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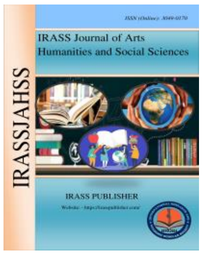

Flood Hazard Mapping of Kogi State, Nigeria: The Case of September 2022

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Abstract: Flooding, exacerbated by climate change, continues to devastate Nigerian communities, particularly in Kogi State, Nigeria. The lack of flood-control measures, such as reservoirs, and encroachment on flood plains have worsened the impacts. This study aims to mitigate these effects by creating a flood hazard map for Kogi State. The objectives of the study are to identify flood-prone areas; assess settlement vulnerability, and produce a vulnerability assessment map. Eight spatial datasets (rainfall, soil, land use, DEM, NDVI, TWI, and drainage density) were integrated using Spatial Multi-Criteria Decision Analysis (SMCDA) and Analytical Hierarchical Process (AHP). The weighted overlay of reclassified raster datasets in ArcGIS produced a hazard map. Findings show that the intense rainfall, low relief, and low vegetation index (NDVI) characterizing the study are risk factors for flood ability.

Keywords: Flooding; Kogi; Mapping; September 2022.

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1.0 Introduction

Floods and other natural disasters can happen anywhere, even in places far from bodies of water. Heavy rainfall, poor drainage, and even nearby construction projects might put a region at risk for flood damage. Two of the most common types are coastal and river floods. The purpose of flood hazard mapping is to identify coastal regions that could flood in the event of severe weather. Therefore, lessening the effects of coastal flooding is its main goal. Nonetheless, erosion risk reduction may be accomplished through mapping erosion risk zones (CTCN, 2022). Developing a flood danger map for Kogi State is the goal of this work. Finding flood-prone areas within the research area, evaluating the settlements' susceptibility, and creating a vulnerability assessment map are the goals of the project.

2.0 Problem Statement

The September 2022 floods have impacted numerous Nigerian settlements along the courses of the Rivers Niger and Benue in Kogi, Benue, Adamawa, Taraba, Anambra, and Nasarawa state, among other places. The floods in Northeast Nigeria have caused the displacement of at least 15,000 internally displaced people (IDPs) and more than 39,500 people who were not previously living in IDP camps (Abdulkareem, 2022). In addition to the deaths and displacement caused by the flood, farmlands were swept away, and floodwaters frequently destroy or wash away food that has been kept in homes, farmhouses, or warehouses. According to Oladipo (2022), approximately 121,318 homes nationwide suffered partial damage, 82,053 total damage, 108,392 hectares of agriculture suffered partial damage, and 332,327 hectares of farmland suffered whole damage. Six people have reportedly died in Kogi state alone, while numerous buildings and more than 600 hectares of rice crops have sustained damage. When creating flood hazard maps, which are used as input in the creation of master plans, the aforementioned elements and careless encroachment into flood plains are typically taken into account. From an academic and research standpoint, prior studies have employed a variety of methodologies. Jimoh (2022) investigated the geographical patterns of flood inundation in Lokoja, Kogi state, using the Maximum Likelihood Classifier algorithm of the supervised land use/cover classification technique. Using five flood risk identification indices—elevation, proximity to the river land use, population density, slope, and flow accumulation—Udo & Eyoh (2017) examined the flood risk potential locations and the spatial impact of the 2012 flooding in Kogi State. Using a grading system, flood risk zones were divided into four categories: high risk, moderate risk, low risk, and no risk. Similar studies have been conducted in Kogi state, where hazard zone classifications were less than five and less than ten (10) criterion factors were applied. To help with the creation of master plans, this study evaluates Kogi state's flood-hazardous zones in an effort to pinpoint the local government districts most at risk from flooding. For the flood assessment, nine (9) criteria were used as inputs: rainfall data, elevation, slope, drainage density, soil, road, and river vector files, Normalized Difference Vegetative Index (NDVI), Topographic Wetness Index (TWI), and Land Use Land Cover (LULC). The Analytic Hierarchy Process (AHP) was used to evaluate the criteria. Five categories were used to categorize the hazard zones: extremely high, very high, high, moderately high, and low. By combining the water supply from upslope catchment areas and downslope water drainage for every cell in a DEM, the TWI is a physically based index or indicator of how local topography affects runoff flow direction and accumulation (Kopecký, Macek, & Wild, 2021).

3.0 Materials and Methods

Among other things, a clear map that indicates the locations of flood-hazard regions is necessary for drainage engineers and land use planners to approve residential building. Vulnerability arises when exposure to or lack of exposure to a danger represents a risk that could potentially lead to a catastrophe. Flood disasters are becoming more frequent, which hinders the state's urban areas' ability to develop quickly. This analysis was inevitable since a policy plan to mitigate and direct this development necessitates a hazard assessment. All of the data used in this study came from trustworthy internet sources. Secondary data was gathered from books, manuals, literature, and other secondary sources. The National Aeronautics and Space Administration Digital Elevation Model (NASA DEM) data (https://search.earthdata.nasa.gov/downloads/5915390643) was used to calculate the slope, elevation, and drainage density. An improved elevation model called the NASA DEM is utilized to support data before hydraulic modeling and calculations.

Advanced Land Observing Satellite (ALOS) provided the land use and land cover (LULC)

(https://www.arcgis.com/apps/instant/media/index.html?appid=fc92d38533d440078f17678ebc20e8e2), while the Office of Surveyor General of the Federation (OSGOF) provided the Drainage Network details and vector shape files of the area's roads, streams, buildings, etc. The harmonized world soil database version 1.2 website (https://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/harmonized-world-soil-database-v12/en/) provided the soil data. To illustrate the degree of vegetation in the research area, 2918 Landsat 8 OLI images were used to calculate the Normalized Difference Vegetative Index (NDVI). The Topographic Wetness Index (TWI), which was created from the DEM to measure the topographic control on hydrological processes in the region, and monthly rainfall data were obtained from the Global Precipitation Measurement (GPM) website (https://daac.gsfc.nasa.gov/) for hydrologic modeling. It makes use of a terrain's topological features to ascertain the water's flow or buildup. After calculating TWI from the digital elevation model raster, the program's various capabilities were used to determine the slope, flow direction, flow accumulation, and tan of slope using straightforward equations. The following expressions provide TWI:

DEM: Fill DEM: Direction of flow Scaled Slope (degree), Slope (Radian), and Slope (Tan) Flow buildup equals TWI.

The multicriteria evaluation phase used all of the collected data as inputs. The NDVI essentially enables us to designate as "flooded" those areas that are completely submerged in water. The backscatter mean value is near 0 on smooth surfaces, such as streets, paved roads, airport runways, bare lands, etc. The mean value of all non-smooth surfaces—forests, bushes, agricultural areas, woods, horticulture, etc.—is significantly higher than zero. To identify a specific discontinuity in the time series, such as pixels that exhibit very low backscatter during the flood, the minimum value of each pixel in the stack holding the flood photos is used. These discontinuities, such as flood regions, are characterized by the difference between the mean and the base worth. In addition to helping specify a cutoff to identify flood regions, normalizing the difference enables us to have values somewhere between 0 and 1 (Cian, Marconcini, & Ceccato, 2018).

Multicriteria Evaluation (MCE)

The Analytic Hierarchy Process (AHP) Multicriteria Evaluation Method (Tables 1&2) is one of the various methods that have been developed for multi-criteria decision making. The evaluation method assists decision-makers in reclassifying all of the data used in this study using the ArcGIS 10.6 weighted overlay tool. When faced with a complex problem that involves multiple conflicting and subjective criteria, the AHP considers how to measure inconsistencies and improve the judgments, when possible, to obtain better consistency; examples of this include location or site selection, project ranking, and others.

Table 1: Ranking Criteria Comparison Matrix

CRITERIA	*PPT*	*DEM*	*SLOPE*	*TWI*	*LULC*	*NDVI*	*RIVER*	*ROAD*	*DRAIN_DENSITY*	*SOIL*
PPT	1.00	5.00	5.00	5.00	4.00	5.00	2.00	5.00	5.00	5.00
DEM	0.20	1.00	2.00	2.00	2.00	2.00	4.00	5.00	2.00	3.00
SLOPE	0.20	0.50	1.00	3.00	2.00	3.00	4.00	3.00	2.00	3.00
TWI	0.20	0.50	0.33	1.00	3.00	3.00	5.00	2.00	2.00	2.00
LULC	0.25	0.50	0.50	0.33	1.00	2.00	3.00	3.00	2.00	2.00
NDVI	0.20	0.50	0.33	0.33	0.50	1.00	3.00	2.00	2.00	2.00
RIVER	0.50	0.25	0.25	0.20	0.33	0.33	1.00	5.00	2.00	2.00
ROAD	0.20	0.20	0.33	0.50	0.33	0.50	0.20	1.00	2.00	2.00
DRAIN_DENSITY	0.20	0.50	0.50	0.50	0.50	0.50	0.50	0.50	1.00	2.00
SOIL	0.20	0.33	0.33	0.50	0.50	0.50	0.50	0.50	0.50	1.00

Sum	*3.15*	*9.28*	*10.58*	*13.37*	*14.17*	*17.83*	*23.20*	*27.00*	*20.50*	*24.00*

Table 2: Normalized Criteria Comparison Matrix (C)

CRITERIA	PPT	DEM	SLOPE	TWI	LULC	NDVI	RIVER	ROAD	DRAIN_DENSITY	SOIL	Average	Weight
PPT	0.32	0.54	0.47	0.37	0.28	0.28	0.09	0.19	0.24	0.21	0.30	29.89
DEM	0.06	0.11	0.19	0.15	0.14	0.11	0.17	0.19	0.10	0.13	0.13	13.43
SLOPE	0.06	0.05	0.09	0.22	0.14	0.17	0.17	0.11	0.10	0.13	0.13	12.52
TWI	0.06	0.05	0.03	0.07	0.21	0.17	0.22	0.07	0.10	0.08	0.11	10.74
LULC	0.08	0.05	0.05	0.02	0.07	0.11	0.13	0.11	0.10	0.08	0.08	8.09
NDVI	0.06	0.05	0.03	0.02	0.04	0.06	0.13	0.07	0.10	0.08	0.06	6.49
RIVER	0.16	0.03	0.02	0.01	0.02	0.02	0.04	0.19	0.10	0.08	0.07	6.76
ROAD	0.06	0.02	0.03	0.04	0.02	0.03	0.01	0.04	0.10	0.08	0.04	4.32
DRAIN_DENSITY	0.06	0.05	0.05	0.04	0.04	0.03	0.02	0.02	0.05	0.08	0.04	4.38
SOIL	0.06	0.04	0.03	0.04	0.04	0.03	0.02	0.02	0.02	0.04	0.03	3.38
Sum	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	100.00

The Study Area

With a total area of about 28.968 km2, Kogi State is one of the biggest states in Nigeria. Its geographic coordinates are 778034.37mE, 943817.51mN, and 348220.70mE, 774890.60mN. The two main rivers in Nigeria, the Niger and Benue, as well as their tributaries, the Mabolo, Ofu, Okura, Ubele, Inachalo, and Oyi rivers, drain Kogi state (Ozim, Olufemi, Ekpo, Alamaeze, & Mban, 2021). The vegetation of the research region is composed of Guinea savanna to the north, a mosaic of forest savanna to the south, grasslands and wooded savanna to the east, and rain forest to the west. According to Ozim et al. (2021), Kogi state's climate is classified as both wet and dry AW, with an average annual temperature of 27.7°C and rainfall of 1016 and 1524 mm between April and October.

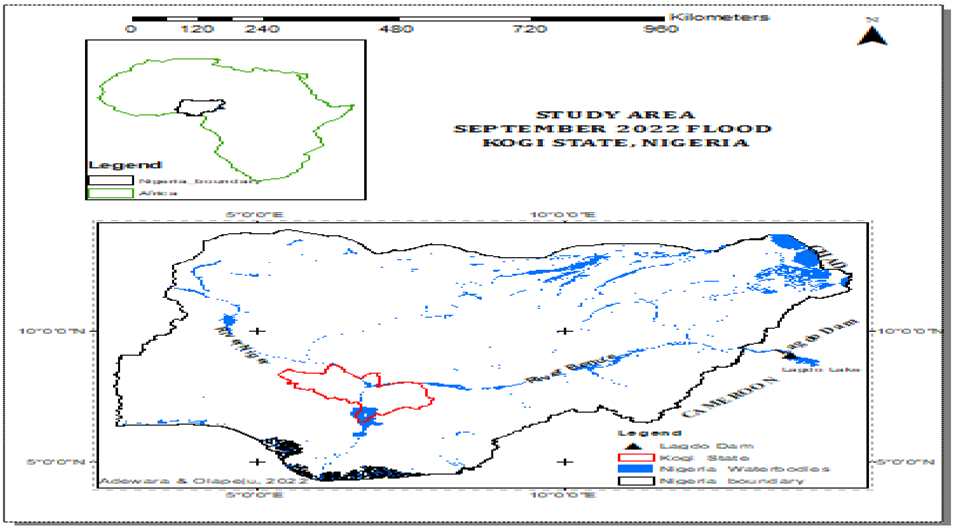

Figure 1: Study area (Authors Survey, 2022)

Hazard Assessment

Communities in Kogi State that are vulnerable to flooding are the focus of this study. In order to map the state's flood hazard, it uses a systematic series of procedures (such as weighted overlay and spatial multi-criteria decision making) (Table 2). A flood vulnerability evaluation is essential to any flood defense. At the moment, the vast majority of the state's local government districts lack master plans that would direct growth and shield residents from dangers. Flood hazard maps must be created as a prerequisite for efficient planning because the development master plans have limitations, including insufficient data for analysis and flood plain features. Flood indicators (rainfall, elevation, slope, drainage density, NDVI, TWI, LULC, soil, road, rivers) were reclassified into five hazard scales, with 1 denoting "Low," 2 "Moderate," 3 "High," 4 "Very high," and 5 "Extremely High." The reclassified identified flood factors were then weighted overlayed using the Pairwise comparison method and Analytical Hierarchical Process (AHP) (Table 2) until a consistency ratio of less than 0.1 was obtained.

4.0 Results and Discussion

According to the study, the state's greatest elevation is between 145 and 247 meters, while its minimum elevation is between 18 and 48 meters. Even with elevation above this, flooding still occurs in parts of Ifo LGA in Ogun State and Uzowani LGA in Enugu State, Nigeria. This is among the explanations for why Kogi State is susceptible to flooding. These low-lying, elevated regions, which include the LGAs of Ibaji, Idah, Igalamela, Ajaokuta, Lokoja, Bassa, Ofu, Kotonkarfi, and Omala, are located along the Niger River. In addition to their low heights, these areas receive the most rainfall all year long (Figure 3). Water bodies, farming, built-up areas, bare grounds, and vegetative coverings are the main land uses and covers in the area. To ascertain the area's level of vegetation, the NDVI was computed. The range of the NDVI is -1 to 1. Roads, buildings, bare land, sand, rock, water, snow, clouds, and so on are the areas with the lowest NDVI values (-1 to 0). Compared to places with ratings between 0 and 1, such plants and flora, these areas are more susceptible to flooding. The state's lowest NDVI is between -0.1992 and 0.482. These ranges are found in the state's most susceptible areas.

While Kaba and Mopa-Muro LGAs are moderately hazardous, other LGAs are very dangerous to flooding, and three (3) LGAs in the state—Ibaji, Idah, and Igalamela—are classified as extremely hazardous (Table 3).

Table 3: LGAs Flood Hazard coverage area

SN	LGA	Area (Km^2)	Hazard Coverage	% Hazard by State	% Hazard per LGA	Hazard
1	Ibaji	1377	1101.6	7.663650878	80	**Very High**
2	Idah	48	43.2	0.300535329	90	**Very High**
3	Igalamela-Odolu	1990	796	5.537641702	40	**Very High**
4	Okene	290	203	1.412237771	70	High
5	Olamaboro	1205	843.5	5.868091427	70	High
6	Ajaokuta	1371	959.7	6.676475806	70	High
7	Ankpa	1264	884.8	6.155408766	70	High
8	Ofu	1652	991.2	6.89561615	60	High
9	Adavi	715	429	2.984482777	60	High
10	Bassa	1917	1341.9	9.335378643	70	High
11	Dekina	2485	1242.5	8.643869114	50	High
12	Koton Karfe	1528	764	5.31502294	50	High
13	Lokoja	3396	2037.6	14.17524966	60	High
14	Ogori/Magongo	75	37.5	0.260881362	50	High
15	Okehi	728	436.8	3.0387461	60	High
16	Omala	1746	873	6.073318098	50	High
17	Ijumu	913	91.3	0.635159155	10	High
18	Yagba East	1517	455.1	3.166056204	30	High
19	Yagba West	1180	354	2.462720053	30	High

20	Kabba/Bunu	2694	269.4	1.874171702	10	Moderate
21	Mopa-Muro	877	219.25	1.525286361	25	Moderate

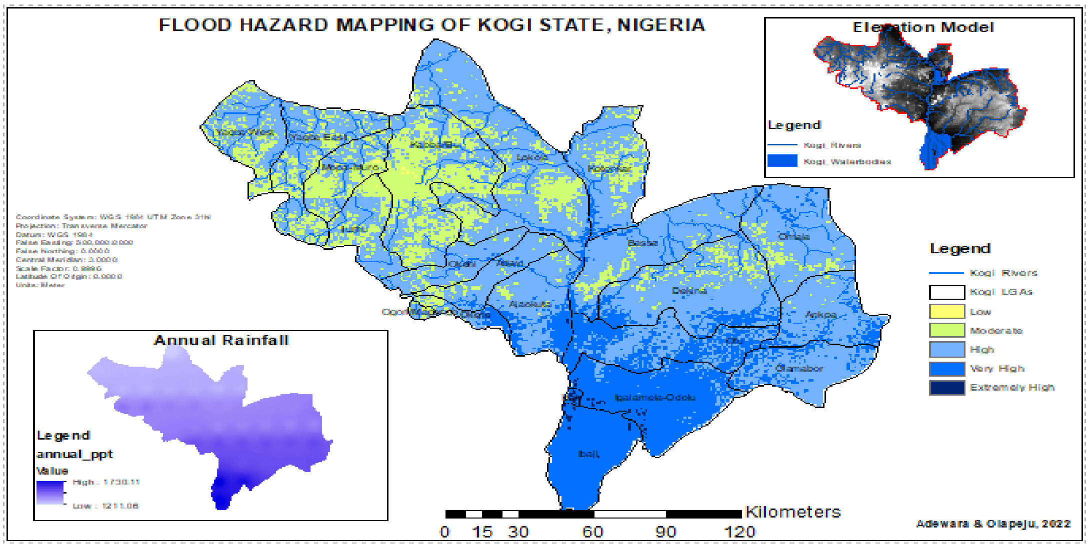

Figure 3: Hazard map

5.0 Conclusion/Recommendation

Kogi State's flood danger map was created using a variety of natural parameters, including rainfall, elevation, slope, drainage density, NDVI, TWI, LULC, soil, roads, and rivers, all of which were obtained from internet sources. Lower elevations and locations nearer rivers are typically riskier than higher elevations and locations farther from rivers or other bodies of water (Figure 3). The danger maps and flood data produced by this study can serve as a foundation for further flood research aimed at creating an alert system for nearby flood zones. Using hazard maps, it is also necessary to keep an eye on the many forms of urbanization and floods that occur within the LGAs.

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- **Competing Interests**: The authors have no relevant financial or non-financial interests to disclose.
- **Ethical Approval**: Not applicable.
- **Consent to Participate**: Informed consent was obtained from all subjects involved in the study.
- **Data Availability Statement:** the field data that formed the basis of the study's results can be made available upon reasonable request.
- **Author Contributions**: All authors were involved in the production and writing of the manuscript. Conceptualization was done by Babalola Adewara. Data collection was coordinated by Babalola Adewara and Olasunkanmi Olapeju. Formal analysis was performed by Babalola Adewara and Olasunkanmi Olapeju. Babalola Adewara and Olasunkanmi Olapeju were involved in investigation. Methodology was ideated by Babalola Adewara and Olasunkanmi Olapeju. The writing of the original draft was done by Olasunkanmi Olapeju. Review and editing were performed by Babalola Adewara and Olasunkanmi Olapeju.

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