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Urban flooding vulnerability analysis using weighted linear method with geospatial information system

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Abstract

This study was carried out to investigate the causative factors responsible for flooding in Etsako east, Nigeria. The study applied weighted linear method and geospatial information technology to obtain relevant data which were subjected to analysis. Sentinel 2 imagery of the area was downloaded from the United States Geological Survey (USGS) website and analyzed to produce digital elevation model, rainfall distribution, soil texture classification, topographic wetness index (TWI), hillside slope, land use/cover contour and slope maps of the area. Saaty weighted scale (1 – 5) was used to assign importance to the factors selected. The results presented using relevant maps revealed that, TWI (14%), precipitation (14%), distance to river (12%), elevation (11%) and slope (10%) are the major factors responsible for flooding in the area. Using built up areas only (46.57 km^2); 38.6% of it is within the risk range of high to very high flood vulnerability, moderate vulnerability zone (17.97 km^2) occupied 27.28%. Low vulnerability zone occupied 22.05%, (10.27 km^2) while no vulnerability zone occupied 12.05% (5.61 km^2). Communities in the high flood vulnerable region includes Iddo, Iyukwe, Iyogeh, Imiegb and Opepwe; flood control measures and early warning systems should be developed to mitigate the impact of flooding in the area.

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1. Introduction

Flooding is a serious global ecological problem which has recked untold havoc and rendered many homeless. A flood is an overflow of a high-quality frame of water over land that is not always normally submerged [1]. After a flood, a country's society and economy may suffer in several ways, including the loss of people, land, plants, public and private buildings, and critical infrastructure. This results in fewer people being employed, less agriculture being produced for local consumption and export, and fewer businesses to support the growth of the economy [2]. Floods are frequently compared to all other natural disasters because they cause the most fatalities and economic losses. They can be devastating. Flooding is a general term for a temporal condition in which normally dry areas are partially or completely submerged due to inland or tidal water overflow or unusually rapid runoff accumulation [3]. The most frequent natural disasters that have an impact on societies worldwide are floods. About 82 percent of the world's population is

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impacted by flooding, which affects more than one-third of the planet's land area [4]. This is because low-lying coasts and river flood plains are widely distributed geographically and have a long history of attracting habitation. The average annual direct cost of natural disasters on a global scale between 2000 and 2012 was roughly $100 billion [5]. Numerous studies on flooding have determined that flooding accounts for one-third of all natural disasters, one in ten fatalities from natural disasters, and one-third of all economic losses (250 billion USD globally over the last fifteen years alone). Most of those killed in natural disasters in developing nations are killed by floods alone. In addition, 90% of all natural disasters include flooding, costing the world economy $6 billion annually [6–10].

A good number of flood management practices, including flood inundation mapping, flood plain zoning, and river morphological studies, have made extensive use of remote sensing techniques. These techniques involve using satellites or aircraft to observe and collect data about the Earth's surface and atmosphere using parts of the electromagnetic spectrum. They are useful for monitoring large areas with frequent repeated observations and can provide detailed and accurate information about the properties and radiation of objects and terrains [2, 11, 12]. Whilst also gathering and keeping track of information on atmospheric conditions and features of the Earth's surface that may cause natural disasters, remote sensing technologies have also been used to support early warning systems for disasters [13, 14]. The availability of multitemporal satellite data and mapping techniques allows monitoring flooding over large coastal areas. In flood management, these techniques are often used in pre-disaster activities such as mitigation and preparedness, as well as in post-disaster activities such as prediction, prevention, mitigation, and damage assessment [15, 16]. Geographic information system (GIS) can be used to combine and analyze data from different sources, including digital elevation models, maps, aerial photographs, satellite images, to create risk maps that are tailored to the needs of local communities [17–19]. The purpose and applications of these techniques in flood management are highlighted in this project. Prediction, preparation (mapping flood hazards, vulnerabilities, and risks), prevention, and mitigation, as well as flood damage assessment, are all stages of flood management that are taken into consideration in this sense. Modern remote sensing techniques enable real-time flood disaster monitoring, early warning, and rapid damage assessment. Geographical data is saved in a database with a GIS, where it can be searched for and graphically displayed for analysis. Different geographical layers can be overlaid or intersected to identify flood-prone areas and target them for mitigation or more stringent floodplain management procedures. Remote sensing techniques can be used in various ways to support flood management efforts. Some of the ways that remote sensing can be used include flood forecasting, providing spatial information, feeding flood models, updating flood analyses and inventories, and locating people in flooded areas [20–23].

Recent flood disasters in 2012 which occurred around Ikpoba Okha, Edo State, recorded several losses of lives, damage properties, residents of the areas affected homeless. In Etsako east area of Edo State, flooding is a major problem and occurs often, this is majorly because of several activities which includes prolong rainfall, undersized drains in places where it exists, insufficient or lack of drainage system, blocked or poorly constructed drainages, building on flood plains, poor planning, and improper land use. In view of the above, the objective of this study is to apply remote sensing and GIS technology in flood mitigation in Etsako East local council area in Edo state, Nigeria.

2. Study area

The study area is Etsako East local government council in Edo State, Nigeria geographically located and bounded by latitude 6°40′ 43.57′′N and 7°20.4′ 47.8′′N and longitude 6°40′ 4.325′′E and 6°14′ 36.14′′E with its administrative headquarters in the town of Agenebode. It has an area of 1,133 km^2 (437 sq mi) sharing borders to the north with communities in Kogi state, to the west by Akoko Edo, by Etsako west to the south-west region, and to the south by Etsako central with a population of 145,996 at the 2006 census. The river Niger which is a principal river of West Africa, extending about 4,180 km (2,600 mi) is located east of this region. Its drainage basin is 2,117,700 km^2 (817,600 sq mi) in area. The map of the study location is shown in Figure 1.

3. Materials and method

The imagery for the study were obtained from European Space Agency (ESA) which launched the Sentinel-2 satellite in 2015 to provide high-resolution multispectral and radar data for environmental studies. Sentinel-2 L1C products are georeferenced to the (UTM-WGS 84) map projection. Sentinel-2 images are freely available via the USGS Earth Explorer web service, where the acquired administrative shapefile will be uploaded and used as a search criterion. Additionally used in this study was the Shuttle Radar Topography Mission (SRTM), which has the highest quality and a horizontal resolution of 1 arc second (30 m Resolution). Digital elevation models (DEMs) of the images are freely accessible worldwide (Sentinel Online. (n.d.), though this would be streamlined to area of interest. Hydrological data which includes Multi-Temporal Annual Rainfall Data were obtained from global climate Research Unit (CRU) for global climate monitoring and Soil Data was obtained from food and Apiculture organization (FAO) UNESCO was integrated into the GIS workspace for overlay analysis.

3.1. Flow chart methodology

The project methodology entails classification of the water bodies in the study area using Shuttle Radar Topography Mission (SRTM). The classification was also based on the homogenous properties of the data to reveal water level. ArcGIS software and

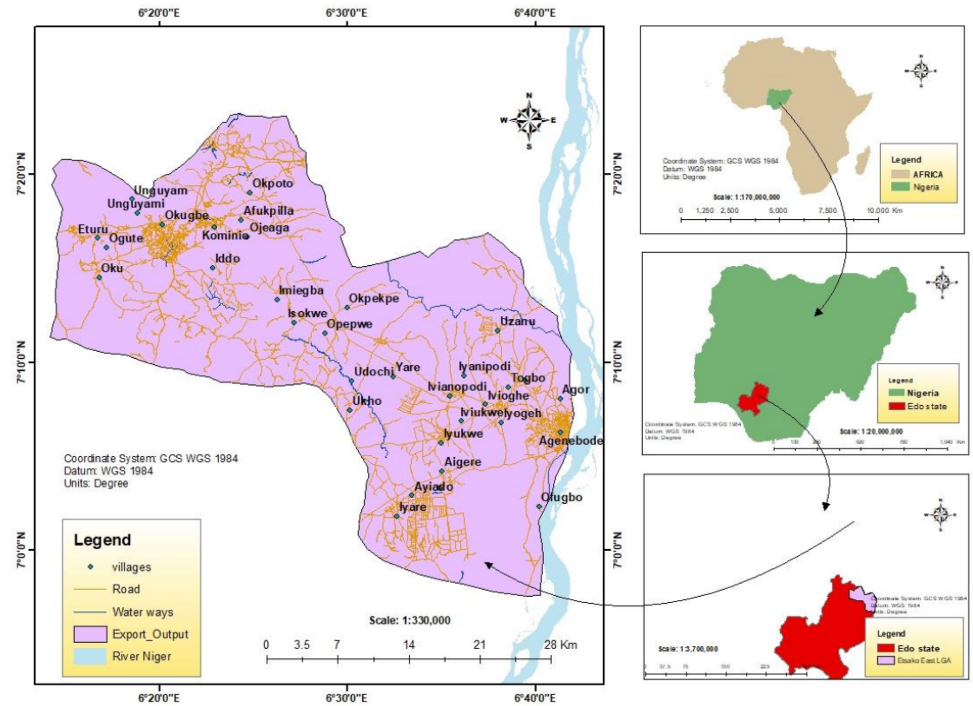

Figure 1. Map of the study area.

satellite imagery (Sentinel 2 was then used to extract water bodies based on two periods. The water index was then calculated using the different bands of Sentinel 2 data. The integration of GIS and Remote Sensing in the procedure resulted in the generation of DEM and flood hazard map of the study area. A description or directional flow-chart is presented in Figure 2.

3.1.1. Data acquisition and processing

The MODIS instrument that is onboard the NASA Terra satellite is used to capture land data. Other datasets include administrative maps, from which political boundaries and roads were digitized, and these were used to determine the spatial locations of some flooded communities. By combining satellite data with other up-to-date spatial and non-spatial data, the possibilities of flood zones could be predicted allowing for the mapping, and monitoring of flood-inundated areas, the assessment of flood damage, the zoning of flood hazards, and flood protection. The stages of creating a geographic information system (GIS) are data input, data storage, data analysis and modeling, and data output and presentation were carried out for efficient processing of the data.

The acquired satellite images of Sentniel 2 (with a map projection of UTM_ zone 32, spheroid, and datum WGS_ 84) were used for land use/land cover mapping and change detection processes. These images were then layered in ArcGIS Pro software and clipped and extracted by the Etsako east LGA boundary. In this study, the most common image processing function (Spatial Image processing) would consist of four steps: pre-processing, image enhancement, image sub-mapping and classification. The class categories process involved identifying and defining various class features on the scene. In this case, four class categories were identified and defined according to a level 1 classification scheme: built up areas, water body, vegetation, and open space. The resolution of the image sets and the need to adequately discriminate the features are reasons for adopting this classification scheme [16].

(a) Slope analysis. From the DEM obtained for the region, the slope was obtained by running the raster analysis operation in ArcGIS software.

(b) Thematic land use activities and mapping. The land use mapping and activities was extracted from the European Space Agency (ESA) global land use map. The ESA global Land use map has been developed for 1998 to 2015, which give a wide range to study land use changes over this period.

(c) Normalized Difference Vegetation Index (NDVI) mapping. NDVI measures the greenness and healthiness of vegetation. It is used to assess vegetation health for example, agriculture, forestry, and ecology. NDVI uses two properties to quantify healthy vegetation which are near infrared (NIR) because vegetation strongly reflects it, and red light, because plants strongly absorb it. Landsat 8 imageries for the region was downloaded from the United State Geological Services websites, this was used to classify high and low vegetation. Pixels with high NDVI values indicated high vegetation or chlorophyll and low NDVI values indicated a low vegetation

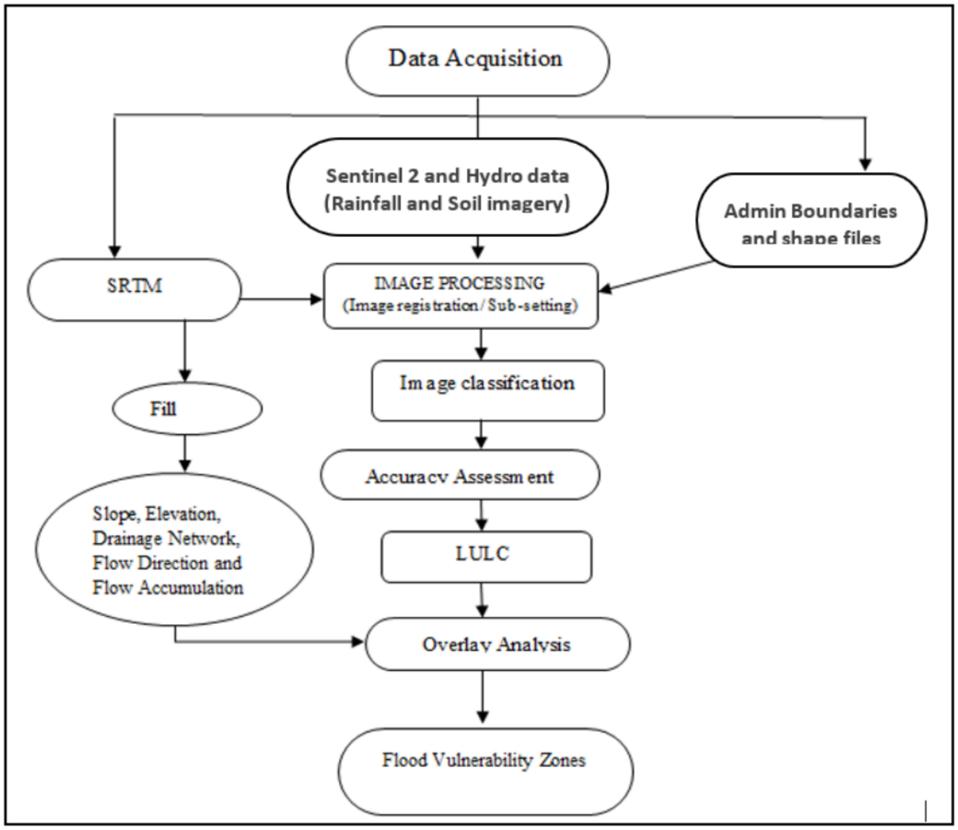

Figure 2. Flow chart methodology.

or chlorophyll value. While negative NDVI value was used to identify water. ArcGIS was used to compute the NDVI value for the study area.

3.1.2. *Flood risk assessment parameters*

The final product of flood Risk assessment is the generation of flood susceptibility or vulnerability map through the application of a weighted overlay analytic tool. This is one method of modeling suitability by a multi-criteria or factors approach processed as raster features, with each raster layer assigned a weight in the suitability analysis. Overlapping raster layers yields a suitability value by multiplying each raster cell's suitability value by its layer weight and totaling the values. These values are reclassified to new layer output, the output layer's symbology is based on these values. The procedure adopted for the effective flood risk susceptibility assessment include but is not limited to the following: downloading of the Digital Elevation Model (DEM) of the study from USGS and exporting into ArcGIS environment, generation of flow direction, generation of flow accumulation, slope, and stream order. The Topographic Wetness Index was calculated using equation (1) as suggested by Sen [16] with the flow chart methodology for the TWI computation shown in Figure 3.

$$TWI = \ln \frac{\text{Flow accumulation scaled}}{\text{tan slope}} \tag{1}$$

3.2. *Weighted data requirement*

Geographic information systems (GIS) are helpful tools for the synthesis of various input data and variables using specific logical and mathematical relations to produce flood susceptibility maps because floods are multi-dimensional phenomena with spatial and temporal aspects [24, 25].

The flood causative criterion (input data) employed in this study include soil data, slope data, land use/land cover data, precipitation data, flow length data, river distance data, drainage density data, topographic wetness index (TWI) data, normalized difference vegetation index (NDVI) data, road distance data, and elevation data. The susceptibility class include the ranges and rating of each criterion presented in Tables 1.

Definition of parameter significance scale. To define the one to nine scale of parameter significance, the scheme proposed by Saaty [26], reported in Table 2 was employed to translate linguistic judgments into numbers.

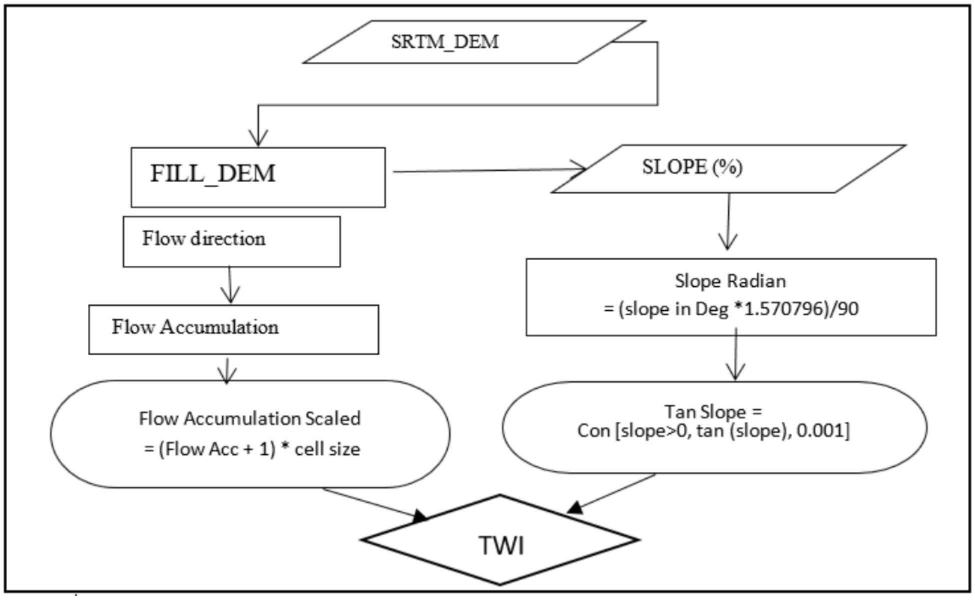

Figure 3. Flow chart model for TWI in the study area.

4. Results and discussion

4.1. Rainfall impact in the study area

The accuracy of monitoring is crucial for determining the volume of flooding as well as the geographic and temporal distribution of the inundated area. Precipitation monitoring is essential for flood forecasting and mitigation. Based on radar echo data, weather radar is an effective tool for estimating the amount of precipitation. Heavy rainfall is a factor in the analysis of flood risks because it may cause flash flooding. Figure 4 shows the estimated Inverse Distance Weighting (IDW) annual rainfall distribution of Etsako East LGA Edo state Classified into 5 Distinct ranges (Low to High Values) and stream order. The map revealed that the southern part of the study area is highly susceptible to heavy and prolonged precipitation which triggers flooding. Also, the central part of the catchment is disposed to flooding as rainfall events as well as expected is relatively high. About 64% of the catchment area is disposed to flooding of varying levels depending on the intensity and duration of rainfall. Similar results were obtained by Agbonkhese *et al.* [19]; the IDW map of the annual rainfall for the catchment study indicated that over 60% of the area is predisposed to heavy rainfall and eventual flooding of the catchment. Findings from the studies carried out by authors in Refs. [27, 28] revealed that Ibadan city (southwestern Nigeria) has experienced continuous flooding since the unprecedented increase in precipitation on annual basis coupled with abandonment of river channels enhancement. The most visible effect of climate change in tropical region has been traced to increased precipitation and river flooding arising from the inability of the receiving basins to accommodate excess surface runoff [29].

4.2. Soil texture classification map

One important soil characteristic that affects water infiltration rates is soil texture. The textural class of a soil is determined by the proportion of sand, silt, and clay in the soil. Four main textural classes—sandy, silty, loamy, and clay—were used to categorize soil textures. The soil's texture affects how quickly water drains through a saturated soil; water flows more freely through sandy soils than through clayey soils. When the same conditions apply, a soil with a high proportion of silt and clay particles has greater erodibility than a soil with sand. Soils also differ in their susceptibility to erosion (erodibility) based on texture. Figure 5 depicts the distribution of soil texture and its group over the study area. The soil in the study area is predominantly clay although loamy and sandy soil admix also exist within the location of study. Clay soil materials are easily eroded under the influence of running water hence the presence of gully of various dimensions in some parts of the study area. Ikabigbo and Oshiomagbe are two major communities in the study area with huge gullies arising from clay soil displacement [20]. Predominant soil type in a catchment area also influence infiltration rate as revealed by the study carried out by Vorogusgyn *et al.* [30], sandy soils with silt admix enhances infiltration faster than clayey soil which rather swells than allow passage. Catchment with such high deposit of clay materials as base soil are usually predispose to riverbank erosion due to low erodibility index and flooding [31].

4.3. Elevation map

Figure 6 shows the elevation model of the study area. The highest elevation is 460m which lies on the eastern portion of the sites. This means that the land surface is highest at this point and gradually decreases in elevation towards the southern part of the area It

Table 1. Flood causative criterion and their susceptibility classes [26].

Flood Causative Criterion	Unit	Class	Susceptibility Class Ranges and Rating	Susceptibility Class Rating
TWI	Level	3.12-6.47	Very Low	1
		6.48-8.39	Low	2
		8.40-10.98	Moderate	3
		10.99-14.49	High	4
		14.50-24.43	Very High	5
Elevation	m	-1-53	Very High	5
		54-91	High	4
		92-131	Moderate	3
		132-194	Low	2
		195-306	Very Low	1
Slope	%	< 2.15	Very High	5
		2.16-4.15	High	4
		4.16-6.59	Moderate	3
		6.60-10.46	Low	2
		10.47-36.52	Very Low	1
Precipitation	mm/yr	< 8.59	Very Low	1
		8.60-9.28	Low	2
		9.29-10.03	Moderate	3
		10.04-10.74	High	4
		10.77-11.83	Very High	5
LULC	Level	Water Body	Very High	5
		Built up Area	Moderate	3
		Barren Land	Low	2
		Vegetation	Very Low	1
NDVI	Level	-0.061-0.101	Very High	5
		0.102-0.189	High	4
		0.190-0.270	Moderate	3
		0.271-0.348	Low	2
		0.349-0.735	Very Low	1
Distance From River	m	< 453	Very High	5
		454-907	High	4
		908-1314	Moderate	3
		1315-1939	Low	2
		1940-3988	Very Low	1
Distance From Road	m	< 25	Very High	5
		26-50	High	4
		51-100	Moderate	3
		101-150	Low	2
		> 150	Very Low	1
Drainage Density	m	< 0.733	Very Low	1
		0.734-1.316	Low	2
		1.317-1.917	Moderate	3
		1.918-2.707	High	4
		2.708-4.793	Very High	5
Soil Type	Level	Silty Clay	Very High	5
		Silty Sediments	Moderate	3
		Sandy Clay Sand	Low	2

drains into the river at the part of the study area from a low elevation portion of 150m. It is seen that runoff flows from the low-lying area towards the rivers, which are presumably located at a lower elevation than the rest of the study. This helps to understand the topography and hydrology of the study area and the incessant flooding experienced when the water carrying capacity of the river is over stretched especially during the wet season. The difference in elevation (150 – 460 m) in the catchment area has a significant effect on flooding. Whenever there is prolong rainfall or a rise in sea level due to storm surge, the region within the lower elevations are susceptible to flooding and are usually submerged causing damages to buildings and infrastructure, as well as posing risk to human lives. However, it is worth noting that selected areas within the catchment with elevation nearing 370m is still at the risk of flooding in certain circumstances as experienced in 2021. The river overflowed it bank arising from prolong rainfall and the release

Table 2. Saaty summary table [26].

Sig. Strength	Explanation	Comments
1	Equal significance	Two elements contribute equally to the objective
3	Moderate significance	Judgment slightly favours one element over another
5	Strong significance	Judgment strongly favours one element over another
7	Very strong significance	Judgment strongly favours one element over another, its dominance is demonstrated by experience
9	Maximum significance	The dominance of one element over another is demonstrated and absolute
2, 4, 6, 8	Can be used to express intermediate values	

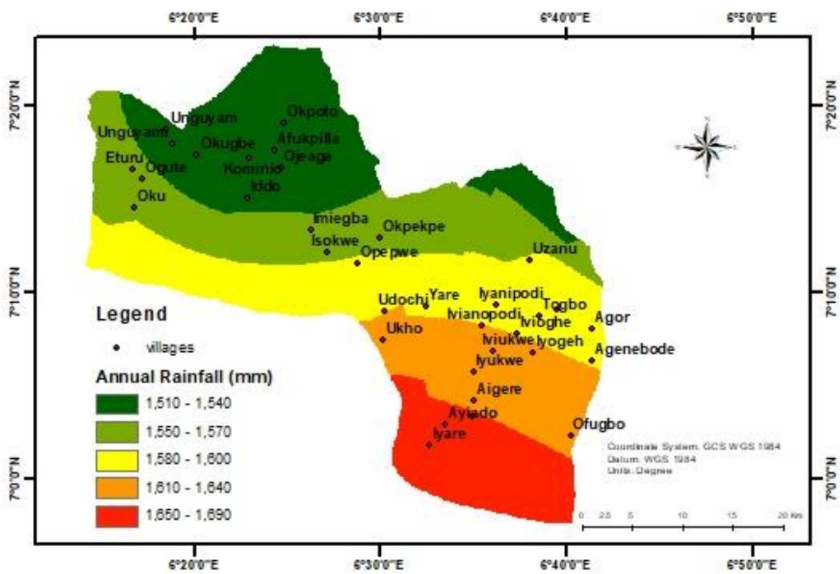

Figure 4. Annual rainfall IDW classified output.

of water from Cameroon dam resulting in flash flood due to accumulation of water in the area. Similar findings were reported by Ogunlela & Adelodun [32]; regions with elevation of about 500m were submerged arising from over 72 hours of continuous rainfall in Ogun state Nigeria and environ in 2012.

4.4. Topographic wetness index map

Topographic wetness index (TWI) is a commonly used analysis tool to quantify the amount of water that accumulates in a particular location based on its slope and contributing area. The TWI for this study was derived from the DEM and it identified the areas of high to low water accumulation potential across the landscape of the study area during the flood period. The eastern part of the catchment with higher elevation (> 450m) had low TWI of as shown in Figure 7 and the location with elevation of less than 150mm had higher values. The Topographic wetness index in the study area ranged from moderate to high in most places and relatively low in selected areas toward the southern region of the catchment. The TWI also showed that the lower elevation location are predisposed to heavy soil saturation and soil erosion while the region with elevation between 200 to 300m will be most suitable for agriculture and forestry. Apekejiori [20], reported that TWI of a catchment area can affect flooding in numerous ways as locations with high values of TWI tend to have low infiltration rate, which mean there is high volume of water accumulation at the surface and increase the likelihood of flooding during heavy rain events. Also, such areas often correspond with low elevation except in the event of flash flood. Generally, TWI is also a useful tool for understanding and predicting the effects of topography on flooding. Taking into cognizance the role of terrain in the hydrological cycle, better understanding of the causes of and consequences of flooding and the steps to mitigate the impact can be designed [33].

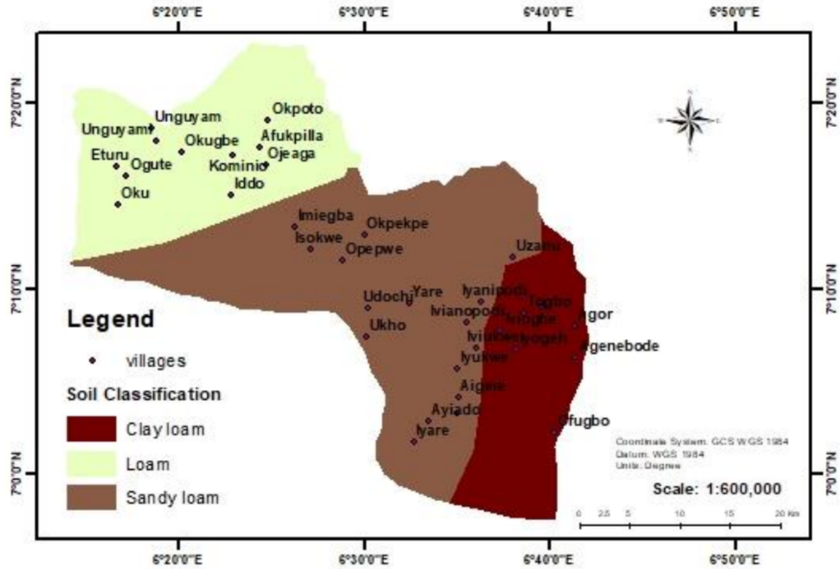

Figure 5. Soil texture classification map.

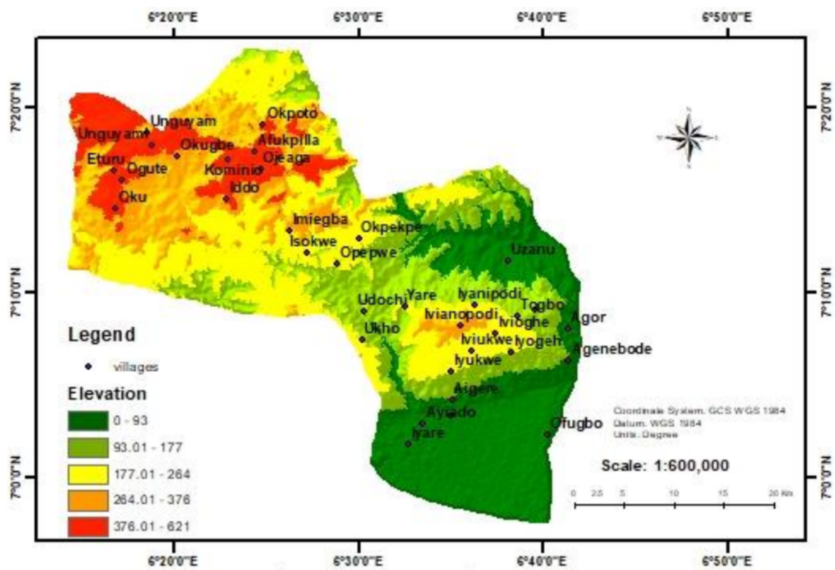

Figure 6. Elevation map of study area.

4.5. *Hillside slope of the study area*

A hillside map is a shaded relief map that highlights the topography of a study area which is created by calculating the slope and aspect of the terrain which was then used to create a three-dimensional model of the landscape. This was used for the visualization of the slope as areas with steep slopes were shown to be darker in Figure 8 with relatively flatter slope represented with light grey. The aspect of the terrain which shows the direction the slope faces helped in understanding how the landscape is affected by the sunlight, precipitation, and other environmental factors. The landforms in the area basically consist of ridges and valleys with intermittent canyons with dense vegetation scattered within the region closer to the river inlet. The hillside slope features areas common with regions which experiences perennial flooding at the peak of wet season. The hillside slope in the catchment area increased the speed and volume of runoff during heavy precipitation. Whenever it rained, the sloped surfaces gathers quickly and flow downhill carrying sediments, soil, and other debris with it. This is usually responsible for flash flooding in low lying areas downstream. Adewumi [5], reported that steep gradient hillside slopes could also result in soil erosion especially during wet seasons. Such events carry away the topsoils and nutrient leaving behind barren and exposed soil that is vulnerable to further degradation. Landslides and reduced infiltration have also been linked to hillside slope [34]. Similar studies by Komolafe *et al*. [35] enumerated the catastrophe accompanying hillside slope collapse. Hillside slopes are susceptible to landslides which are triggered by prolonged rainfall and block rivers and streams leading to increase flooding upstream and decreased flow downstream. The steep gradient of hillside slopes

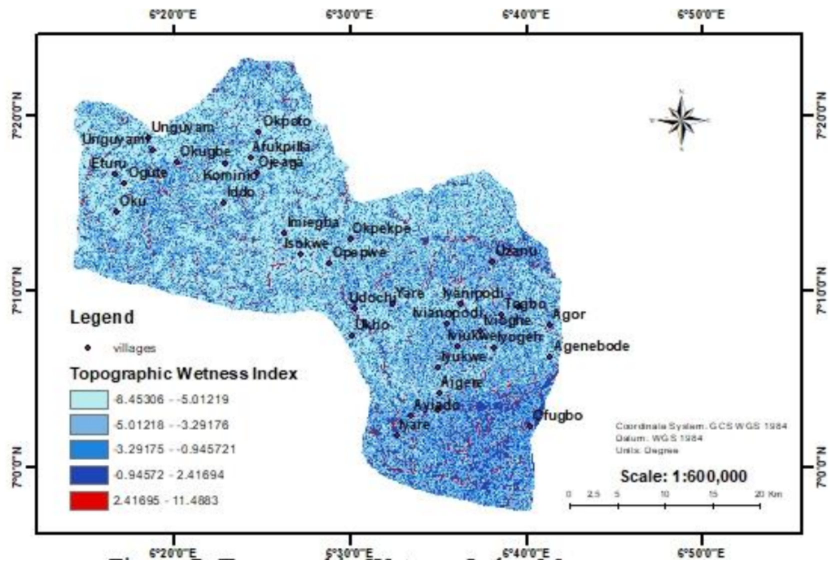

Figure 7. Topographic wetness index map.

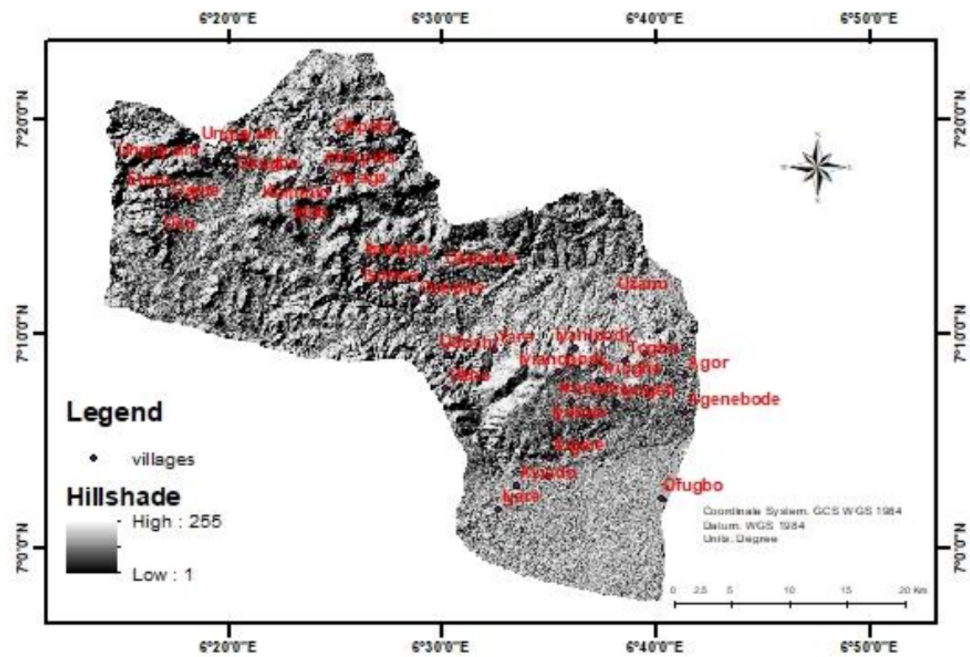

Figure 8. Hillshade map of study area.

also reduces the ability of the soil to absorb rainfall. This can increase the volume of runoff and contribute to flooding downstream.

4.6. Land use/cover in the study area

Land Use /Land cover analysis was carried out on the entire local Government area to study the rate of changes in the area as to how it affects the river flooding experienced in the flood season. The main land use types that were studied in this area are Crop, Built Area, Bare Ground, Range Land and Trees. Figure 9 shows the Land use changes for crops, build area, bare ground, trees, and range land. Land use/cover have a significant impact on flooding as it affects the way water is absorbed and flows across the land. Most parts of the urbanized locations within the catchment that used to be natural areas with forests and wetlands have been replaced with impervious surfaces like concrete and asphalt which makes land unable to absorb rainfall. The unhindered cumulative effects is increased surface runoff which overwhelms stormwater systems causing flood. Previous study by Tehrany & Kumar [31], revealed that deforestation plays a crucial role regulating water cycle by absorbing and releasing water. When such forests are removed, and land made bare, such water absorption is hampered and soil becomes less permeable which can result in increased surface runoff

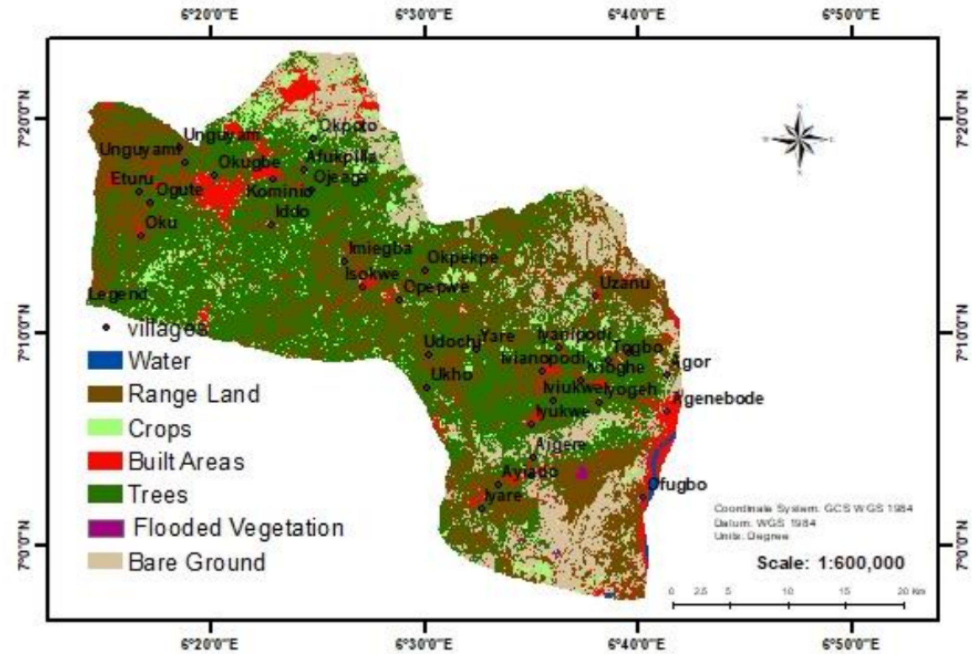

Figure 9. Land use/cover map of study area.

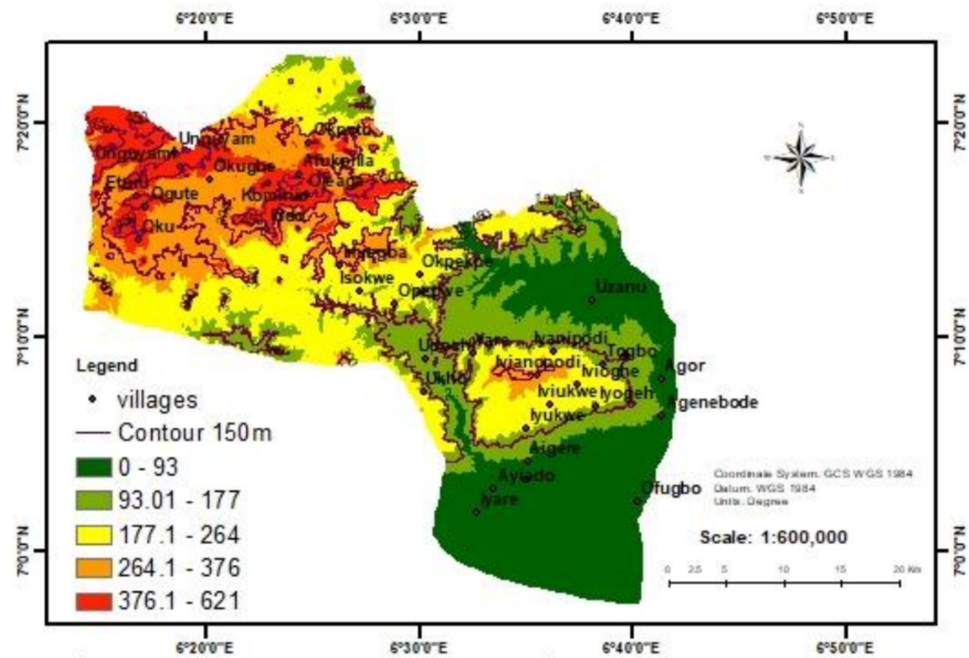

Figure 10. Contour map of the study area.

and flash floods. Wetlands are a sort of natural sponge that absorbs excess water during heavy rainfall and releases it gradually over time. In the cause of large-scale development, wetlands are drained or filled with suitable construction materials, this reduces the absorption of water and increases the likelihood of flooding [20]. Figures 10 and 11 are the maps of slope and contour of the study area which shows the depression in the catchment area and the disposition to future flooding events if mitigative measures are not in place.

4.7. Flood risk map

The flood risk map was also generated based on the information gathered from the downloaded satellite imagery and the DEM, ArcGIS software was used to generate this map. This map showed the flood risk/prone areas of the study area with relevance

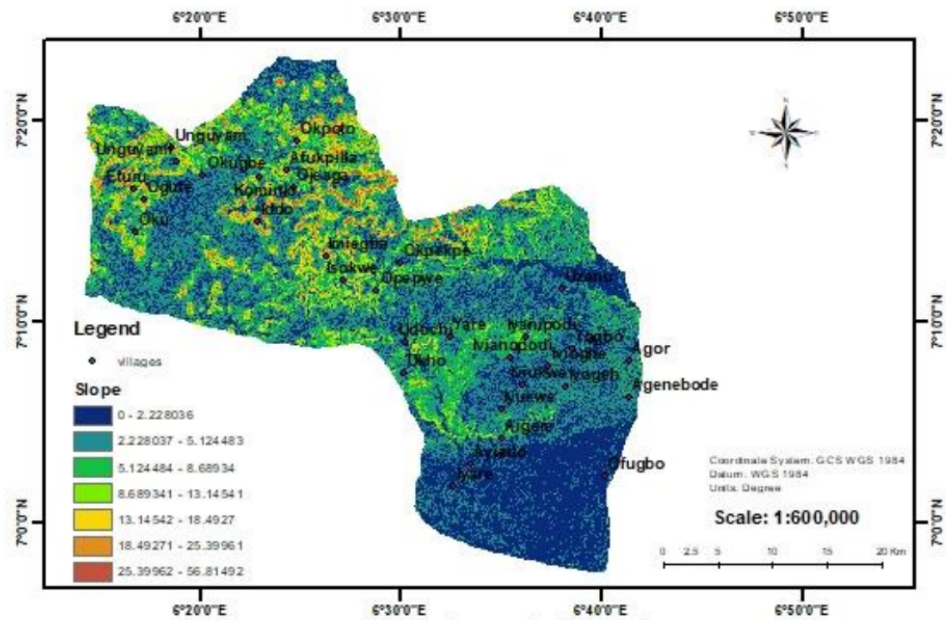

Figure 11. Map of slope of the study area.

Table 3. Statement on scale values.

Weight intensity	Definition	Explanation
1	Equally important	Two elements contribute equally to the objective
2	Moderate importance	one element slightly more than another.
3	Strong Importance	one element is strongly more than another
4	Very strong importance	One element is favored very strongly over another,
5	Extreme importance	One element is highly weighted is over the order

Table 4. Flood susceptibility criteria and sub-criteria ranges for risk assessment.

Criteria	%
TWI	14.31
Elevation	11.05
Slope	10.00
Precipitation	14.0
LULC	9.48
NDVI	6.02
Distance From River	12.11
Distance From Road	5.01
Drainage Density	9.00
Soil Type	9.02

to locations or areas after. The map created shows the class information which also correlates with the Land Use/Cover map by zonal analysis such as Areas highly susceptible to flood, Areas moderate susceptible, Low susceptible areas and the boundary of the study area. Table 3 shows a statement on scale values where a GIS-based multi-criteria method and the analytical hierarchy process was used to create a flood susceptibility map with ten (10) stated criteria, each of which was compared to the others based on its importance, and the resulting Scale, which is regarded as the overall score. Table 4 shows the flood susceptibility criteria and sub criteria ranges for risk assessment which was used in the generation of Figure 12 (flood hazard map of the study area).

The attribute of flood Hazard Classes highlights region of High to Very High Risk within 109.2 km^2 (10.2%), Moderate Risk 641.3106 km^2 (57.2%) and Low to Very low Risk within 370.32 km^2 (33.0%) of the entire study area. With regards to Build up only, having an area of 46.57 km^{2,} 38.6% of developed regions are within the risk range of High to very High flood Vulnerability, covering an area of 17.97 km^2 of Land use Land Cover (LULC), moderate vulnerability zone occupied 27.28%, covering an area of 12.7 km^2. The low vulnerability zone occupied 22.05%, covering 10.27 km^2 while no vulnerability zone occupied 12.05% covering an area of 5.61 km^2.

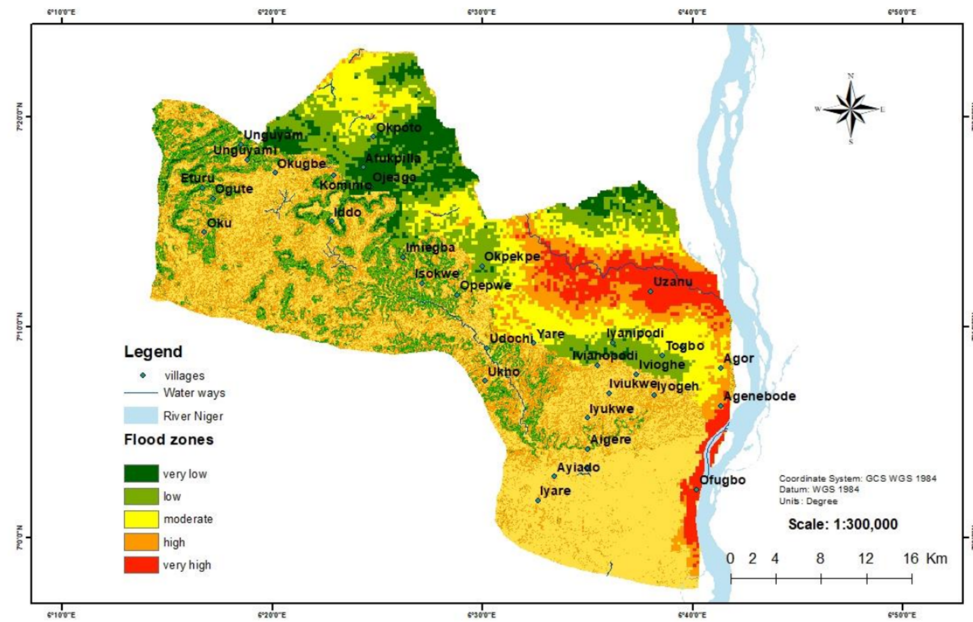

Figure 12. Flood hazard map of the study area.

Flood risk management is critical because it is a fundamental activity aimed at assessing techniques for mitigating, but not necessarily eliminating, overall risk. This is because flood risk cannot always be eliminated. As a result, flood risk management requires a comprehensive approach that addresses issues such as rainfall, runoff, rivers, and flood inundation, as well as human and sociodemographic issues such as planning, development, and management. These results concur with a few other related studies that covered the entire study area or only a portion of it in terms of mapping flood vulnerability. According to the study by Eguaroje *et al*. [7] using the weighted linear combination technique, 56% of the study area is classified as slightly vulnerable. Most of the built-up areas are highly vulnerable to flash floods, according to a study that only examined the urban LGAs of the study area [36]. However, the study provided no quantitative data on the impacted areas. Urbanization was linked to flood vulnerability in earlier studies [37, 38], and this study suggests that the two are directly related because most of the study area's flood-prone areas are found in its urban areas. In this context, flood hazard and risk maps provide significant state-wide critical insights, and the results of such hazard and risk mapping, as well as the methods used, the following include some applications of result:

i. Serve as a flood warning system: Implementing early warning systems, such as flood prediction models and alerts, which help to reduce the impact of flooding by allowing people in flood-prone areas to evacuate or take other protective measures.
ii. Provides authorities with methods for mitigating and implementing flood management, by visually assessing the potential impact of flooding on critical infrastructure, such as roads, bridges and buildings thereby reducing flood hazards and providing insurance and plan development.
iii. Emergency response: Flood maps can be used by emergency responders to identify areas that are at risk of flooding and to develop evacuation plans. The flood inundation maps can also be used to quickly identify potential vulnerability to reduce.

5. Conclusion

This study was able to demonstrate the utility of Remote Sensing and GIS technologies in classifying and identifying areas with high, moderate, and low flooding vulnerability within the study area. In conclusion, an integrated approach that incorporates input/data from several diverse/different techniques is required for understanding, monitoring, defining, and managing various natural disasters. It is critical to ensure coordination at all levels to facilitate the smooth operation of the entire system involved as well as good cooperation. It is also critical that large-scale digital map data with detailed information about any disaster be made available to disaster management/environmental agencies for effective and possible solutions to be recommended. Several other means for the reduction of flood risk are reducing flood hazards, reducing flood vulnerability and land use planning.

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References

[1] F. Mukherjee & D. Singh, "Detecting flood prone areas in Harris County: A GIS based analysis", GeoJournal **85** (2019) 647. https://doi.org/10.1007/s10708-019-09984-2

[2] C. Cao, M. Xu & P. Insom, *Environmental remote sensing in flooding areas*, Higher Education Press and Springer Nature, Singapore, 2012. https://doi.org/10.1007/978-981-15-8202-8

[3] I. Elkhrachy, "Flash flood hazard mapping using satellite images and GIS tools: A case study of Najran City, Kingdom of Saudi Arabia (KSA)", The Egyptian Journal of Remote Sensing and Space Science **18** (2015) 261. https://doi.org/10.1016/j.ejrs.2015.06.007

[4] J. R. Adewumi, O. J. Ejeh, K. H. Lasisi & F. O. Ajibade, "A GIS-AHP based approach in sitting MSW landfills in a Nigerian confluence state", Springer Nature Applied Sciences **1** (2019) 1528. https://doi.org/10.1007/s42452-019-1500-6

[5] J. R. Adewumi, J. K. Akomolafe & F. O. Ajibade, "Development of flood prone area map for Igbokoda township using geospatial technique", Journal of Applied Science and Process Engineering **4** (2017) 178. https://doi.org/10.33736/jaspe.433.2017

[6] F. E. Abellavia, "Prototype land cover map over Africa at 20 m released", Climate change initiative–European space agency, (2018) 7. https://www.esa-landcover-cci.org/?q=node/187

[7] E. O. Eguaroje, T. A. Alaga, J. O. Ogbole, I. S. Kolawole, K. H. Muibi, D. S. Popoola, S. A. Samson, J. E. Adewoyin, R. A. Badru & O. O. Ajileye, "Flood vulnerability assessment of Ibadan City, Oyo state, Nigeria", World Environment **5** (2015) 159. https://doi.org/10.5923/j.env.20150504.03

[8] V. Flemas, "Remote sensing of floods and flood-prone: An overview, Journal of Coastal research **31** (2015) 1013. https://doi.org/10.2112/JCOASTRES-D-14-00160.1

[9] T. Giuseppe, C. F. O. Iyalomhe & P. O. Adekola, "Determinants of flooding and strategies for mitigation; two-year case study of Benin City", Journal of geosciences, **21** (2019) 6. https://doi.org/10.3390/geosciences9030136

[10] I. T. Ezekiel, N. Maurice & K. Maurice, "Seawater intrusion vulnerability assessment of a coastal aquifer: North coast of Mombasa, Kenya as a case study", International Journal of Engineering Research and Applications **6** (2016) 45. https://www.ijera.com/papers/Vol6_issue8/Part-%203/G0608033745.pdf

[11] B. Jabri & M. A. Hessane, "Production of a curve number map using GIS techniques in the watershed of the high Sebou (Morocco)", E3S Web of Conferences **150** (2020) 03003. https://doi.org/10.1051/e3sconf/202015003003

[12] S. A. Doocy, S. Daniels, S. Murray & T. D. Kirsch, "The human impact of floods: A historical review of events 1980–2009 and systematic literature review", PLOS Currents **5** (2013) 17. https://doi.org/10.1371/currents.dis.f4deb457904936b07c09daa98ee8171a

[13] H. Sharif, F. Al-Juaidi, A. Al-Othman, I. Al-Dousary, S. Jamal-Uddeen & A. Elhassan, "Flood hazards in an urbanizing watershed in Riyadh, Saudi Arabia", Geomatics, Natural Hazards, and Risk **7** (2016) 720. https://doi.org/10.1080/19475705.2014.945101https://doi.org/10.1080/19475705.2014.945101

[14] C. Kousky, "A historical examination of the corps of engineers and natural valley storage protection: The economics and politics of "green" flood control", Journal of Natural Resources Policy Research **7** (2015) 40. https://doi.org/10.1080/19390459.2014.963372

[15] C. Klemas, "The role of remote sensing in predicting and determining coastal storm impact", Journal of Coastal Research **25** (209) 1264. https://www.jstor.org/stable/27752776

[16] Z. Sen, *Flood modeling, prediction and mitigation*, Springer Cham, 2018. https://doi.org/10.1007/978-3-319-52356-9

[17] A. Glaize, A. Duenas, C. Di Martinelly & I. Fagnot, (2019). "Healthcare decision-making applications using multicriteria decision analysis: A scoping review", Journal of Multi-Criteria Decision Analysis **26** (2019) 83. https://doi.org/10.1002/mcda.1659

[18] P. A. Bariweni, C. C. Tawari & J. F. N. Abowei, "Some environmental effects of flooding in the Niger Delta region of Nigeria", International Journal of Fisheries and Aquatic Sciences **1** (2012) 35. http://www.maxwellsci.com/print/ijfas/v1-35-46.pdf

[19] O. Agbonkhese, G. L. Yisa & P. I. Daudu, "Bad drainage and its effects on road pavement conditions in Nigeria", Journal of Civil and Environmental Research **3** (2013) 11. https://www.iiste.org/Journals/index.php/CER/article/view/7717

[20] I. J. Apekejiori, "Flood monitoring and flood risk Assessment in Agenebode, Edo State, Nigeria", International Journal of Engineering Research and Application **7** (2017) 53. http://dx.doi.org/10.9790/9622-0703015359

[21] P. Negi, & K. Jain, "Spatial multicriteria analysis for siting groundwater polluting industries", Journal of Environmental Informatics **12** (2008) 63. https://doi.org/10.3808/jci.200800124

[22] C. J. Van Westen, "Remote sensing and GIS for natural hazards assessment and disaster risk management", In J. F. Schroder & M. P. Bishop (Eds.), Treatise on geomorphology **3** (2013) 298. https://www.cdema.org/virtuallibrary/images/Background%20paper%20Spatial%20data%20for%20hazard%20and%20risk%20assessment.pdf

[23] A. D. Weiss, (2001). "Topographic position and landforms analysis", The Nature Conservancy **12** (2001) 9. http://www.jennessent.com/downloads/TPIposter-TNC_18x22.pdf

[24] H. Zabihi, M. Alizadeh, P. K Langat, M. Karami, H. Shahabi, A. Ahmad, M. N. Said & S. Lee, "GIS multi-criteria analysis by ordered weighted averaging (OWA): Toward an integrated citrus management strategy", Sustainability **11** (2019) 1009. https://doi.org/10.3390/su11041009

[25] S. Park, C. Choi, B. Kim & J. Kim, "Landslide susceptibility mapping using frequency ratio, analytic hierarchy process, logistic regression, and artificial neural network methods at the Inje area, Korea", Environmental Earth Sciences **68** (2013) 1464. https://doi.org/10.1007/s12665-012-1842-5

[26] T. L. Saaty, *The analytic hierarchy process: Planning, priority setting, resource allocation (decision making series)*, McGraw-Hill International Book Company, 1980. https://doi.org/10.1016/0377-2217(82)90022-4

[27] F. O. Ajibade, O. Olajire & T. Ajibade, "Groundwater potential assessment as a preliminary step to solving water scarcity challenges in Ekpoma, Edo State, Nigeria", Acta Geophysica **12** (2021) 723. https://doi.org/10. 1007/s11600-021-00611-8

[28] F. O. Ajibade, N. A. Nwogwu, B. Adelodun, T. S. Abdulkadire, T. F. Ajibade, K. H. Lasisi, O. G. Fadugba, T. A. Owolabi & O.O. Olajire, "Application of RUSLE integrated with GIS and remote sensing techniques to assess soil erosion in Anambra state, south-eastern, Nigeria", Journal of Water and Climate Change **11** (2020) 422. https://doi.org/10.2166/wcc.2020.222

[29] Q. Zou, J. Z. Zhou, C. Zhou, L. X. Song & J. Guo, "Comprehensive flood risk assessment based on set pair analysis-variable fuzzy sets model and fuzzy AHP" Stochastic Environmental Research and Risk Assessment **27** (2013) 546. https://doi.org/10.1007/s00477-012-0598-5

[30] S. Vorogushyn, K. Lindenschmidt, H. Kreibich & H. Apel, "Analysis of a detention basin impact on dike failure probabilities and flood risk for a channel-dike-floodplain system along the river Elbe, Germany", Journal of Hydrology **436** (2012) 131. https://doi.org/10.1016/j.jhydrol.2012.03.006

[31] M. S. Tehrany, and L. Kumar, "The application of a Dempster–Shafer based evidential belief function in flood susceptibility mapping and comparison with frequency ratio and logistic regression methods", Environmental Earth Sciences **77** (2018) 24. https://doi.org/10.1007/s12665-018-7667-0

[32] A. O. Ogunlela & B. Adelodun, "Kinematic flood routing of Asa River, Ilorin, Nigeria", International Journal of Engineering and Technical Research **2** (2014) 17. https://www.academia.edu/10381185/Kinematic_Parameters_for_Asa_River_Routing

[33] J. O. Ehiorobo & O. C. Izinyon, *Measurements and documentation for flood and erosion monitoring and control in the Niger Delta states of Nigeria, TS07EEngineering Surveying*, FIG Working Week 2011 Bridging the Gap between Cultures, Marrakech, Morocco, 2012. https://www.fig.net/resources/proceedings/fig_proceedings/fig2011/papers/ts07e/ts07e_ehiorobo_izinyon_5126.pdf

[34] K. Li, S. Wu, E. Dai, & Z. Xu, "Flood loss analysis and quantitative risk assessment in China natural hazards", Journal of the International Society for the Prevention and Mitigation of Natural Hazards **63** (2012) 760. https://doi.org/10.1007/s11069-012-0180-y

[35] A. A. Komolafe, B. S. Awe, I. E. Olorunfemi & P. G. Oguntunde, "Modelling flood-prone area and vulnerability using integration of multi-criteria analysis and HAND model in the Ogun River basin, Nigeria", Hydrological Sciences Journal **65** (2020) 1783. https://doi.org/10.1080/02626667.2020.1764960

[36] A. E. Adefisan, B. S. Abdulkareem & R. I. Orimoloye, "Application of geospatial technology in identifying areas vulnerable to flooding in Ibadan metropolis", Journal of Environment and Earth Science **5** (2015) 166. https://www.academia.edu/22749676/Application_of_Geo_Spatial_Technology_in_Identifying_Areas_Vulnerable_to_Flooding_in_Ibadan_Metropolis

[37] O. Ajayi, S. B. Agbola, B. F. Olokesusi, B. Wahab, O. J. Taiwo, M. A. Gbadegesin, D. O. Taiwo, O. Kolawole, A. B. Muili, M. Adeola, O. G. Olutade, F. Shi-ji, F. & N. Abiola, "Flood management in an urban setting: A case study of Ibadan metropolis", Special Publication of the Nigerian Association of Hydrological Sciences (2012) 65. http://journal.unaab.edu.ng/index.php/NAHS/article/download/914/882

[38] J. R. Adewumi, J. K. Akomolafe, F. O. Ajibade & B. B. Fabeku, "Application of GIS and remote sensing technique to change detection in land use/land cover mapping of Igbokoda, Ondo State, Nigeria", Journal of Applied Science and Process Engineering **3** (2016) 54. http://dx.doi.org/10.33736/jaspe.173.2016