: Land use/land cover Map

4. Rainfall

The rainfall within the study area ranges from 1453 mm at the southern part of the basin to 1355 mm at the upper basin (Figure 5). Rainfall as an agent of erosion by water contributes significantly to soil erosion. Precipitation within the basin occurs during the wet season (April – October) which influences the weightage value of 0.2.

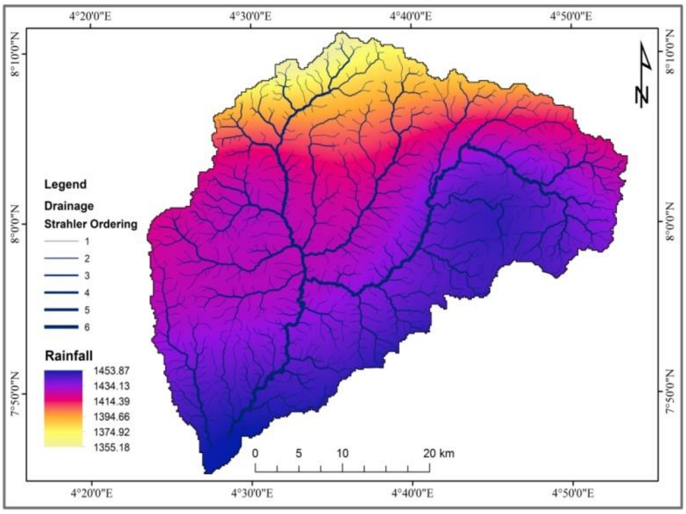

Figure 5: Mean Annual Rainfall Map

5. Stream Frequency

Stream frequency is the ratio of total number of streams in a drainage basin to the area of the basin [10]. According to Montgomery et al. [17], stream frequency has been related to permeability, infiltration capacity and relief of watersheds. Drainage frequency is one of the dominant parameters which act as major erosion vector. Frequent drainage segment (order one streams) influences more erosion and therefore 0.15 weightage value has been given.

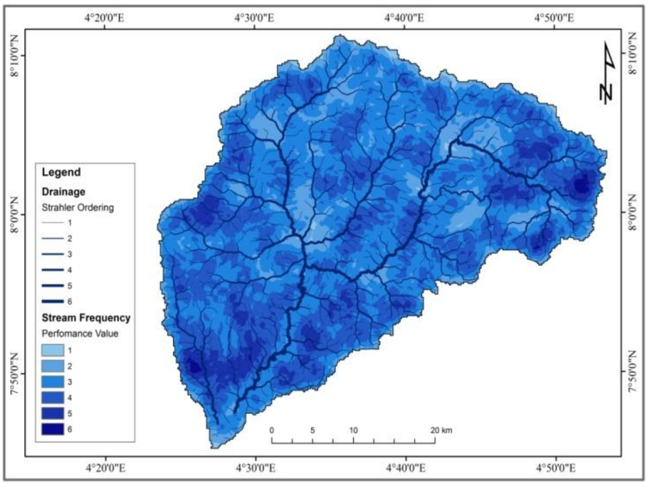

Figure 6: Stream Frequency Map

6. Soil Erosion Vulnerability Map

Figure 7 shows the spatial vulnerability of soil across the study area. It was discovered that land cover around Ifon Osun, Ilobu and Erin Osun are more susceptible to soil erosion. The estimated value of 86% of the overall basin is moderately susceptible to erosion while 0.01% are highly vulnerable (Table 4.2).

Table 2 : Soil Erosion Vulnerability Statistics

Class	Area (ha)	Percentage (%)
Low	11692.89	7.98
Moderate	126655.2	86.38
High	8260.65	5.63
Very high	12.40673	0.01
	146621.2	100

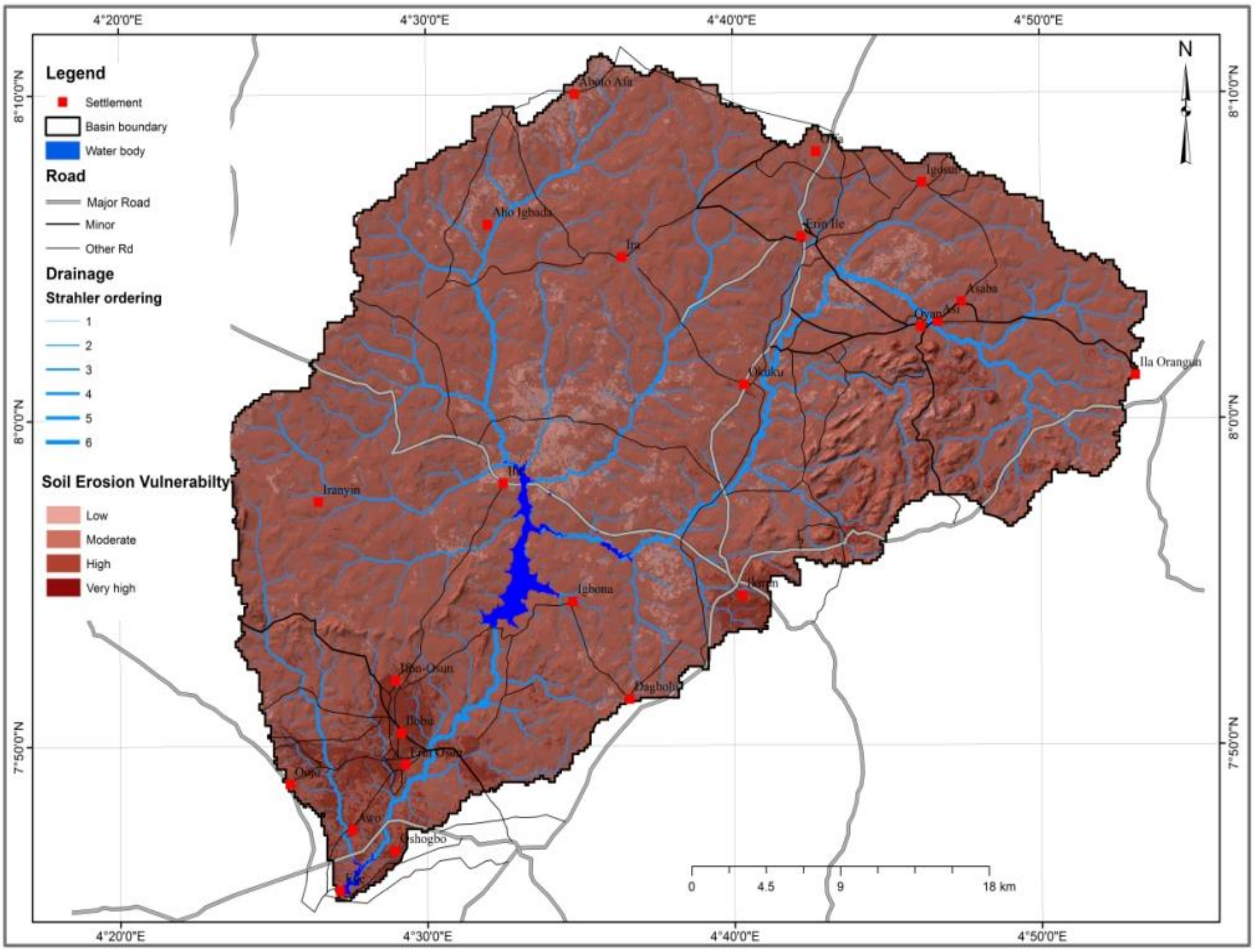

Figure 7: Soil Erosion Potential Map

Figure 8 shows the 3D model of the study area where the reality of the basin earth surface can be observed. The aerial photographs are taken with Phantom Small Unmanned Aerial Vehicle (sUAV) to validate the model via grand truthing. Regions which were classified as high vulnerable was captured with sUAV and the photograph shows an evidence of erosion occurrence.

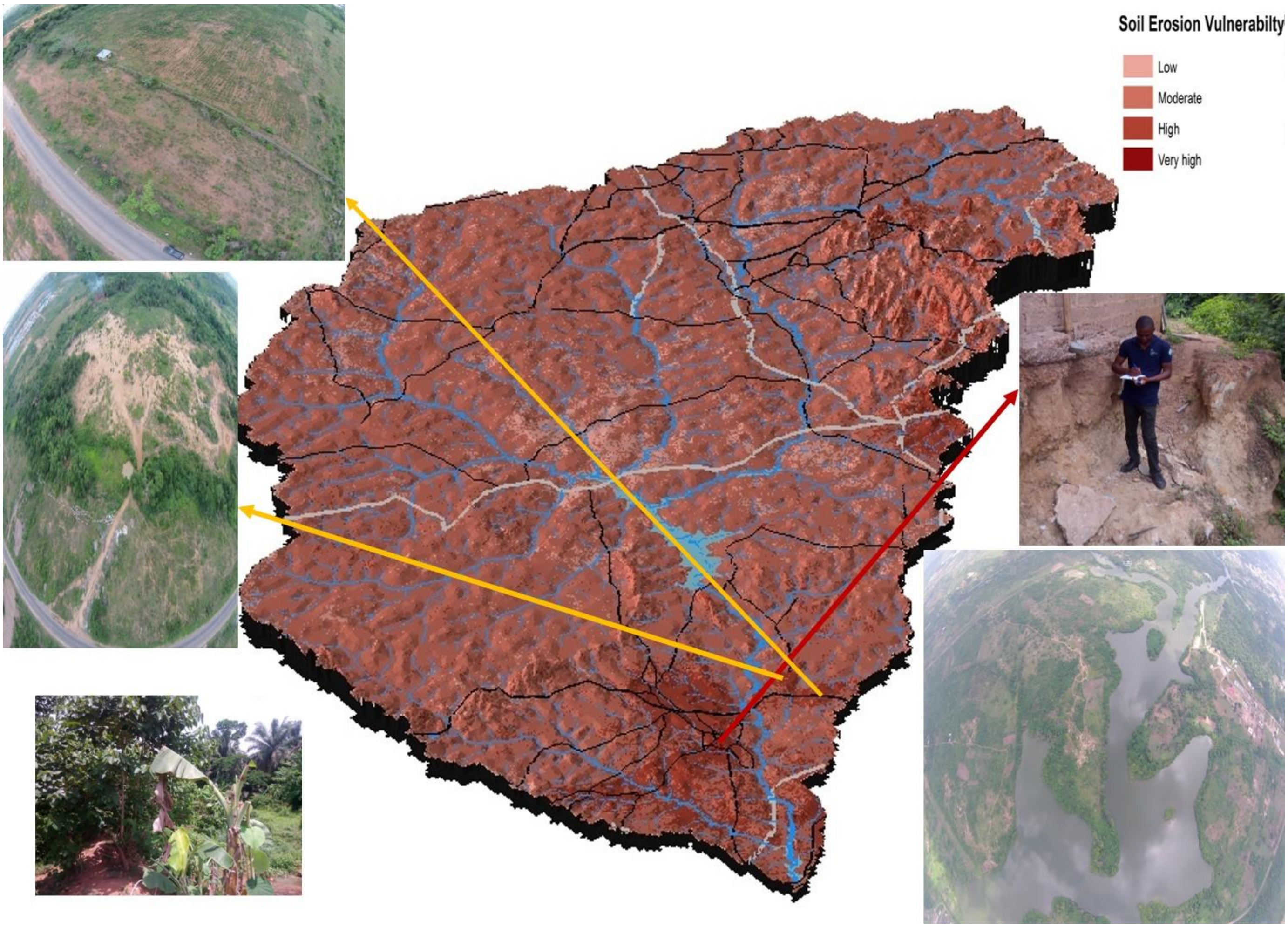

Figure 8: Soil Erosion Vulnerability Model and Fieldwork Validation Arial photograph

B. Impact of Soil Erosion on Vegetal Cover

Normalized Difference Vegetation Index (NDVI) map shows the health of vegetation across the basin (Figure 9). Higher NDVI value represents regions with dense vegetation cover while zero (0) to negative values represents bare-surface to water body as shown in the NDVI map. Vegetation serves as a binding agent and cover to the soils, thus preventing raindrop from dispersing soil particles and transporting it to a distance place. Therefore, areas with less NDVI values are more prone to soil erosion caused by water across the basin of study. Table 3 and Figure 10 clearly shows decline in NDVI mean values as it moves toward the high vulnerable areas.

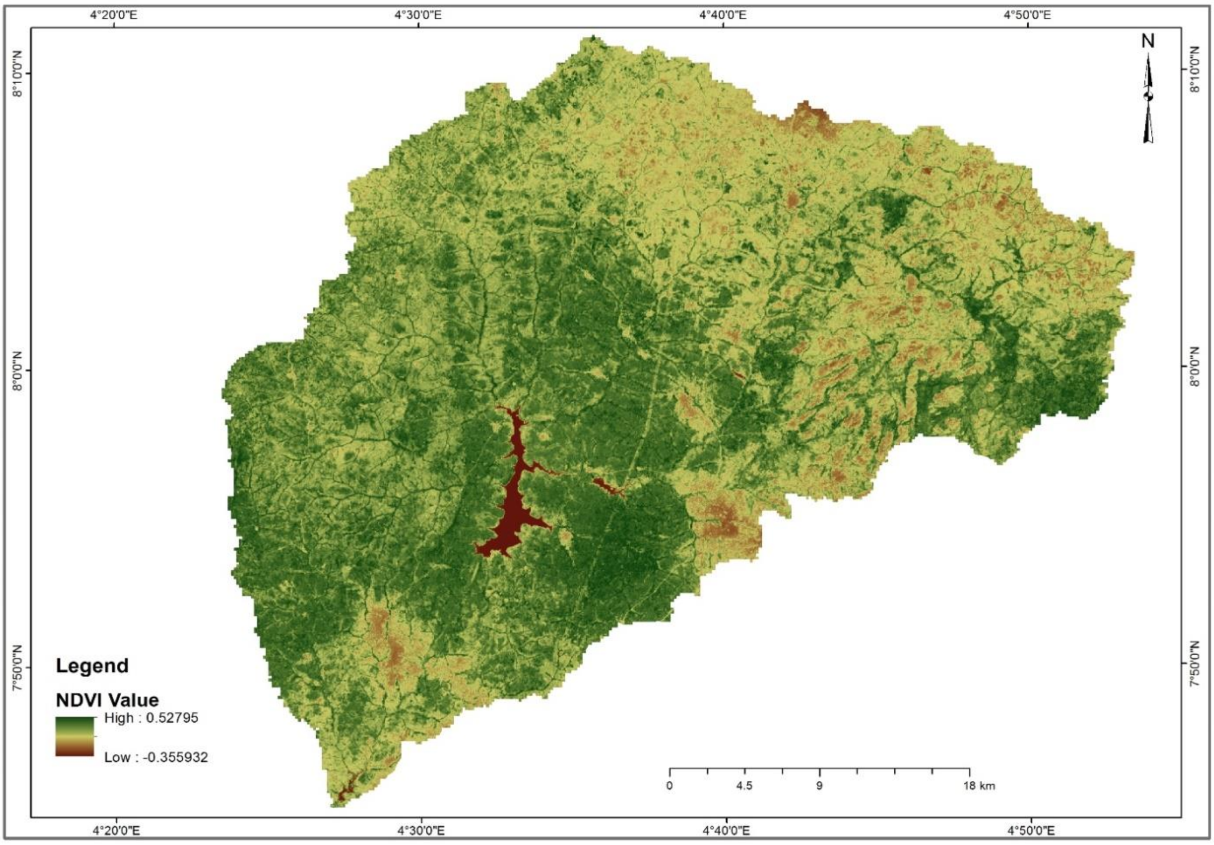

Figure 9 : Normalized Difference Vegetation Index Map

Table 3: Soil Erosion Vulnerability Class Across NDVI

Soil Erosion Vulnerability	NDVI Mean Value	Standard Deviation
Low	0.185151	0.070922
Moderate	0.184999	0.042975
High	0.155168	0.04676
Very high	0.143945	0.030818

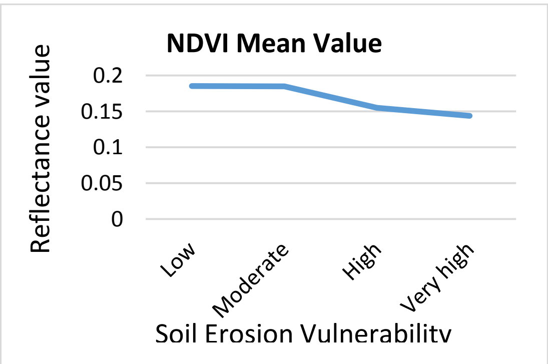

Figure 10 : Vegetation Change across Soil Erosion Vulnerability Classes

IV.CONCLUSION

Application of geospatial techniques, remotely sensed dataset and integrated analogue archived topographic maps for mapping soil erosion potential areas in part of Oshun-Ogun River Basins Nigeria has proven to be efficient with high precision on a basin scale mapping. The soil erosion vulnerability map shows that 86.38% is moderate and 0.01% is highly susceptible to soil erosion caused by water. The highly susceptible areas are found within the built-up areas where natural vegetal cover has been altered and/or totally cleared. Although, this high vulnerable area is very low, awareness programs should be carried out to those living within these vulnerable areas in other to educate them on the precautional measures to carry out incase of the soil erosion.

Considering the NDVI reflectance value plotted across soil susceptibility to erosion, it was discovered that the higher the NDVI values, the less the soil is susceptible to erosion. Hence, there is a significant relationship between vegetal cover to soil susceptibility for erosion occurrence. Development of various agricultural cropping system and soil conservation and management practices should be carried out in various areas to further cub the effects of soil erosion within the study area.

V. REFERENCES

[1] Angima SD, Stott DE, O'Neill MK, Ong CK, Weesies GA (2003), Soil erosion prediction using RUSLE for central Kenya highland conditions. Agric Ecosyst Environ 97:295–308

[2] Banai R (1993), Fuzziness in geographic information systems: contributions from the analytic hierarchy process. Int J Geogr Inform Syst 7(4):315–329

[3] Browning, K. A. (1990), Rain, rainclouds and climate. Quarterly Journal of the Royal Meteorological Society, 116(495), 1025-1051. doi:10.1002/qj.49711649502]

[4] Christoffel den B., Rattan L., Keith W., Hari E., Vince B., and Paul R., (2004): The Global Impact of Soil Erosion on Productivity II: Effects on Crop Yields and Production Over Time. Advances in Agronomy, Volume 81. DOI 10.1016/S0065-2113(03)81002-7

[5] FAO (2000), Land and Water Constraints to Sustainable Agriculture. www.fao.org/waicent/faoinfo/agricult/agl/swl/wpr/nigeria/e-bright.htm.

[6] FAO (2006), Guidelines for Soil Description. FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS Rome, 2006

[7] Fasinmirin, J.T., and Olorunfemi, I.E., (2014), Soil Erodibility Estimation under Different Tillage Systems Assessment in the Rain Forest Climate of Osun State, Nigeria. International Journal of Plant & Soil Science. Article no. IJPSS.2014.002; 3(1): 16-35,

[8] Fresco, L. 0.n (1993), The dynamics of cassava in Africa: an outline of research issues. COSCA Working Paper No. 9 Collaborative Study of Cassava in Africa. IITA. Ibadan, Nigeria.

[9] Grove, A.T., (1956), "Soil Erosion in Nigeria". In R.W. Steel and C.A. Fisher (eds.): Geographical Essays on British Tropical Lands, Philip, pp. 77-111.

[10] Ifabiyi I.P. A. (2004), Reduced Rank Model of Drainage Basin Response to Runoff in Upper Kaduna Catchment of Northern Nigeria. Geostudies Forum. Pp 109-117.

[11] Igwe, C.A. (2012), Gully Erosion in Southeastern Nigeria: Role of Soil Properties and Environmental Factors. INTECH. http://dx.doi.org/10.5772/51020

[12] Isikwue, M.O, Adakole, S.A., (2010), Effect of Tillage and Soil cover on Soil Erosion in the Lower Benue River Basin of Nigeria. Dept of Agricultural and Environmental Engineering University of Agriculture, Makurdi.

[13] Isikwue, M.O., Idike, F.I., Chukwuma, G.O., (2001), Seasonal Nutrient losses from River Ukoghor Agricultural Watershed. Proc. Nigerian Inst of AgricEngrs.; 23:229–234.

[14] Kelvin M, Siddique M, Julian S. (2012), Using multi-criteria evaluation and GIS for flood risk analysis in informal settlements of Cape Town: The case of graveyard pond. South African Journal of Geomatics.

[15] Matthew I., and Adegboyega, S., (2012), Indigenous Aproach to Soil Erosion Control in the Southwest Nigeria. FIG Working Week 2012 Knowing to manage the territory, protect the environment, evaluate the cultural heritage Rome, Italy 6 -10 May, 2012

[16] May, L., C.J. Place, O'Hea, B., Lee, M.J., Dillane, M. & McGinnity, P. (2005), Modelling soil erosion and transport in the Burrishoole catchment, Newport, Co. Mayo, Ireland. Freshwater Forum 23, 139-154.

[17] Montgomery D.R. and Dietrich W. E, (1989), "Source areas, drainage density, and channel initiation," Water Resources Research, vol. 25, no. 8, pp. 1907–1918.

[18] Nasim Yeganeh, Soheil Sabri. (2014), Flood vulnerability assessment in Iskandar Malaysia using multi-criteria evaluation and fuzzy logic. Research Journal of Applied Sciences, Engineering and Technology. ;8(16):1794-1806.

[19] Nyakatawa, E.Z., Reddy, K.C., Lemunyon, J.L., (2001), Predicting Soil Erosion in Conservation Tillage Cotton Production System using the Revised Universal Soil Loss Equation (RUSLE), Soil and Tillage Research. 57:213–224.

[20] Ofomata G.E.K. (1985), Soil Erosion in Nigeria: The View of a Geomorphologist. An Innagural Lecture of the University of Nigeria, Nsukka.

[21] Ogwo V., Ogbu K. N., Okoye C. J., Okechukwu M. E. and Mbajiorgu C. C. (2012), Comparison of Soil Erosion Models for Application in the Humid Tropics. Hydrology for Disaster Management, Special Publication of the Nigerian Association of Hydrological Sciences.

[22] Oke, M.O., Martins, O., Idowu, O.A. and Aiyelokun, O. (2015), Comparative Analysis of Groundwater Recharge Estimation Value Obtained Using Empirical Methods in Ogun and Oshun River Basins. Ife Journal of Science. Vol. 17, No. 1.

[23] Oladeebo, J.O., and Adekilekun, S.K. (2013), Land Use Intensity and Efficiency of Food Crops Production in Osun State of Nigeria. Journal of Natural Sciences Research ISSN 2224-3186 (Paper) ISSN 2225-0921 (www.iiste.org) Vol.3, No.9, 2013

[24] Samson S.A., Eludoyin A.O., Ogbole A.T., Alaga A.T., Oloko-Oba M., Okeke, U.H., Popoola O.S., (2016), Drainage Basin Morphometric Analysis for Flood Potential Mapping in Owu Using Geospatial Techniques. Journal of Geography, Environment and Earth Science International 4(3): 1-8,

[25] Swades P., (2016), Identification of soil erosion vulnerable areas in Chandrabhaga river basin: a multi-criteria decision approach. Model. Earth Syst. Environ. 2:5 DOI 10.1007/s40808-015-0052-z

[26] Tomczak, M. (1998), Spatial interpolation and its uncertainty using automated anisotropic inverse distance weighting (IDW) - Cross-validation / Jackknife approach, Journal of Geographic Information and Decision Analysis 2(2): 18-30.

[27] Yu, Z. (2008), The Principle and Application of Distributed Hydrological Model. Beijing: Science Press. (in Chinese).