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DETERMINATION OF ORTHOMETRIC HEIGHTS FOR ENHANCING BUILT-UP EXPANSION IN AN URBAN FLOOD PLAIN ON PARTS OF LOKOJA, KOGI STATE, NIGERIA

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Abstract

Elevation is crucial for determining the location of points on or beneath the Earth's surface, particularly in flood-prone areas. In Lokoja, many residents live in low-lying regions and river floodplains, attracted by natural resources and agricultural opportunities. However, this rapid urban growth often leads to flooding, which damages infrastructure, livelihoods, and public services. This study aimed to acquire coordinates, determine orthometric heights, and identify flood-prone areas to guide urban expansion. Researchers selected 234 points at 25-meter intervals and recorded Easting, Northing coordinates, and ellipsoidal heights using a South Galaxy Differential GPS, while with a benchmark of known orthometric height, orthometric heights were measured using a spirit levelling instrument. Various maps were generated using Surfer 13 and ArcGIS software, including contour, digital terrain, watershed, shaded relief, vector, and flood vulnerability maps. Findings indicated that areas with orthometric heights between 49m and 61m are especially vulnerable to flooding and unsuitable for development, posing significant risks to human safety. Development in these regions is deemed unsustainable and threatens the well-being of the local population.

Key words - Orthometric Height, Ellipsoidal Height, Built-up Expansion, Urban Flood Plain.

1.0 INTRODUCTION

A crucial factor in determining the position of any point on or below the earth's surface is height [10]. A deeper understanding of the main factors behind built-up development is a prerequisite for designing policies that enhance efficient land use. Orthometric heights are normally obtained from spirit levelling and gravity measurement [11]; [10]. Orthometric height is the height above or below the geoid along the gravity plumb line [15]; [10]. It is the distance, measured positively outwards or negatively inwards along the plumb line, from the geoid (zero orthometric height) to a point of interest, usually on the topographic surface [9]. Orthometric heights can be determined using geometric or trigonometric levelling [12].

The method of GPS/geodetic levelling for obtaining geoidal heights which in turn can be used in the determination of orthometric height cannot be assumed as a new theory. In fact, as a result of case studies that have been conducted by different researchers, [4]; [1]; [5]; it is evidenced that the GPS/geodetic levelling can provide a possible alternative to traditional techniques of levelling measurement, which is tedious, time-consuming and prone to errors over a long distance.

According to [7], "Orthometric heights are the natural 'heights above sea level,' that is, heights above the geoid [6]. They thus have an unequalled geometrical and physical significance." National Geodetic Survey (1986) defines orthometric height as, "The distance between the geoid and a point measured along the plumb line and taken positive upward from the geoid".

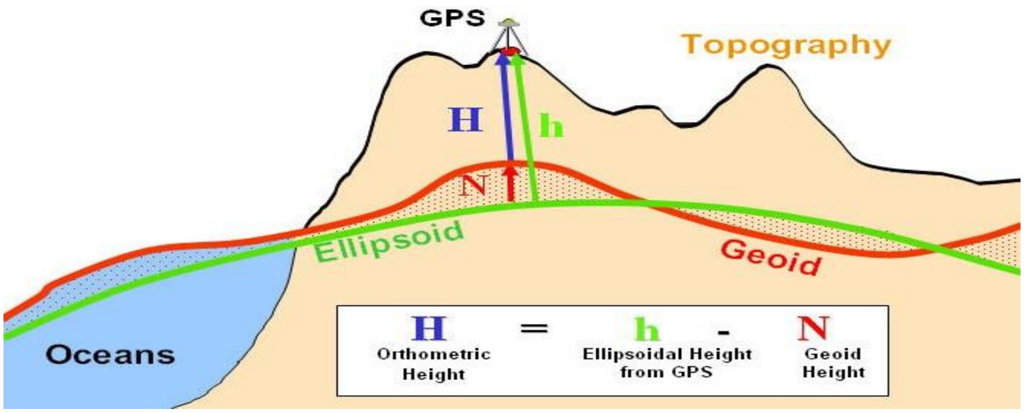

Figure 1: Showing the relationship between Geoidal, Ellipsoid and Orthometric heights
Source: [8]

A floodplain is an area of land adjacent to a stream or river that stretches from the banks of its channel to the base of the enclosing valley walls and experiences flooding during periods of high discharge [14] [15]. Floodplain encroachment has caused urban floodplain management to become a major concern worldwide, especially with the contemporary rising trends in urban flooding.

Built-up expansion is a human settlement with a high population density and infrastructure of the built environment [16]. A flood is an overflow of large amounts of water onto a usually dry land in a built-up area due to the overflow of rivers, oceans, and streams or due to excess rainfall in a particular location. It is one of the most frequently occurring environmental hazards of various types and magnitudes, occurring in most built-up areas of the globe, causing huge losses in terms of damages and disruption to economic livelihoods, businesses, infrastructure, services and public health. Floods can be described as the most frequently occurring destructive natural occurrences affecting both rural and urban settlements, [9].

Nigeria as a nation suffers the effect of Climate Change majorly through the events of flooding thereby causing almost 90 per cent of damages from natural hazards [2]. Recent flood disasters in Nigeria have been of major concern to people, communities and institutions. Flash floods are the most common in Nigeria during the peak of the rainy season (May-September) and the 2012 flood event in Nigeria is described as the worst in recent times [3].

Kogi State was the worst affected state during the flood disaster in 2012 due to its location at the confluence of the country's major rivers (Niger-Benue Rivers), [13]. This led to most settlements being inundated rendering millions of people homeless, destroying thousands of hectares of farmlands and livestock and loss of aquatic animals. This flooding came because of water release from the Ladgo dam

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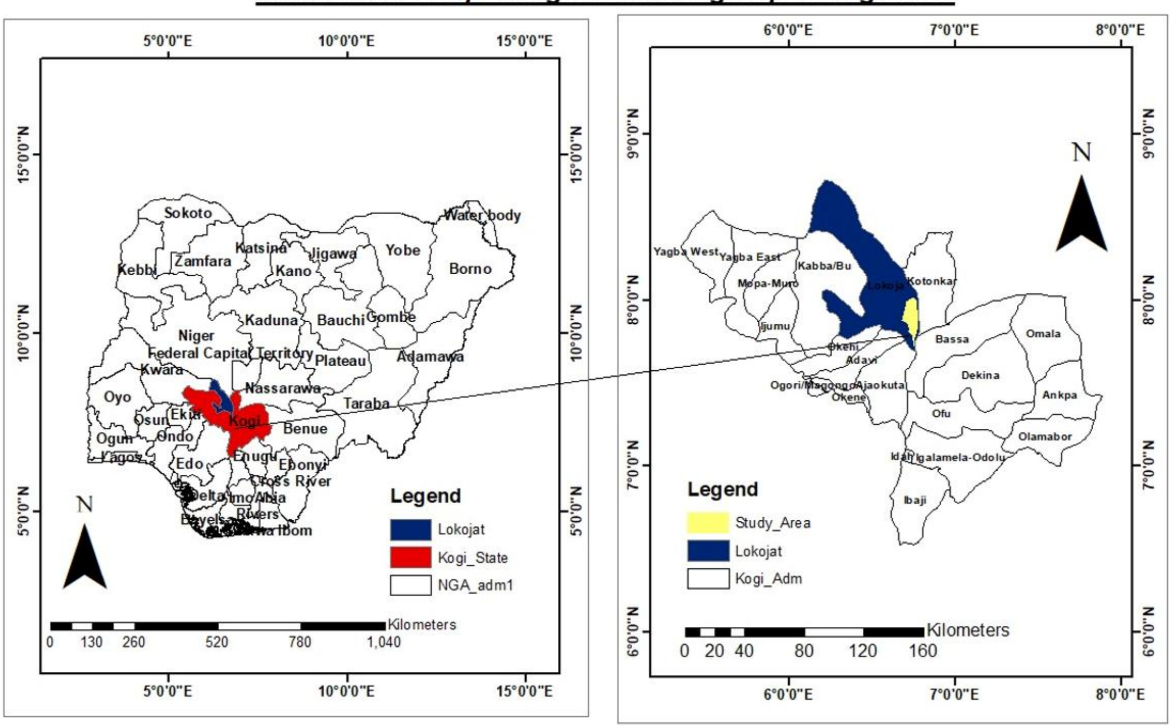
into river Benue, Shiroro and Kanji dam also released water into river Niger, as well as climate change itself which led to excess precipitation [13].

2.0. THE STUDY AREA

The study area is Lokoja, the capital of Kogi State (the confluence state) which is geographically located between latitude $7^{0}44$'N to 8^{0} 2'N and longitude 6^{0} 38'E to 6^{0} 50'E. With an area of 3,152 Km² and a population of 265,000 as at 2006 census. (National Population Commission of Nigeria 2006). The occupation includes mostly fishermen, civil servants and Farmers. The crops produced include cassava, yam, rice, maize, guinea corn, beans, soya beans, melon, asha and millet. The State is blessed with precious mineral resources like columbite, aquamarine, limestone, iron, tin, and coal. An area of 1502.701 hectares was mapped out for the purpose of this research and 234 points within the study area were selected at 25m chainages which define the core areas along the riverbank.

Aministrative Map of Nigeria Showing Map of Kogi State



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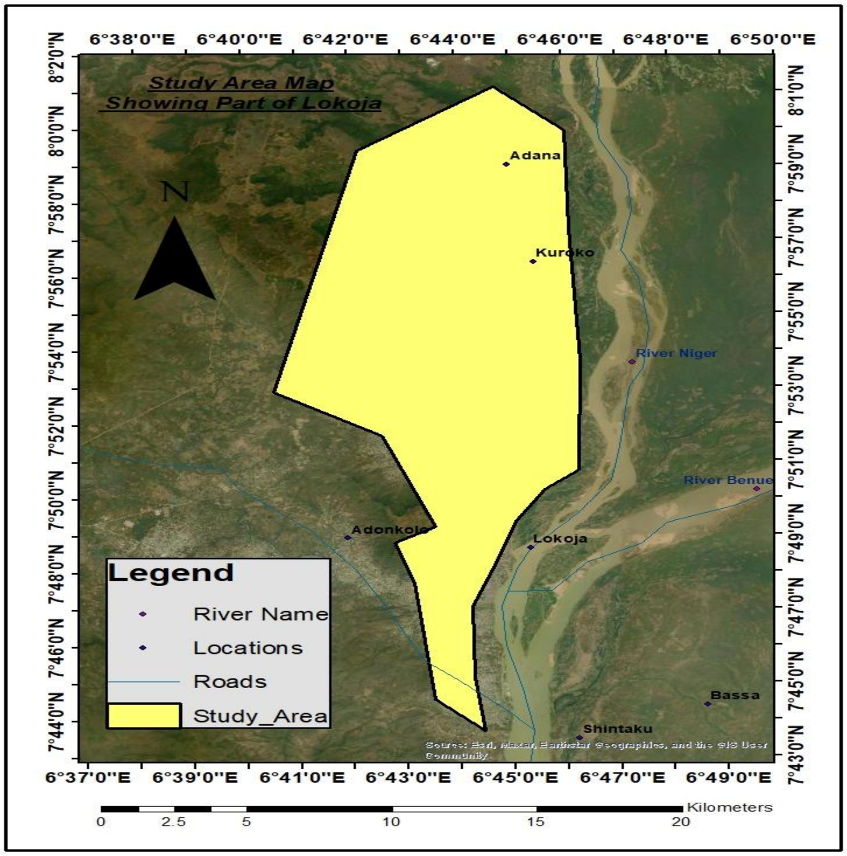


Figure 2: Map of Nigeria showing Kogi State.

3.0 MATERIALS AND METHOD

Orthometric heights were obtained using a benchmark with a known orthometric height, along with the difference between Differential GPS observations, Geoidal Undulation, and Shuttle Radar Topography Mission (SRTM) data of 30m from www.earthexplorer.usgs.gov alongside the Landsat 8 image of the year 2020 for the Land use Land cover data of the study area was downloaded. Prior to the use of the data, an image preprocessing technique was carried out on the image to remove any error embedded in the image because of disturbance in the communication between the ground control system and the satellite. The DEM of the study area was extracted from the downloaded DEM using the clip tool present within ArcGIS 10.3. The slope, Drainage Pattern and Drainage Density of the study area were extracted from the DEM of the study area using the Slope and Hydrology tool present within the ArcGIS 10.3 toolbox respectively. The summary of the process adopted is illustrated in the table below.

Table 1: The source of data alongside their respective resolution

S/N	Data	Parameters	Source	Resolution
1	Rainfall	Rainfall	Giovanne	MM resampled to 30m
2	SRTM-DEM	DEM	USGS	30m

3	Landsat 8 Imagery (2020)	Land use Land cover	USGS	30m

(Source: Author's work, 2022)

4.0 RESULTS AND DISCUSSIONS

4.1 Coordinate Extraction

This study was able to determine orthometric heights as shown in Table 1. In achieving this aim, a number of 234 points within the study area were selected at 25m chainages. An area of 1502.701 hectares was mapped out for this work. The Easting, Northing coordinates and ellipsoidal heights of these 234 points were acquired with the aid of south Galaxy Differential GPS and Orthometric heights were acquired with the aid of a Spirit levelling instrument after applying corrections. The dataset presented in this study is an extract of the full dataset of the research.

Table 2: Ellipsoidal heights derived from GNSS data and orthometric heights derived from levelling observation

S/N	Point name	Northing	Easting	Orthometric Height	Latitude	Longitude	Ellipsoidal height
1	VON JAMA 01	862835.198	251729.901	46.4544	7.799867465	6.748725109	69.405
2	Lot404	862833.617	251728.353	47.5527	7.799853093	6.748711159	69.478
3	VON JAMA 02	862857.366	251655.169	45.3198	7.800064221	6.748046737	69.496
4	VON IBOHU 03	862870.742	251639.624	47.9321	7.800184378	6.747905207	69.578
5	XSP18	862891.898	251648.871	47.0637	7.80037604	6.747987989	69.462
6	GMB 01	862844.584	251638.766	45.4201	7.800515534	6.747895656	70.704
7	FGPKGY08	862907.223	251638.334	46.7797	7.800514055	6.747891754	70.335
8	PL1	862913.852	251606.543	47.2872	7.800572432	6.74760331	70.756
9	PL2	862919.68	251596.165	45.5621	7.800624608	6.747508965	70.746
10	LKJ1	862873.276	251630.147	47.1644	7.800206821	6.74781919	70.743
11	LKJ2	862869.928	251607.803	48.7906	7.800175482	6.747616849	72.283
12	LKJ3	862876.753	251593.421	45.9274	7.800236475	6.747486173	72.019
13	LKJ4	862872.56	251618.331	48.4919	7.800199781	6.747712135	72.295
14	LKJ5	862801.51	251439.11	51.4752	7.799548938	6.746091289	72.108
15	LKJ6	862746.18	251426.975	52.7157	7.799048245	6.745983984	72.29
16	LKJ7	862668.677	251390.995	52.8402	7.79834599	6.745661651	73.33
17	LKJ8	862631.174	251374.498	52.7361	7.798006218	6.745513953	73.06
18	LKJ9	862561.981	251358.356	52.6144	7.797380031	6.745371006	73.342
19	LKJ10	862535.196	251403.981	52.7736	7.797140138	6.745785805	72.936
20	LKJ11	862521.624	251481.418	54.9174	7.7970212	6.746488274	73.29

(Source: Author's 2021)

4.2 Extract from Levelling Observation

A spirit levelling instrument was used to acquire Orthometric heights after corrections were applied.

Table 3: Sample Levelling Data of Observed Points

STATION	BS	IS	FS	HI	RL	CORR	COORD RL
FGPKGY08	4.721			51.501	46.780	0	46.780
PL1		4.218			47.283	-0.000	47.283
PL2		5.946			45.555	-0.000	45.555
LKJ1		4.324			47.177	-0.000	47.177
LKJ2		2.719			48.782	-0.000	48.782
LKJ3		5.589			45.912	-0.001	45.911
LKJ4		2.988			48.513	-0.001	48.512
LKJ5	1.702		0.021	53.182	51.480	-0.001	51.479
LKJ6		0.454			52.728	-0.001	52.727
LKJ7		0.322			52.860	-0.001	52.859
LKJ8		0.482			52.700	-0.001	52.699
LKJ9	3.936		0.567	56.551	52.615	-0.001	52.614
LKJ10		3.775			52.776	-0.001	52.775
LKJ11		1.635			54.916	-0.002	54.914
LKJ12		2.261			54.290	-0.002	54.288
LKJ13		1.511			55.040	-0.002	55.038
LKJ14		1.996			54.555	-0.002	54.553
LKJ15		1.611			54.940	-0.002	54.938
LKJ16		1.421			55.130	-0.002	55.128
LKJ17		1.349			55.202	-0.002	55.200
LKJ18		1.208			55.343	-0.002	55.341
LKJ19		1.139			55.412	-0.002	55.410
LKJ20		1.245			55.306	-0.003	55.303

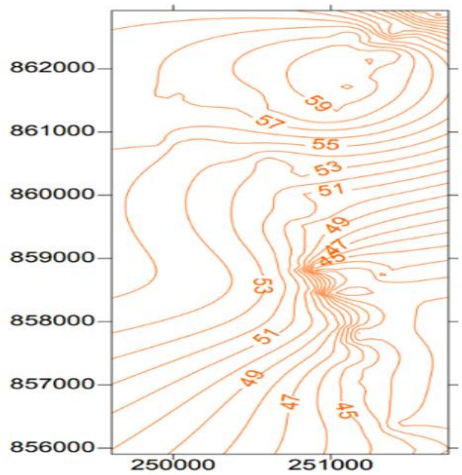
Where:
BS stands for Backsight,
IS stands for Intermediate sight,
FS stands for Foresight,
RL stands for Reduced level,
Corr stands for Correction
and
Corr RL stands for Corrected Reduced level.

4.3 Contour Map

The contour map shows topography with 2-meter interval lines representing elevation changes. Closely spaced lines indicate steeper slopes, while wider spacing shows flatter areas. Figure 5a highlights densely packed lines in the central region, suggesting steep slopes or raised elevation. The map helps visualize terrain, understand slope gradients, and predict water flow, useful for assessing drainage patterns and identifying flood-prone areas.

4.4 Digital Elevation Model

The digital elevation model (DEM) provides a 3D view of the study area's terrain, with colour gradients indicating different elevation levels. Generated using kriging interpolation, it predicts values between known points for a smooth surface. In Figure 5b, warmer colours (red, orange) represent higher elevations, while cooler ones (green, blue) indicate lower areas. The DEM helps analyze slopes, water runoff, and erosion risks, aiding in land-use planning, flood assessments, and environmental management.



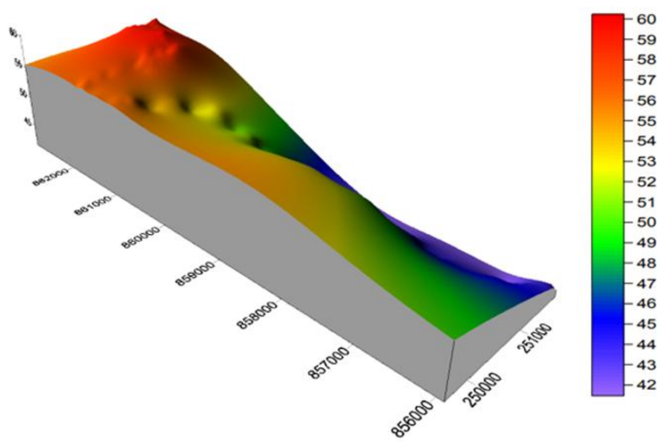


Figure 3a: Contour Map of Study Area *Figure 3b: Digital Elevation Model of Study Area*

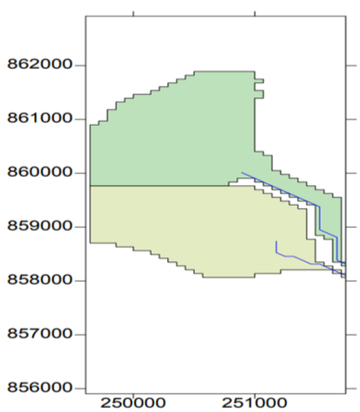


Figure 4a: Watershed Map

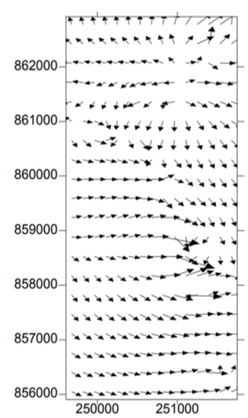


Figure 4b: Vector Map

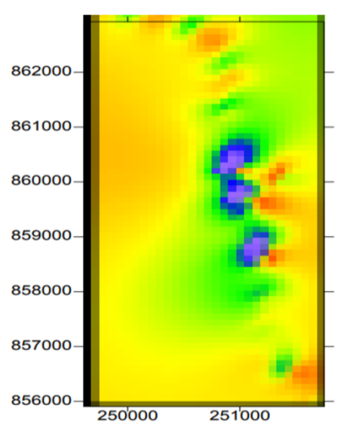


Figure 4c: Shaded Relief Map

4.5 Watershed Map

The watershed map, generated with Surfer 13, shows natural water flow boundaries in the study area. Figure 4a uses different shades of green to highlight sub-watersheds, where water drains toward shared outlets, like rivers (shown as blue lines). Boundaries represent ridgelines separating drainage systems.

This map is essential for understanding water flow, identifying flood-prone areas, and planning for flood management and water conservation within the study area.

4.6 Vector Map

The vector map in Figure 4b, generated with Surfer 13, depicts directional flow patterns in the study area. Arrows represent flow direction and speed, with longer arrows indicating faster flow and shorter arrows signifying slower movement. The predominant flow direction is from northwest to southeast, with some local variations, likely influenced by topography. Understanding these dynamics is essential for assessing flood risk, water distribution, and other hydrological processes in the area.

4.7 Shaded Relief Map

The shaded relief map, created using Surfer 13, visually emphasizes terrain elevation through color gradients and shading, simulating light and shadow for a 3D effect. In Figure 4c, warmer colors (red, orange) denote higher elevations, while cooler colors (green, blue) represent lower areas, such as valleys. This map aids in identifying terrain features like hills and valleys, making it useful for terrain analysis, flood risk assessment, and land use planning by linking elevation to water flow.

4.8 Rainfall of the Study Area

The rainfall map below shows precipitation distribution in the study area, which significantly influences flood events. The amount of water available is largely dependent on rainfall, particularly in Nigeria, where rainfall is a primary form of precipitation. For the study area, rainfall levels ranged from 23,294 mm to 23,940 mm between 2000 and 2020. The rainfall map was reclassified into five classes, with a value of 1 assigned to areas with high rainfall and 9 to those with low rainfall, reflecting their influence on flood occurrence.

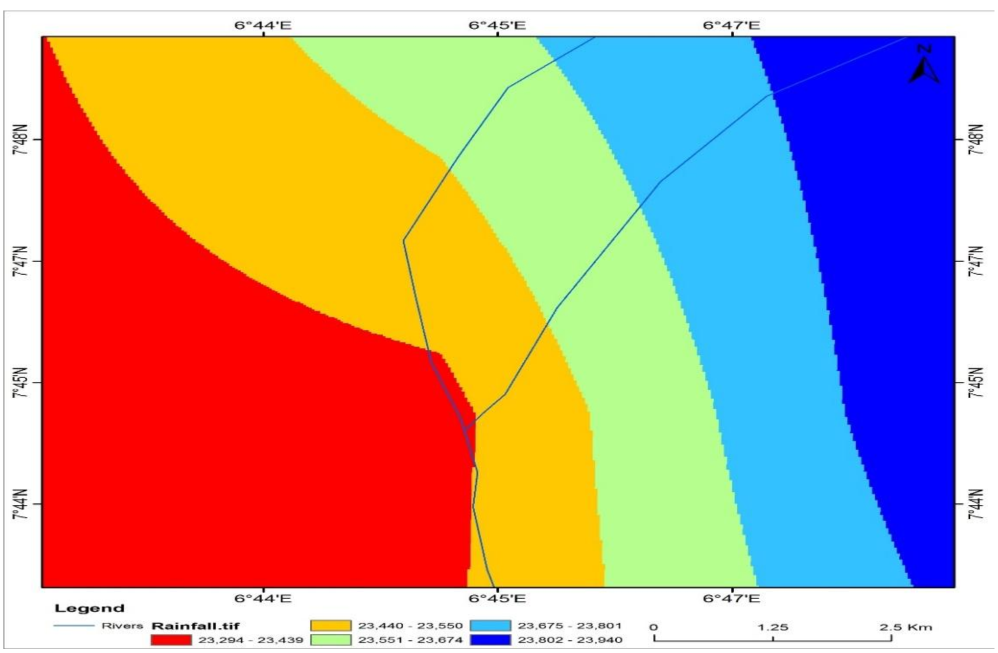


Figure 5: Rainfall distribution of the study area

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4.9 Drainage Density

Drainage Density provides insights into the water abundance within a specific area and is a key factor when creating flood risk or vulnerability maps. It helps determine the rate at which water infiltrates the ground. In the study area, as shown in Figure 6, the drainage density ranged from 1,269 square meters to 13,479 square meters. The majority of the area exhibits very low to low drainage density, likely due to its proximity to the river.

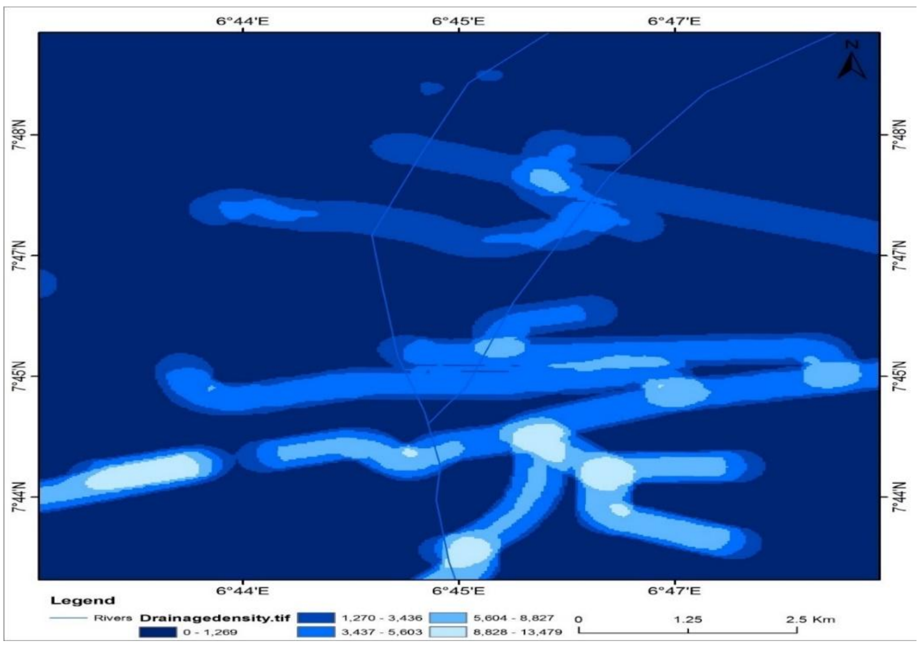

Figure 6: Drainage Density of the study area

4.10 Slope

The slope represents the steepness or gentleness of a topographic surface and can be expressed in degrees or percentages. In this study, the slope of the area was derived from the DEM using the slope tool in the ArcGIS 10.3 Spatial Analyst toolbox and later expressed in degrees. The observed slope ranged from very low to very high, with the study area predominantly exhibiting a relatively low degree rise. This aligns with expectations, as areas with low to very low slopes tend to have higher water accumulation.

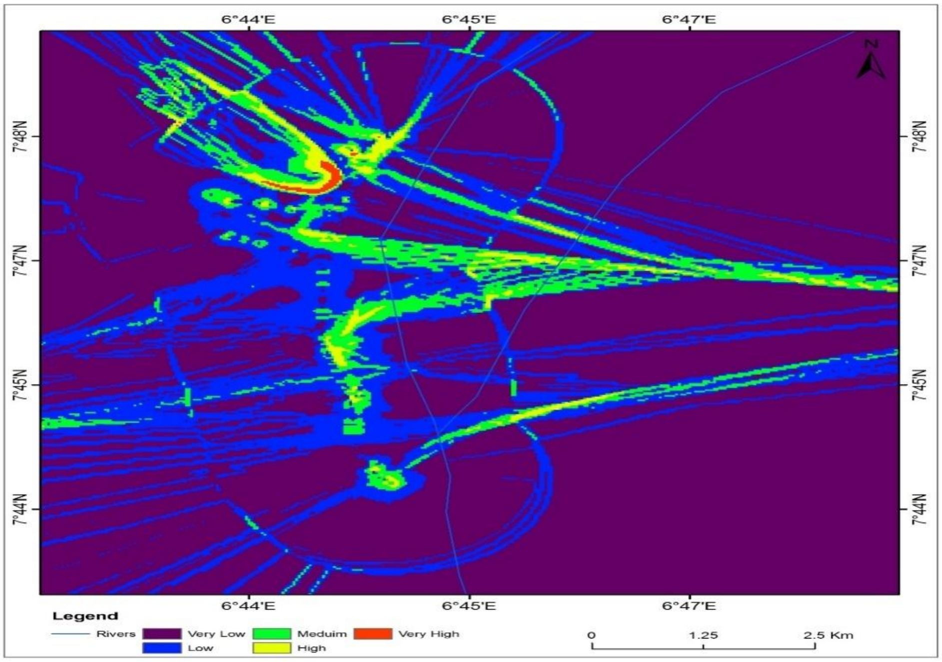

Figure 7: Slope of the study area.

4.11 Land Use Land Cover

Land use and land cover reflect human activities that disrupt the natural arrangement of Earth's surface features. The study area's land use was derived from the supervised classification of Landsat 8 imagery, revealing dominance in urban growth, followed by sparse vegetation and bare lands. Urban areas, with impervious surfaces from roads and buildings, hinder water percolation, leading to increased runoff. In contrast, vegetation mitigates water movement, reducing flood events. Water bodies facilitate water movement, but if unmanaged, they can exacerbate flooding. Figure 8 illustrates the distribution of various land use types in the study area.

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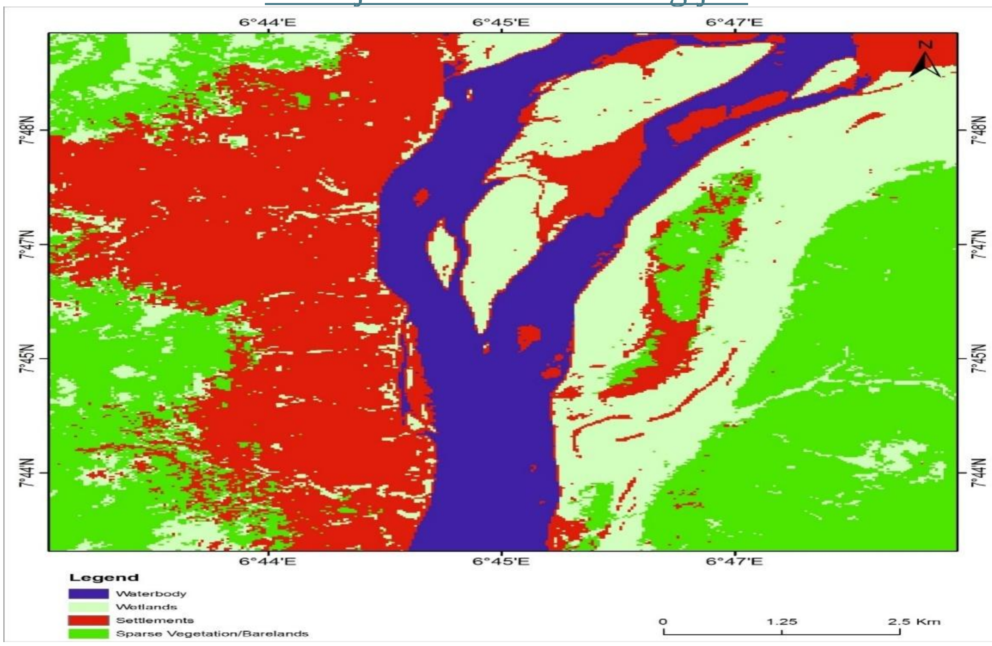

Figure 8: Land use Land cover of the study area

4.12 Distance from River

The proximity from the river was determined using the Euclidean distance tool present within the ArcGIS 10.3 spatial analysis toolbox. This data supplies information about the closeness of particular features to the water bodies within such areas. During the study, it was observed that most of the built-up within the area is located very close to the water body present within the area and as a result very prone to flood events because the closer a feature is to the river, the more liable it is to flood risk. Figure 9 below shows the distribution of features from the major water bodies within the study area.

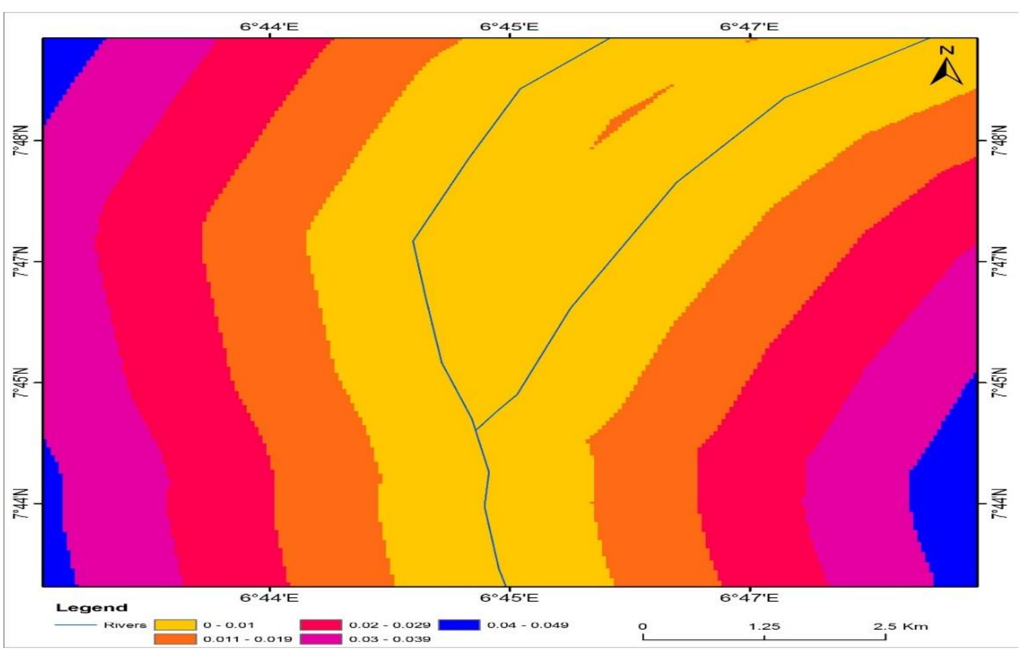

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Figure 9: Distance from the major River Map

4.13 Reclassification of the Parameters for flood events

The reclassification process was carried out to assign the corresponding values of the various parameters contributing to flooding events within the study area. Figures 11, 12 and 13 below show the reclassification result of all the parameters used.

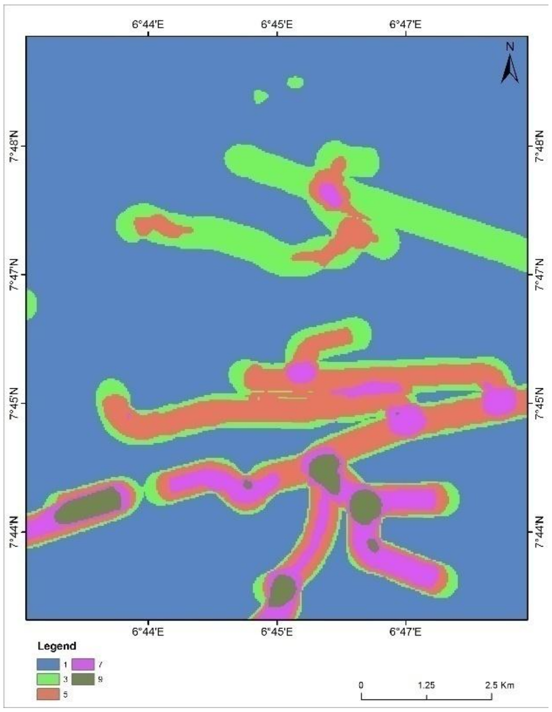

Figure 10a: Reclass Drainage Density

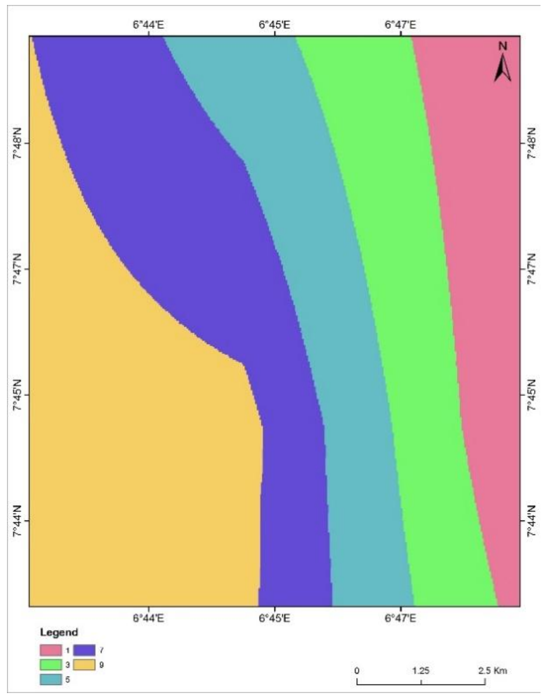

Figure 10b: Reclass Rainfall

Figure 10a (Reclass Drainage Density) identifies areas with higher drainage density, particularly the areas with pink and purple, colours are more prone to flooding. These areas have more concentrated water channels and are more susceptible to surface runoff, indicating a higher risk of water accumulation during heavy rainfall. Figure 10b (Reclass Rainfall) highlights areas with significant rainfall, particularly the areas with green, blue, and purple, coloured experience higher precipitation. These areas are at a greater risk of flooding due to the volume of rainwater that needs to be managed. Combining the two figures, the areas prone to flooding are those where high drainage density (pink and purple zones in Figure 10a) overlaps with high rainfall zones (green, blue, and purple areas in Figure 10b). These overlapping zones indicate areas where water from both surface runoff and heavy rainfall increases the possibility of flooding.

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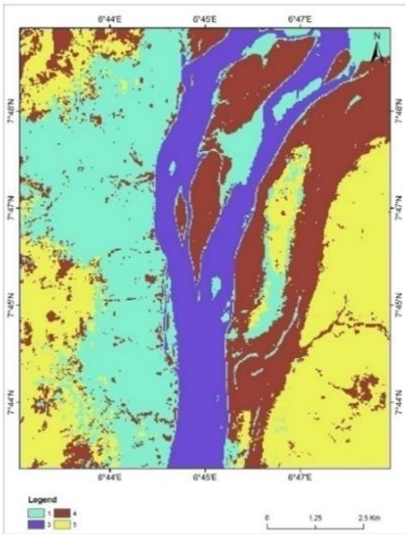

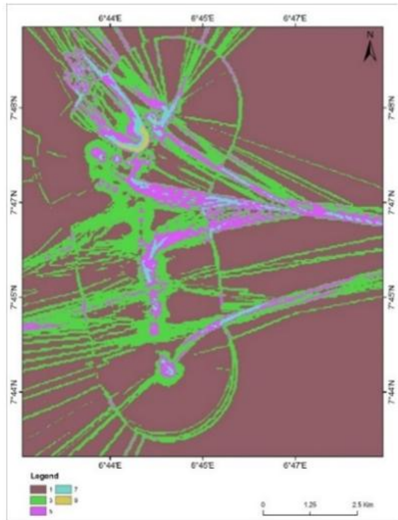

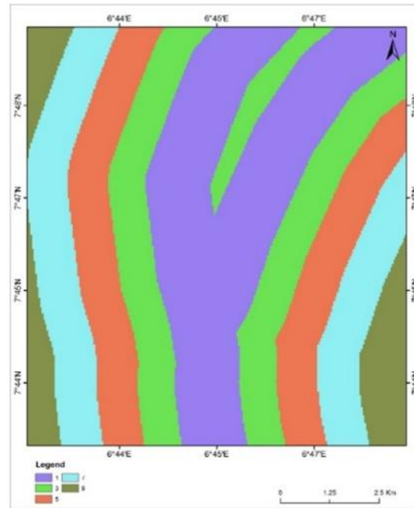

Figure 11a Reclass LULC Figure 11b Reclass Slope Figure 11c Reclass Distance from River

Figure 11a (Reclass LULC – Land Use Land Cover) shows various land uses in the study area. The yellow areas represent built-up areas, while the light blue areas represent water bodies or areas prone to frequent water accumulation, indicating areas with higher flood risks, especially those near the river. Figure 11b (Reclass Slope) classifies the slope gradients of the area, with green areas representing steep slopes and brown areas indicating flat terrains. The flatter areas (brown) are more susceptible to flooding due to slower water runoff, making them more prone to water accumulation during heavy rainfall. Figure 11c (Reclass Distance from River) illustrates the proximity of various areas to the river. Blue and purple areas are closest to the river, making them highly vulnerable to flooding, while orange and green colours areas are farther away and less likely to be impacted by direct river flooding. Based on these maps, the areas at the highest risk of flooding are the light blue regions near the river in Figure 11a, the flat brown regions in Figure 11b, and the blue and purple areas closest to the river in Figure 11c. These overlapping areas are more prone to flood hazards due to their low elevation, flat slope, and proximity to the river.

4.14 Flood Vulnerability Map

Using the percentage influence obtained from the AHP calculator, the flood vulnerability map of the area was derived using the weighted overlay tools within the ArcGIS 10.3 software. The flood risk map represented in Figure 12 shows that the majority of the area is Moderately Vulnerable to Flood events while the area around the Northern part of the study area is at a very high risk of flood events which can be attributed to their proximity to the major river within the study area.

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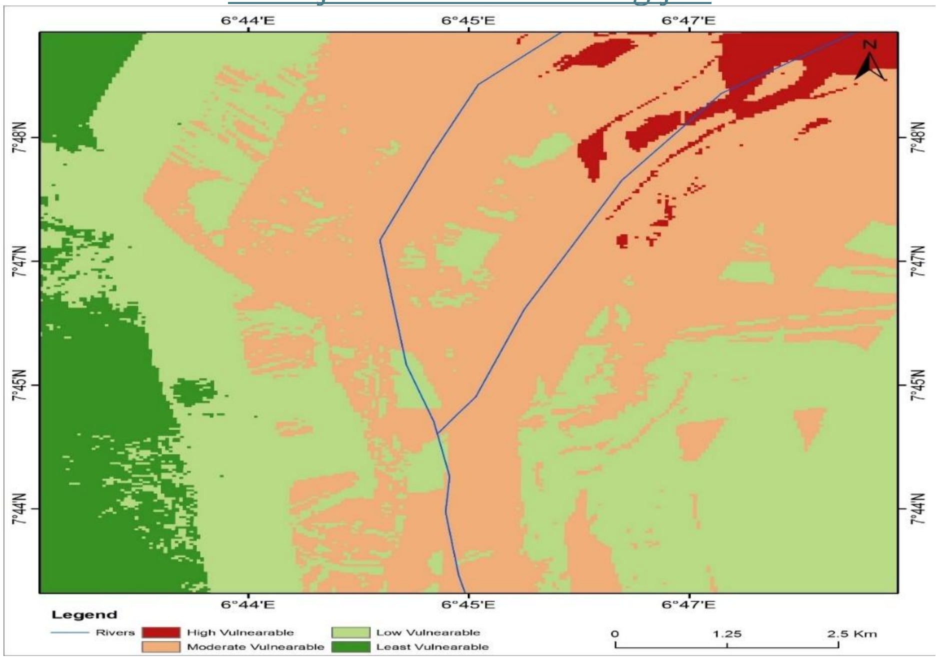

Figure 12: Flood Vulnerability Map of the study area

The area covered by each vulnerable state was calculated and represented in the Table 4. The distribution of flood vulnerability across the 126.245 square kilometre reveals that 56.12 square kilometres (44%) are moderately vulnerable, 49.14 square kilometres (39%) are categorized as low vulnerability, 16.35 square kilometres (13%) are classified as least vulnerable, and 4.64 square kilometres (4%) are highly vulnerable. This suggests that the majority of the area is exposed to some level of flood risk, with only a small portion facing extreme vulnerability.

Table 4: Area (sqr km) and Percentage covered by each vulnerability state

S/n	Vulnerable state	Area (sqr km)	Percentage (%)
1	Highly vulnerable	4.64	3.67
2	Moderately Vulnerable	56.12	44.45
3	Low Vulnerable	49.14	38.92
4	Least Vulnerable	16.35	12.95
	Sum	126.24	100

5.0 CONCLUSION

Orthometric heights play a vital role in enhancing built-up expansion in an urban floodplain. With the aid of the contour maps, digital terrain model, watershed maps, vector map, shaded relief maps of the study area, rainfall distribution of the study area, drainage density, slope of the study area, land use land cover of the study area, distance from the major river and flood vulnerability map of the study area generated using Surfer 13 and ArcGIS software maps, we were able to conclude that areas having orthometric heights between 49m and 61m are vulnerable to flood and not suitable for any built-up facilities as it will pose a threat to human lives. Any built-up facilities around these areas are not sustainable and it can affect human lives.

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