Vol. 20, No. 1, 2023, ISSN 15965538, pp 84-100

Journal of Civil and Environmental Systems Engineering

Department of Civil Engineering, University of Benin, Nigeria

Journal homepage: https://j-cese.com/

Assessment of the Health Condition of Ogba River Watershed in Benin City, Nigeria Using GIS

*Rawlings, A. and Ukaegbu, S. C.

Department of Civil Engineering, Faculty of Engineering, University of Benin, Benin City, Edo State, Nigeria.

Corresponding Author's Email: *animetu.seghosime@uniben.edu

Abstract

Watershed health is crucial for maintaining ecological benefits and services, but it can be degraded by pollution and other factors. To manage watersheds effectively, various methods and tools have been developed to assess their condition and vulnerability. However, most of these methods do not account for the spatial aspect of a watershed, which can vary significantly across different regions and countries. Therefore, this study has applied a spatial modelling approach in a Geographic Information System (GIS) to assess watershed health in Nigeria. In this study, five primary indicators such as annual rainfall, soil type, land slope, land use/land cover type and population density presented in GIS raster maps were used to assess the health condition of Ogba River watershed. A quantitative scoring was used to classify indicator value and to categorize the health level of the watershed in five zones (very good, good, moderate, poor, and very poor). Result from the study revealed that the study area is covered by two health level zone (i.e. good and moderate), Although the good health level zone is sparsely distributed in the entire study area, however it is widely distributed in the eastern part of the study area. While the moderate health level zone is scattered over the study area. Spatially, these zones are covered by loam and sandy clay loam soils, low sloping areas (0-16.28%), settlement and farming land. Hence, the watershed is currently in a healthy state, but it is threatened by farming activities that can degrade its condition. Therefore, sustainable land management practices are needed to preserve the watershed health.

Keyword: Watershed, Health Level Zone, Land Degradation, Primary Indicators, Spatial Modelling

Article History: Received: 24 August 2023**; Accepted:** 20 September 2023

1.0 Introduction

A watershed is an area of land draining into a common body of water, such as a river, wetland, reservoir, or ocean (Aldridge and Baker, 2017). Watersheds are connected through the movement of water. Water is important in this process, as it carries nutrients, sediments, and pollutants from higher to lower elevations. Water also moves through the subsurface and creates a moisture gradient in the soil, thus uplands tend to have drier soils than bottomlands.

The various moisture types in watersheds provide diverse habitat resources for plants and humans. These habitat resources may sometimes seem insignificant, but a few feet in elevation can mean a big difference in water availability to plants. Furthermore, many fish, amphibians, reptiles, birds, and mammals use more than one habitat in a watershed throughout their lifetimes, making the diverse parts of the watershed essential to their life cycles (Aldridge and Baker, 2017; Alaska Department of Fish and Game, 2023).

A healthy watershed is one that sustains ecosystem function and provides for human well-being and livelihood (i.e., ecosystem services). In many cases, human needs and ecosystem functions work well together. Unfortunately, degraded watersheds cannot offer quality water resources for humans and animals. Drought frequently results in crop failure, while high rainfall intensities result in low infiltration and high runoff causing enhanced soil erosion and land degradation (Gebregziabher etal., 2016). However, a healthy watershed has a good ability to control the balance of water availability during the dry and the wet season. Hence, droughts in the dry season and floods in the wet season can be avoided (Setyawan et al., 2019).

Watershed condition changes over time due to natural processes and anthropogenic influences (USEPA, 2022). The most pervasive changes to watershed condition come from population increase (changes in land and water use) and climate change. Currently, intensive land explorations of watersheds for many purposes without good conservation practices increases land degradation problems significantly (Pramono, 2014; Niang et al., 2015; Chalise et al., 2019). This situation endangers the function of the watershed in keeping the system of water balance. Land degradation in the form of soil erosion and declining land fertility is a serious challenge to agricultural productivity and economic growth (Agidew and Singh, 2018).

As the population of Nigeria continue to grow, a lot of people are increasingly moving from rural to urban centres, making cities with greater population density to be larger than ever before. Benin City is one of such cities experiencing a tremendous increase in Urbanization. Increased population, urbanization and industrialization has been attributed to increased anthropogenic activities which has been identified as major source of environmental degradation (Swati et al., 2016). Ogba river watershed drains a large portion of Ogba forest reserve which has been largely degraded by human activities such as agriculture (farming and grazing) or replaced by plantation forestry and urbanization (Enaruvbe and Atafo, 2018; Wangboje and Braimah, 2022). These activities are capable of changing the watershed condition.

Fertilizers are indispensable for increasing food production but their excessive use has occasioned much concern as a possible environmental threat and increase in livestock population results in overexploitation of pastures. The excessive use of fertilizers and overexploitation of pastures leads to soil erosion which adversely affects vegetation and thus leads to soil erosion (land degradation). Also land use dynamics have a higher effect on sediment yield (Weldea and Gebremariam, 2017), excessive use of upstream land (for activities such as agriculture and hydrologic modifications) coupled with atmospheric deposition result to impairments of rivers and streams (USEPA, 2009). During storms, large quantities of runoffs flow freely into Ogba river (Aziegbe, 2006) and this water may probably carry sediments and pollutants (as a result of human activities in the watershed) from the land area it drains, thus impairing the river quality. If water bodies can no longer support their designated or natural uses, the environment and/or humans will be negatively impacted. Hence, assessment of watershed health status is required for maintaining ecological benefits and services. A number of studies have recently assessed the health of watersheds using various methods and tools (Sanchez et al., 2015; Ahn and Kim; 2017; Wu et al. 2021). However, most of these methods do not account for the spatial aspect of a watershed, which can vary significantly across different regions and countries. This study aims to fill this gap by applying a spatial modeling approach in a Geographic Information System (GIS) to assess watershed health in Nigeria. A Geographic Information System (GIS) is a multi-component environment used to create, manage, visualize and analyze data and its spatial counterpart. GIS application uses data such as: raster data, coordinate reference system and vector data (Nabaggala and Agaba, 2019). Rasters are made up of a matrix of cells, each containing a value that represents the condition of the area covered by the cell. Coordinate Reference System (CRS) provide a framework for defining real-world locations and vector data are used to represent spatial objects with well-defined shapes as ordered sets of coordinates (spatial references). GIS is a useful tool for supporting better decisions in the implementation, planning, and management of land and water resources (Halefom et al., 2018). GIS can also help assess the health condition of a watershed and provide more specific information for watershed management purposes (Setyawan et al., 2019). Therefore, the aim of this study was to assess the health condition of the Ogba river watershed in Benin City, Nigeria using GIS and to provide information for effective management and protection of the Ogba river watershed.

2.0 Materials and Methods

2.1 Study Area

Ogba river watershed is situated in Oredo Local Government Area (LGA) of Benin City in Edo State, Nigeria (see Figure 1) and it has a total area of approximately 340.1km^2 (Aziegbe, 2006). The watershed is underlain by deeply weathered sedimentary rock that is often referred to as the Benin formation (Ikhile, 2016) which is made up of over 90% massive, porous, coarse sand with thick clay/shale interbeds having high groundwater retention capacity (Adegbite et al., 2018). The topography is undulating with a relative relief of 12m (Odemerho, 1992). Common mean annual rainfall observed in the area is about 2000 mm and mean monthly temperature ranges from 23°C to 28°C (Enaruvbe and Atafo, 2018). Also, relative humidity of about 90% may be observed in the area around September (Odjugo et al., 2015; Enaruvbe and Atafo, 2018). The climate of the area is moist tropical rainforest with two distinct seasons. These are the wet (rainy) season and the dry season. The rainy season occurs between the months of March and October with a short break in August. The dry season on the other hand lasts from November to February with dry harmattan winds between December and February, but with the effect of global warming and climate change, rains have been observed to fall irregularly almost in every month of the year with double peak periods in in July and September (Rawlings and Ikediashi, 2020). The watershed drains a large portion of Ogba forest reserve which has been largely degraded by human activities such as agriculture or replaced by plantation forestry (Enaruvbe and Atafo, 2018) and urbanization (Aziegbe, 2006). The population of Benin City is estimated to be about 1.75 million (United Nations, 2016).

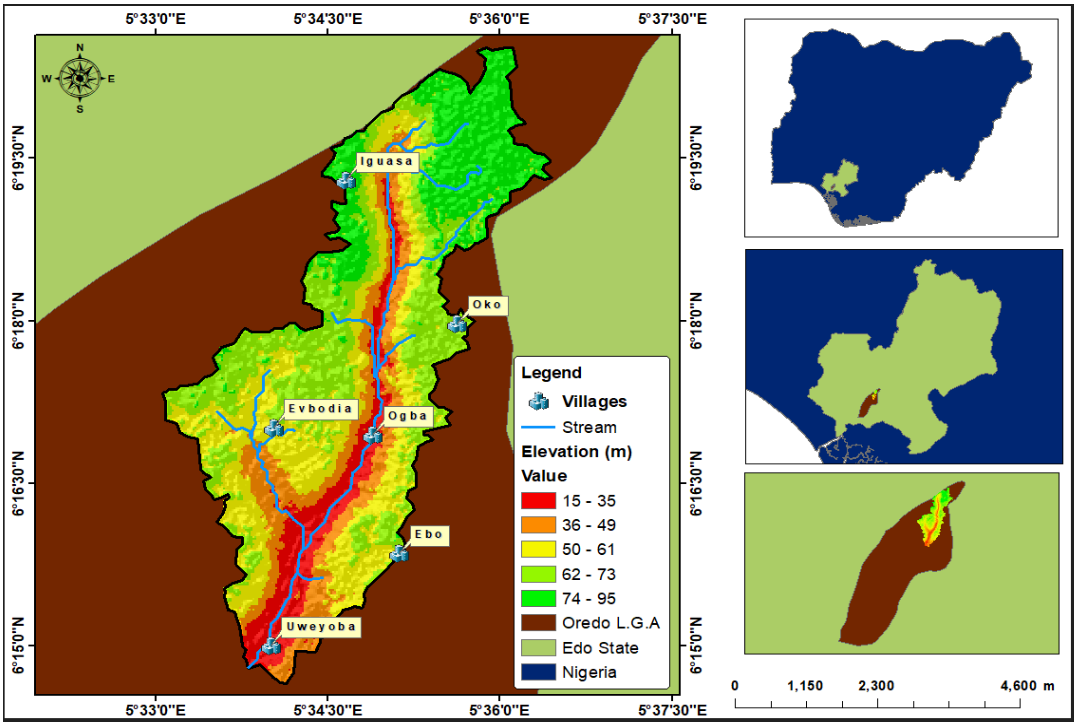

Figure 1: Ogba River Watershed in Oredo LGA of Benin City (Source: Created by Authors, 2023)

2.2 Indicators of the Study

The foundation of a healthy watershed assessment is compilation of ecological information that is measurable, comparable and consistent across the area of the assessment, and relevant to summarizing the primary attributes of a watershed's condition (USEPA, 2023). In this study, five primary indicators were selected and they are annual rainfall, soil type, land slope, land use land cover (LULC) type and population density. Each indicator was scored based on three categories according to Setyawan et al. (2019); poor (score= 5), moderate (score= 3) and good (score= 1) and the category of each indicator was determined based on standard values (from various sources) and their impact on land degradation. The indicators were presented in raster maps of GIS in 30 m resolution (see Figure 2 to 6) and then scored accordingly based on their existing values/types (see Table 1). Spatial modelling for watershed health assessment was carried out using overlaying technique in Arc GIS 10.8.1. A raster calculator (map algebra) of spatial analysis tools was used for total scoring of indicators. The total score of indicators was obtained by addition of all indicators' scores in Table 1.

2.2.1 Annual rainfall: Rainfall data were obtained from Climate Research Unit Timeseries (CRU-TS v4.07) and evapotranspiration data was obtained from Ezeigbo (1993). The Rainfall data obtained were for a period of three years (2018-2020). The category and score for annual rainfall value were determined based on the evapotranspiration for the study area (1,321 mm) according to Setyawan et al. (2019). Three categories were proposed for this indicator and these include; good (score = 1) for annual rainfall >2,000 mm, moderate (score = 3) for annual rainfall 1,321-2,000 mm and poor category (score = 5) for annual rainfall < 1,321 mm. A low annual rainfall may result in drought which in turn can give rise to some problems in the watershed (Setyawan et al., 2019). Such problem includes drying out of soils, dying of vegetation, decline in the flow of streams and rivers which can increase the concentration of harmful pollutants (Garthwaite, 2019) among others. Hence, annual rainfall data (see Figure 2) is necessary as one of the primary indicators for watershed health assessment.

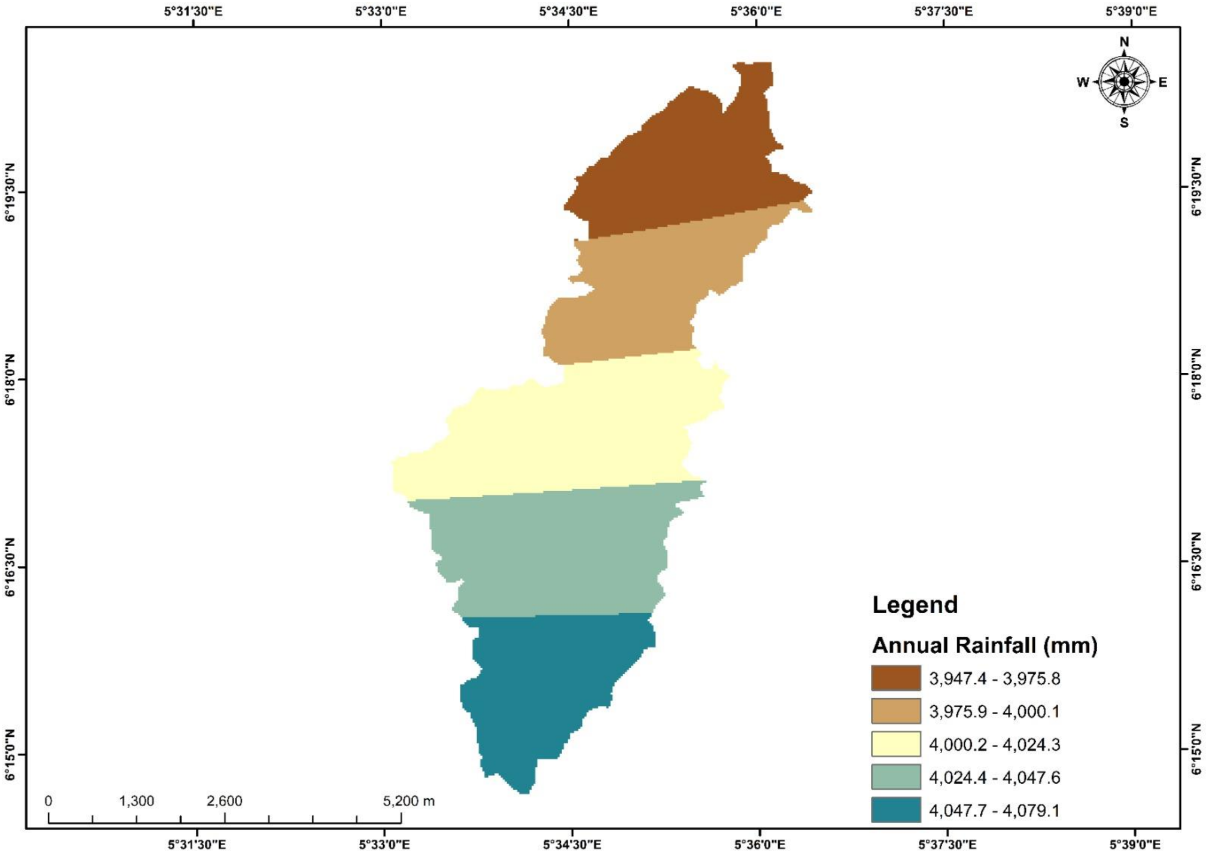

Figure 2: Map of Annual Rainfall of the Study Area

2.2.2 Soil Type: Soil type is an important and basic indicator for watershed health assessment. Soil type is among the major factors affecting erosion process based on the physical and chemical constitute. It controls soil detachability, soil particle transport and infiltration of water into the soil (Setegn et al., 2009). Soil texture contributes to soil erodibility (Tolosa et al., 2019), it is associated with soil porosity which in turn regulate the water holding capacity, gaseous diffusion and water movement that determine the soil health (Upadhyay and Raghubanshi, 2020). Soil map of the study site as at 2020 was obtained from International Soil Reference and Information Centre (ISRIC-world soil information). The Soil classification used in this study was in accordance with the US Department of Agriculture Soil Classification System (Soil Taxonomy, 1999) and they were categorized based on their sensitivity (vulnerability) to erosion. Three categories of soil groups which are commonly found in Benin City were used for this study (Akujieze, 2004; Ikhile, 2016); good (score= 1) for soil type of Sandy Clay Loam, moderate (score= 3) Loam and poor (score= 5) for Sandy Loam. Soil map (see Figure 3) indicates that the study site (watershed area) is covered by Loam (score=3) and Sandy Clay Loam soils (score=1).

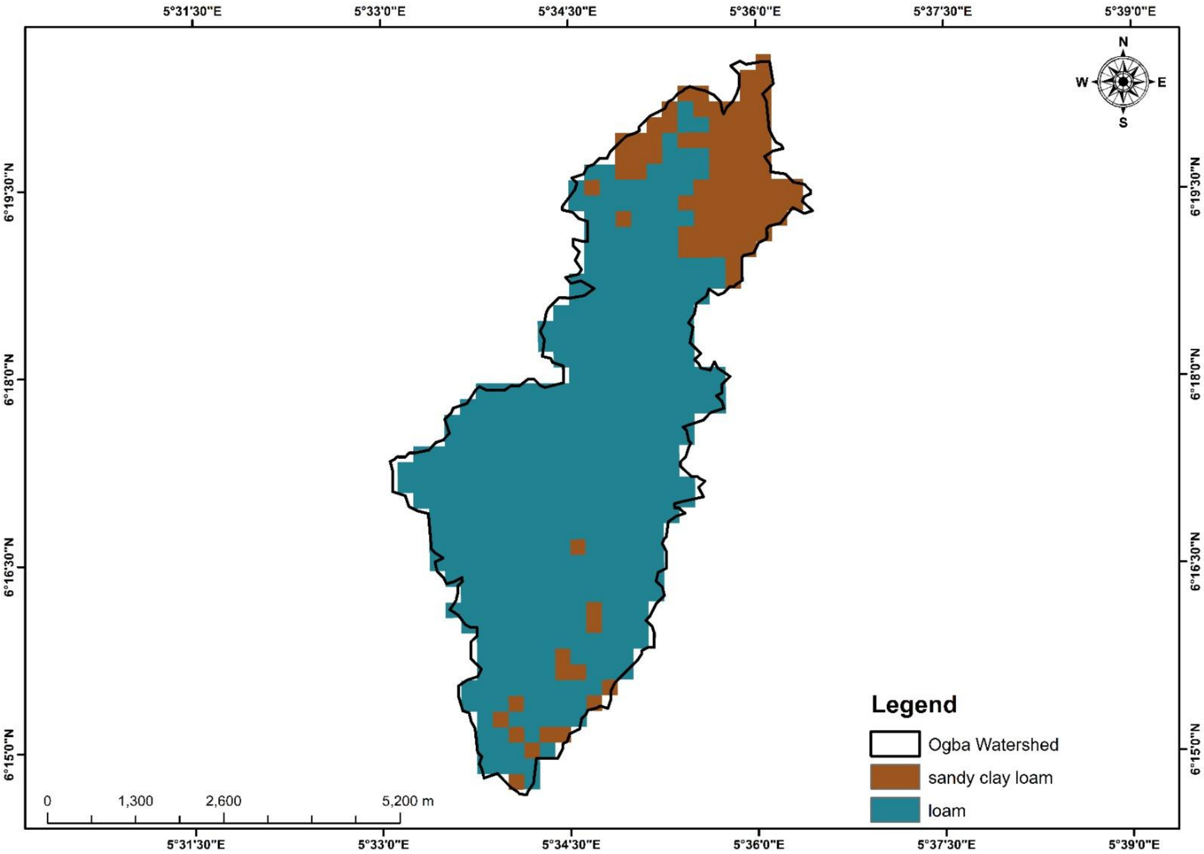

Figure 3: Map of Soil Types in the Study Area

2.2.3 Land Slope: Land slope data (map) as at 2020 was obtained from Shuttle Radar Topography Mission (SRTM- DEM data). Land slope was classified and categorized into three classes according to Guidelines for Soil Description (FAO, 2006) and these are; good (score= 1), moderate (score= 3) and poor (score= 5) for areas with land slope class: 0-5%, 6-19% and >19% respectively. Land slope has a crucial effect on watershed degradation problem. It is one of the most vital factors affecting surface flow erosion as it aids runoff, sheet erosion and gullying. Gullying erosion is expected to be common over steeper slopes (Ofomata, 2011), thus low slope area was scored (1) and steep sloping area was five (5). Land slope map of the study area is presented in Figure 4.

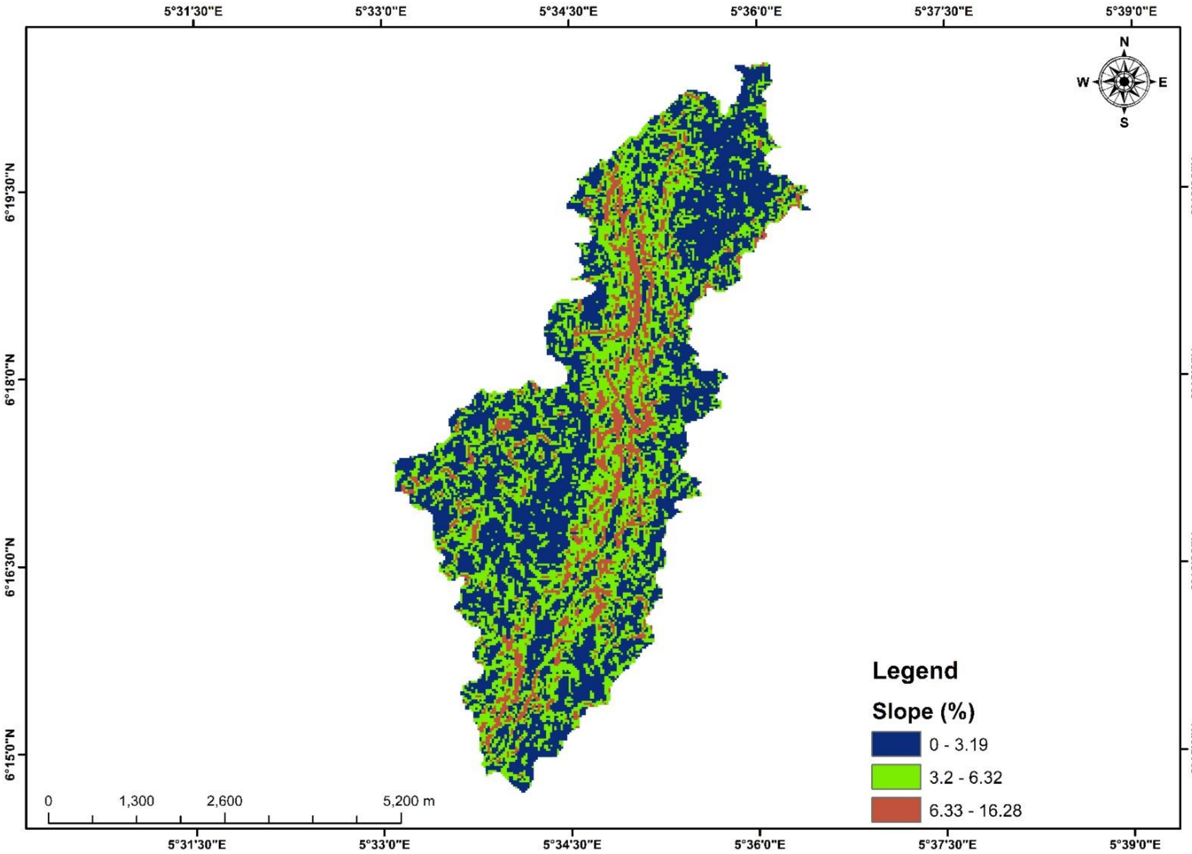

Figure 4: Map of Land Slope of the Study Area

2.2.4 Land Use/Land Cover (LULC): The LULC types was obtained from the USGS Earth Explorer data portal. The LULC identified in the study area were four types (excluding the water body) as indicated in Figure 5. LULC is necessary for assessing the health condition of the watershed since is a major driver of environmental problem like soil erosion. Population growth increases the demand for land for agriculture, thus grassland and forest land are increasingly been converted into cultivated lands which result in land degradation in the watershed (Tolosa et al., 2019). In this regard, this indicator was scored by grouping and categorizing the LULC types in the study area into three types based on the Universal Soil Loss Equation (USLE) C factor value for erosion studies carried out by Yang et al. (2003), Morgan (2005), Kuok et al. (2013), Yang (2014), Ganasri and Ramesh (2015), and Bouguerra et al. (2017). The categories are; good (score= 1) for Vegetation type (forest/trees), moderate (score= 3) for Settlement type (built up areas) and poor (score= 5) for Farming land type (farmland, cultivated and bare lands). Settlement (built up areas) occupies the largest part of the study site followed by farmlands, cultivated and bare lands (see Figure 5).

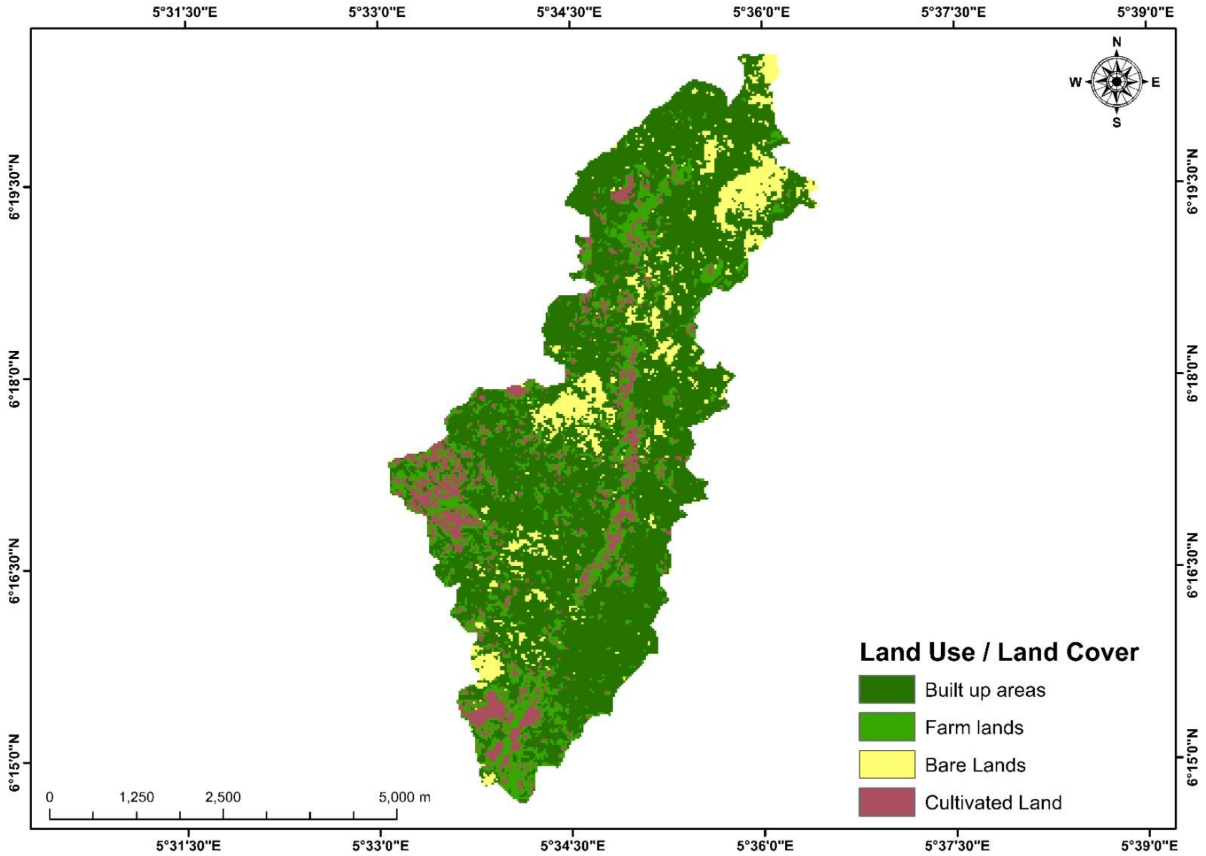

Figure 5: Map of LULC Types in the Study Area

Population Density: Population data were obtained from National Population Commission (2006) for two years period (1999 and 2006). These data were used to project population to three consecutive recent years (2018, 2019 and 2020) using geometric method with a growth rate of about 5%. The population density was estimated for the three years (2018, 2019 and 2020) respectively using equation 1 (Dillon and Posey, 2022):

$$DP = {}^{N}/_{A} \quad \text{...} (1)$$

Where:

DP = Density of Population

N = Total Population as a number of people

A = Land Area covered by the population

Population density of the study area for three previous years (2018, 2019 and 2020) is presented in Figure 6. Population density is also considered as a major indicator for assessing watershed health condition. Haregeweyn et al. (2017) reported that erosion risks are strongly linked to population density, they found that high erosion risk area were in areas with very high population density implying that slight erosion risk is a characteristic of very sparsely populated areas. In line with this, three categories were proposed for population density based on its association with erosion risk as described by Your Article Library (2023); good (score= 1), moderate (score= 3) and poor (score=5) for population density (people/km^2) of <250 people/km^2, 250-1000 people/km^2 and >1000 people/km^2 respectively.

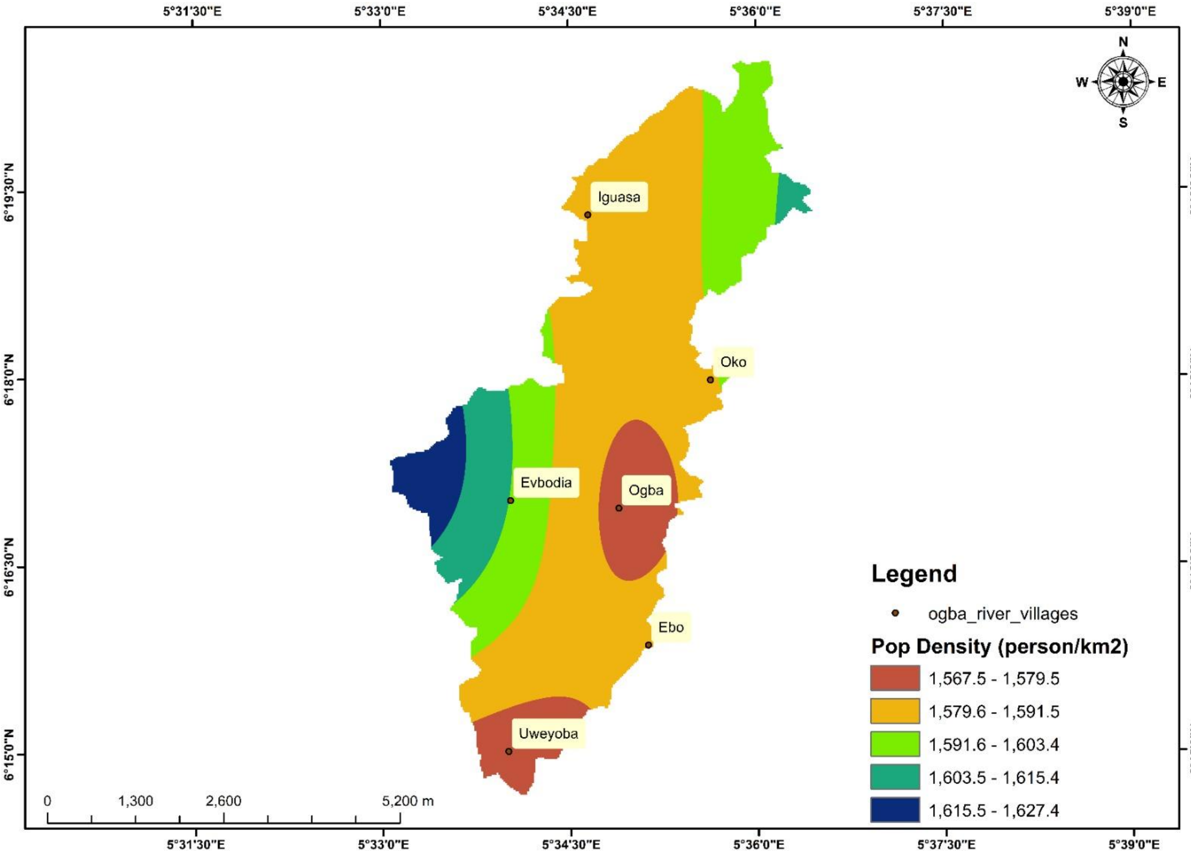

Figure 6: Map of Population Density in the Study Area

Raster maps of indicators reflect the existing condition in the study area (see Figure 2 to 6). Although, three categories were used for scoring, but all the indicators do not have the three categories (three types range value) as described in Table 1. The range value of indicators has no fixed standard, they were created based on reference materials (Journals, textbooks etc.) as aforementioned.

Table 1: Scoring Details of Attribute Table in the Raster Maps of the Indicators (Source: Authors, 2023)

S/N	Name of Map/Indicator	Type of Range Value	Existing Value (Existing Range Value)	Category	Score of Indicator
1	Annual Rainfall (mm)	1	>2000	Good	1
2	Soil Type	2	Sandy Clay Loam Loam	Good Moderate	1, 3
2	Land Slope (%)	2	0-5, 6-19	Good, Moderate	1, 3
4	LULC Type	2	Settlement (built up areas) Farming Land	Moderate, Poor	3, 5
5	Population Density (persons/km^2)	1	>1000	Poor	5

2.3 Criteria for the Watershed Health Condition: The present status of the watershed health level was determined based on the total score of indicators as described by Setyawan et al. (2019) (see Table 2). Assessing a watershed condition status requires the use of more categories as it provide more specific information about the status and problems in the watershed (Setyawan et al., 2013; Susanto and Setyawan, 2010; Setyawan et al., 2019). In this regard, five categories were used to describe the present status of the watershed health level.

Table 2: Categories for Assessing the Health Level of the Watershed Based on the Total Score of Indicators (Source: Setyawan et al., 2019)

S/N	Range of Value Based on Total Score of Indicators	Categories for Watershed Health Level
1	0-5	Very Good
2	6-10	Good
3	11-15	Moderate
4	16-20	Poor
5	21-25	Very Poor

3.0 Results and Discussion

The result obtained from the study is presented in Figure 7. Raster overlay method was used to combined the raster maps of indicators. This was done by using the overlaying method in a raster calculator to combined (add) scores of the raster maps. Figure 7 shows the spatial distribution of health level status in Ogba river watershed.

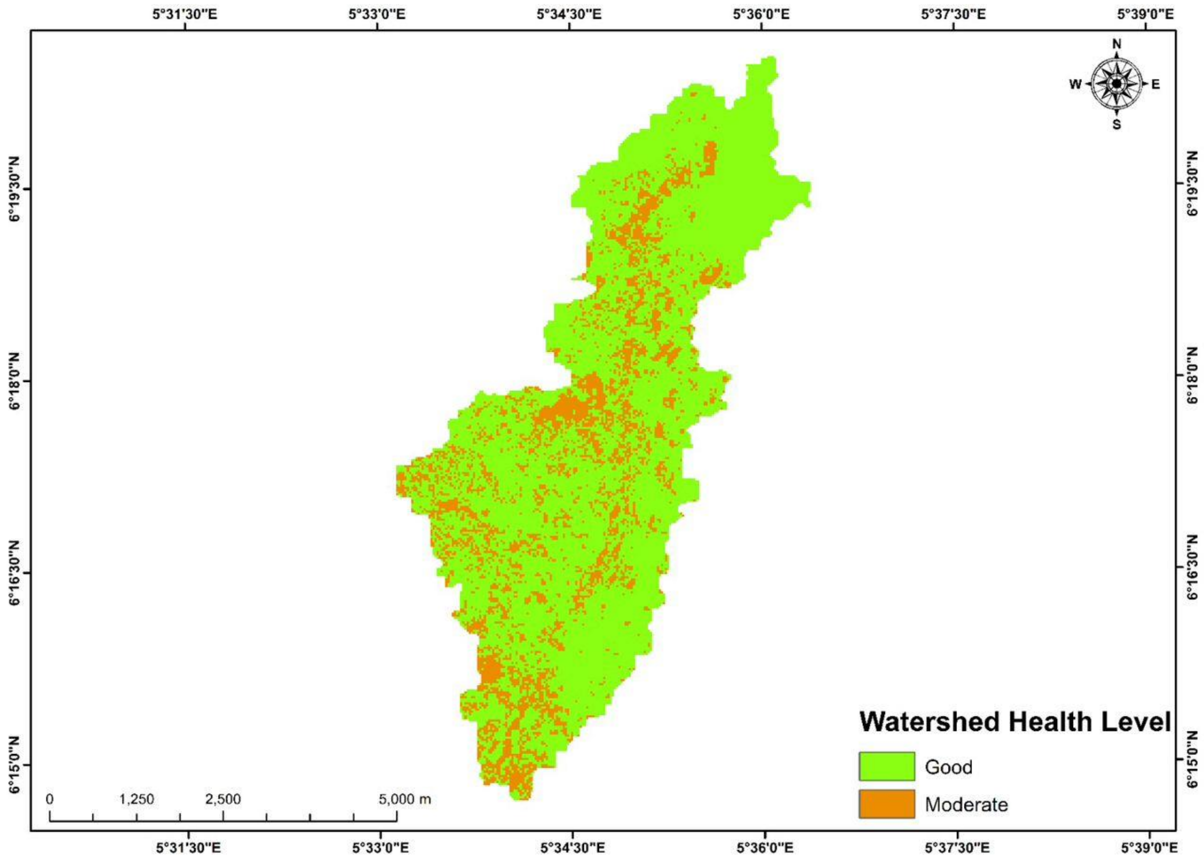

Figure 7: Spatial Distribution of Health Level Status in Ogba River Watershed

Figure 7 revealed that there are two types of health level zone in the study area, namely; good and moderate with lowest and highest scores of seven (Good) and twelve (moderate). Also, the figure indicated that three factors (indicators) such as soil type, land slope and LULC type have a dominant effect on the present status of the watershed health in the study area due to their various values (more than one type of value as indicated in Table 2). Study have reported the dominant effect of some of these factors (land slope and LULC) on the health status of a watershed (Setyawan et al., 2019).

Generally, the zone with the good health level sparsely occupies the entire study area. However, more of it is found in the eastern part of the study area. In this part, based on the indicator raster map, the zone is dominated by sandy clay loam soil with low sloping areas (mostly 0-3.19% and 3.2-6.32% with few 6.33-16.28%). It is mostly covered by settlement and bare lands with few farm lands. The zone with the moderate health level is scattered over the study area. This zone is covered by loam and sandy clay loam soils, low sloping areas (0-16.28%), settlement and farming land (farmlands, cultivated and bare lands). The soil texture and topographic characteristics of the watershed can reduce the effect of farming on the watershed in terms of soil erosion. This is because some of the soil in the watershed have cohesive forces and glue-like characteristics (loam and clay) that can hold the particles together, thus providing resistance against the erosive forces of water and wind. Also, the high permeability and large particle size of some of the soil (sandy) can reduce surface runoff and prevent entrainment. Regarding the topographic characteristics of the watershed, the low sloping areas (short slopes) can decrease the flow of surface runoff, thus soil on low sloping areas are less susceptible to erosion. Hence, the watershed is currently in a healthy state. However, since farming activities are carried out in the watershed, there is a need to maintain the cohesion property of the soil as studies (Merten and Minella, 2013; Guerra and Correia, 2016, Setyawan et al., 2019) have reported that farmland is among the leading cause of land degradation problem of watershed particularly in the form of soil erosion and sedimentation. Therefore, sustainable land management (SLM)practice is essential in the study area to protect the health of the watershed.

Some examples of SLM practices that are suitable for the study area are conservation agriculture, which involves minimum tillage, crop rotation, and mulching (FAO, 2023a), integrated land and water management, which combines soil conservation measures with water harvesting techniques (UN, 2023), local land-use planning, which involves participatory decision-making and conflict resolution among different land users, and sustainable forest management, which promotes the conservation and restoration of forest resources and ecosystem services. These practices have been shown to reduce soil loss, increase soil organic matter, enhance water availability, improve crop yields, conserve biodiversity, and support farmers' income and food security (FAO, 2023a; FAO, 2023b; UN, 2023).

4.0 Conclusion

This study has assessed the health condition of Ogba River Watershed in Benin City using GIS. Result from the study indicated two types of health level zones in the study area (i.e.good and moderate). The entire study area is sparsely covered by good health level, however the eastern part is widely covered (about 15%). The moderate health level is scattered over the study area. Various indicators with the same category (e.g. good/score 1 or moderate/score 3) might have resulted in the different patterns in different areas. The zones were covered by loam and sandy clay loam soils, low sloping areas (0-16.28%), settlement and farming land. Hence, the watershed is currently in a healthy state, but it is threatened by farming activities that can degrade its condition and as such sustainable land management practice is essential in the study area to protect the health of the watershed.

References

Adegbite, J. T., Aigbogun, C. O. and Kuforijimi, O. (2018). Physiochemical Analysis of the Quality of Groundwater in Egbeta, Ovia North East Local Government Area of Edo State, Nigeria. *Journal of Applied Geology and Geophysics;* 6(3): 9-32.

Agidew, A. A. and Singh, K. N. (2018). Factors Affecting Farmers' Participation in Watershed Management Programs in the Northeastern Highlands of Ethiopia: A Case Study in the Teleyayen Sub-watershed. Ecological Processes; 7(15): 1-15.

Ahn, S. R. and Kim, S. J. (2017). Assessment of Integrated Watershed Health Based on the Natural Environment, Hydrology, Water Quality, and Aquatic Ecology. *Hydrology and Health System Science;* 21, 5583–5602.

Akujieze, C. N. (2004). Effects of Anthropogenic Activities (Sand Quarrying and Waste Disposal) on Urban Groundwater System and Aquifer Vulnerability Assessment in Benin City, Edo State, Nigeria. *PhD Thesis, University of Benin, Benin City, Nigeria.*

Alaska Department of Fish and Game, (2023). Watersheds-How can a Watershed Become Unhealthy, Available online from:www.adfg.alaska.gov/index.cfm?adfg=habitatrestoration.watershedhealth [Accessed 6th March, 2023]

Aldridge, C. and Baker, B. (2017). Watersheds: Role, Importance, & Stewardship. Characteristic Protected by Law. *Mississippi State University Extension Service, cooperating with U.S. Department of Agriculture.*

Andriyanto, C., Suprayogo, S. D. (2015). Estimation of Soil Erosion for a Sustainable Land Use Planning: RUSLE Model Validation by Remote Sensing Data Utilization in the Kalikonto Watershed. *Journal of Degraded and Mining Lands Managament;* 3 (1): 459- 468.

Anyanwu, E. D., Ikomi, R. B. and Arimoro, F. O. (2013). Water Quality and Zooplankton of the Ogba River, Benin City, Nigeria. *African Journal of Aquatic Science;* 38(2): 193–199

Asdak, C. (2007). Hydrology and Watershed Management. Yogyakarta: Gadjah Mada University Press, Indonesia.

Aziegbe, F. I. (2006). Channel and Morphological Response of Two Watersheds to Urbanization in Benin City, Edo State, Nigeria. Journal of Human Ecology; 20(3): 177-182

Bouguerra, H., Bouanani, A., Khanchoul, K. and Derdous, O. (2017). Mapping Erosion Prone Areas in the Bouhamdane Watershed (Algeria) Using the Revised Universal Soil Loss Equation through GIS. *Journal of Water and Land Development;* 32 (I-III): 13-23.

Britannica, (2023). Soil Behaviour. Available online from: https://www.britannica.com/science/soil/Soil-behaviour [Accessed 18th July, 2023]

Cadaret, E. M., McGwire, K. C., Nouwakpo, S. K., Weltz, M. A., Saito, L. (2016). Vegetation Canopy Cover Effects on Sediment Erosion Processes in the Upper Colorado River Basin Mancos Shale formation, Price, Utah, USA. *Catena;* 147: 334-344.

Chalise, D., Kumar, L., Kristiansen, P. (2019). Land Degradation by Soil Erosion in Nepal: A Review. *Soil System;* 3:12.

Dillon, A. (Alexandrea) and Posey, L. (Lauren) (2022). How to Measure Population Density. Available online from: http://www.study.com [Accessed 11th June, 2023]

Enaruvbe, G. O., Atafo, O. P., (2018). Land Cover Transition and Fragmentation of River Ogba Catchment in Benin City, Nigeria. Sustainable Cities and Society (2018),https://doi.org/10.1016/j.scs.2018.11.02

Ezeigbo, H. I. and Aneke, B. C. (1993). Water Resources Development Plan for Benin City and Environs. *Journal of Mining and Geology;* 29 (2): 147-158.

Famous Ibhasote Aziegbe (2006). Channel and Morphological Response of Two Watersheds to Urbanization in Benin City, Edo State, Nigeria. *Journal of Human Ecology;* 20(3): 177-182

FAO, (2006). Guidelines for Soil Description, Food and Agriculture Organization of the United Nation, 4th Edition, Viale delle Terme di Caracalla, 00153 Rome, Italy.

FAO, (2023a). Sustainable Land Management: Land and Water. Available online from: https://www.fao.org/land-water/land/sustainable-land-management/en/ [Accessed 6th September, 2023]

FAO, (2023b). Sustainable Land Management (SLM) Practices: Land and Water. Available online from: https://www.fao.org/land-water/land/sustainable-land-management/slm-practice/en [Accessed 6th September, 2023]

Ganasri, B. P. and Ramesh, H. (2015). Assessment of Soil Erosion by RUSLE Model Using Remote Sensing and GIS-A Case Study of Nethravathi Basin. *Geoscience Frontiers;* 1-9.

Garthwaite, J. (Joise) (2019). The Effects of Climate Change on Water Shortage. Available online from: https://earth.stanford.edu/news/effects-climate-change-water-shortages [Accessed 9th June, 2023]

Gebregziabher, G., Abera, D. A., Gebresamuel, G., Giordano, M., Langan, S. (2016). An Assessment of Integrated Watershed Management in Ethiopia. *International Water Management Institute (IWMI) Working Paper 170*, pp1-20.

Google Earth, (2023). Explore Google Earth. Available online from: https://earth.google.com [Accessed 9th March, 2023]

Guerra, C. A., Correia, P. T. (2016). Linking Farm Management and Ecosystem Service Provision: Challenges and Opportunities for Soil Erosion Prevention in Mediterranean Silvo-pastoral Systems *Land Use Policy;* 51: 54-65

Halefom, A., Teshome, A., Sisay, E., Shewayirga, B. and Dananto, M. (2018). Mapping Soil Erosion Potential Zones with a Geo-Spatial Application of Multi-Criteria Evaluation Technique Model in Highlands of Ethiopia. *International Journal of Sustainable Agricultural Management and Informatics;* 4(3/4): 186–204.

Haregeweyn, N., Tsunekawa, A., Poesen, J., Tsubo, M., Meshesha, D. T., Fanta, A. A., Nyssen, J. and Adgo, E. (2017). Comprehensive Assessment of Soil Erosion Risk for Better Land Use Planning in River Basins: Case Study of the Upper Blue Nile River. *Science of the Total Environment;* 574: 95-108.

Ikhile, C. I. (2016). Geomorphology and Hydrology of the Benin Region, Edo State, Nigeria. *International Journal of Geosciences;* 7(2):144-157

ISRIC Data Hub, (2023). World Soil Information, Powered by GeoNetwork 3.10.10.0. https://data.isric.org/geonetwork/srv/eng/catalog.search#/search?facet.q=keyword%2Fdigital%20soil%20mapping%26orgName%2FSRIC%2520-%2520World%2520Soil%2520Infromation%26mdActions%2FmdActions-download&resultType=details&sortBy=relevance&fast=index&_content_type=json&from=1&to=20 [Accessed 7th July, 2023]

Kuok, K. K. K., Mah, D. Y. S. and Chiu, P. C. (2013). Evaluation of C and P Factors in Universal Soil Loss Equation on Tapping Sediments: Case Study of Santubong River. *Journal of Water Resources and Protection;* 5(12): 1-6

Merten, G. H., Minella, J. P. G. (2013). The Expansion of Brazilian Agriculture: Soil Erosion Scenarios. *International Soil and Water Conservation Research;* 1 (3): 37-48.

Mondal, P. (2023). Land Degradation: 9 Main Causes of Land Degradation. Available online from: https://www.yourarticleliabrary,com/land-pollution/land-degradation-9-main-causes-of-land-degradation/39654 [Accessed 6th March, 2023]

Morgan, R. P. C., (2005). Soil Erosion and Conservation (3rd edn). Blackwell Science: Oxford.

Nabaggala, J and Agaba, J. V. (2019). Improving the Current Water Distribution Network for Ndejje University. Unpublished B.Eng. Project, Ndejje University, Uganda. Available from: https://www.academia.edu

Niang, D., Yacouba, H., Doto, C. V., Karambiri, H., Lahmar, R. (2015). Land Degradation Impact on Water Transfer of Soilplant-Atmosphere Continuum in the Burkinabe Sahel. *Larhyss Journal;* 24:109- 127.

Odjugo, P. A. O., Enaruvbe, G. O., and Isibor, H. O. (2015). Geospatial Approach to Spatio-Temporal Pattern of Urban Growth in Benin City, Nigeria. *African Journal of Environmental Science and Technology;* 9(3): 166-175.

Ofomata, G. E. K. (1985): Soil Erosion in Nigeria: The Views of a Geomorphologist. An *Inaugural Lecture Series, University of Nigeria, Nsukka*, Available online from: https://www.unn.edu.ng/wp-content/uploads/2015/09/7th-Inaugral-Lecture.pdf

Ogunkunle, A. O., Omoti, U Ataga, D. O. and Esiche, A.: Field Tours, 8th Annual Conference. The National Soil Correlation Committee and the Soil Science Society of Nigeria, Benin City 27th Nov. 3rd Dec. 1980 (1980).

Pramono, I. B. (2014). Mitigation of Land Degradation at Juana Watershed, Central Java. *Journal of Degraded and Mining Lands Management;* 2 (1): 235-242.

Rawlings, A. and Ikediashi, A. I. (2020). Impact of Urbanizing Ovia-North East on the Quality of Groundwater using Water Quality Index. *Nigerian Journal of Environmental Sciences and Technology (NIJEST);* 4 (1): 87 – 96.

Sanchez, G. M., Nejadhashemi, A. P., Zhang, Z., Marquart-Pyatt, S., Habron, G., and Shortridge, A. (2015). Linking Watershed-scale Stream Health and Socioeconomic Indicators with Spatial Clustering and Structural Equation Modeling. *Environmental Modelling and Software;* 70: 113–127.

Setegn, S. G., Srinivasan, R., Dargahi, B. and Melesse, A. M. (2009). Spatial Delineation of Soil Erosion Vulnerability in the Lake Tana Basin, Ethiopia. *Hydrological Processes;* 23(26): 3738-375

Setyawan, C., Susanto, S. and Lee, C. Y. (2019). Spatial Modelling of Watershed Health Assessment by Using GIS. *The 3rd International Symposium on Agricultural and Biosystem Engineering,* IOP Conf. Series: Earth and Environmental Science, 355 (2019) 012018

Setyawan, C., Susanto, S., Sukirno 2013 A Quantitative Assessment Model of Land and Water Conservation Measures Case Study at Upper Watershed of Kali Progo, Proceedings of International Symposium on Agricultural and Biosystem Engineering, Department of Agricultural and Biosystem Engineering, Faculty of Agricultural Technology, Universitas Gadjah Mada, Yogyakarta, Indonesia.

Susanto, S., Setyawan, C. (2010). Assessment Model of Water Resource Conservation Measures: Case Study at Upper Watershed of Sempor and Wadaslintang Dam, Proceedings of International Seminar of International Commission on Irrigation and Drainage (ICID), Yogyakarta.

Swati,T., Neelam, G., and Rajan, P. (2014). Environmental Degradation: Causes and Consequences. *European Researcher;* 81(8-2):1491-1498

Thompson, D. (2021). How Can Trees Help Prevent Soil Erosion? Available online from: https://sciencing.com/how-can-trees-help-prevent-erosion-12620837.html

Tolosa, A. T., Teka, A. H. and Belay, B. S. (2019). Distribution of Soil Erosion Sensitive Area in Guna-Tana Watershed, Blue Nile, Basin Ethiopia. *Nigerian Journal of Technological Research;* 14(2):18-27.

Topographic Map, (2023). Elevation of Ogbe, Benin City Nigeria, Available online from: elevation.maplogs.com/poi/ogbe_benin_city_nigeria.504674.html [Accessed 5th March, 2023]

United Nations, (2016). The World's Cities in 2016: Data Booklet (ST/ESA/ SER.A/392), Department of Economic and Social Affairs Population Division, Trans., Italy, Rome, pp. 29

UN, (2023). Best Practices in Sustainable Land Management. United Nations Convention to Combat Desertification. Available online from: https://www.unccd.int/land-and-life/land-management-and-restoration/technologies-approaches/best-practices [Accessed 6th September, 2023]

Upadhyay, S. and Raghubanshi, A. S. (2020). Determinants of Soil Carbon Dynamics in Urban Ecosystems. *Urban Ecology: Emerging Patterns and Social-Ecological Systems*, Elsevier, pp 299-314.

USEPA, (2022). Integrated Assessment of Healthy Watersheds. Available online from: https://www.epa.gov/hwp/integrated-assessment-of-healthy-watersheds [Accessed 12th October, 2022]

USEPA, (2023). Developing a Watershed Health Index: Introduction. Available online from: https://www.epa.gov/hwp/developing-watershed-health-index-introduction

USEPA, United States, Environmental Protection Agency Office of Water (2009). National Water Quality Inventory: Report to Congress. Retrieved September 14, 2016, from https://www.epa.gov/ sites/production/files/2015-09/documents/2009_01_22_305b_2004report_2004_305breport.pdf. Annotation: Report Number EPA 841-R-08-001

USGS, (2022). Earth Explorer. Available online from: https://earthexplorer.usgs.gov [Accessed 23rd July, 2023]

Wangboje, O. M. and Braimah, A. (2022). Assessment of Heavy Metal Contamination in Water and Selected Piscean Bio-Indicators from Ogba River Benin City, Nigeria. *Journal of Engineering for Development;* 4(1): 46-62.

Weldea, K. and Gebremariam, B. (2017). Effect of Land Use Land Cover Dynamics on Hydrological Response of Watershed: Case Study of Tekeze Dam Watershed, Northern Ethiopia. *International Soil and Water Conservation Research;* 5: 1-16

Wu S-J, Kuo C-Y, Yeh K-C, Wang, C-D, Wang, W-J. (2021). Reliability Analysis for Reservoir Water Supply due to Uncertainties in Hydrological Factors, Rainfall-runoff Routing and Operating Rule Curves. *Journal of Hydro-environment Research;* 34:24–45.

WWF (World Wildlife Fund) Statement, (2022). Soil Erosion and Degredation: Overview. Available online from: https://www.worldwildlife.org/threats/soil-erosion-and-degradation [Accessed 18th July, 2023]

Yang, D., Kanae, S., Oki, T., Koike, T. and Musiake, K. (2003). Global Potential Soil Erosion with Reference to Land Use and Climate Changes. *Hydrological Processes;* 17(14): 2913-2928.

Yang, X., (2014). Deriving RUSLE Cover Factor from Time-Series Fractional Vegetation Cover for Hill Slope Erosion Modelling in New South Wales. *Soil Research;* 52(3): 253-261.