Geo-spatial Mapping and Multi-criteria Analysis of the Downstream Flood Risk Settlements of Usman Dam Abuja-Nigeria

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Keywords: Environment, Flood Risk Management, Geo-spatial Mapping, Hazard, Multi-criteria Analysis

SUMMARY

Flooding is a worrisome phenomenon especially in recent decades due to its effect on human life and man's environment. This study thus mapped and analysed flood risk settlements in the downstream of Usman dam in Abuja, Nigeria, using geospatial techniques. Spatial data were captured which included positional coordinates, Landsat 7 (ETM+), soil map and the shuttle radar topographic mission (SRTM). The factors of flooding and their effect on the area under study were identified. The study results revealed that criteria weights slope (0.24) and elevation (0.24) were the most important factors contributing to flooding in the study area. Other ranking factors identified include drainage proximity (0.16), land use land cover (0.12) and soil (0.08) respectively. The results also showed that, the built-up area, farmland, forest, grassland, rock outcrop and water body covered about 278.0 km^2, 306.9 km^2, 1406.6 km^2, 1635.8 km^2, 387.5 km^2 and 386.9 km^2, respectively of the study area. Moreover, it was found out that 6.41% of the settlements were located in the highly vulnerable areas, while 64.02% were located within the areas moderately vulnerable to flooding. However, the remaining 29.57% were located in low vulnerable areas. It was suggested based on the results of the study that settlements close to the river course and dam reservoir, and along the flood plains should be relocated to the low vulnerable areas (east of the study area) in order to limit the impact of future flood hazard.

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1. INTRODUCTION

The devastating effect of natural disasters such as flooding, earthquake among others has gotten the attention of the world in recent times. The National Oceanic and Atmospheric Administration [NOAA] (2019), described flooding as water exceeding ground surface level as a result of natural/artificial activity. The flood activity occurs as a result of various activities such as fast snow melting, heavy rainfall or dam destruction. A key concern of any flood event is that it is unpredictable (Odufuwa *et al*., 2012).

The Earth's population is steadily increasing thus, consistently altering flood variables such as climate, catchment channel, and land use land cover (LULC) with an unpredictable consequence on the human social welfare (He *et al*., 2013).

Periodic floods are a common characteristic of most rivers in Nigeria, resulting in the formation of vast flood plains across most of the river banks (Abowei and Sikoki, 2005). Hamilton (2009), highlighted the fact that flood plains are characterized as dominant inland water, seasonal wetlands and permanent water bodies.

The predominant cause of rainfall in Nigeria is rainfall. The excessive rainfall is reported to instigate the need for the opening of the dam spillways so as to prevent dam failures. This hazard is reported to have resulted in the annual devastation of nearly 700,000 Hectares of settlements and agricultural land (Jeb and Aggarwal, 2008).

Greentumble (2019) stated that the persistent construction of dam globally is reported to reflect enormous economic advantages that include vast irrigation, job creation and domestic use of water. The flooding around exposed communities has become a perennial problem (Kolawole *et al*., 2011). Therefore, there have been some research efforts in the recent past to mitigate the effects of flooding in flood-prone environments due to the recurring flood events experienced all over the world (Khalequzzaman, 2011; Jansen *et al*., 2013; Ojigi *et al*., 2013; Azua *et al*., 2019).

However, with no current way of fully compensating for the factors of flooding, it is imperative that periodic investigations are conducted to ameliorate their effects on the environment. It is against this backdrop that this study mapped out flood risk and vulnerable areas downstream of the Usman dam in Nigeria's capital city of Abuja, with a view to mitigating the effects of the flood. This is achieved through the identification/establishment of flood variables and their characteristics with respect to the study area, as well as a multi-criteria generated flood vulnerability map.

1.1 Study Area

The study area is situated in Nigeria's capital city. It covers the communities downstream of Usman dam near Ushapa of Bwari Area Council of the Federal Capital Territory, Nigeria (see Figure 1). The study area is bounded by Bwari Area Council and some parts of Municipal council area of the Federal Capital Territory of Nigeria.

The study area is located within longitudes 7°24'29.596" and 7°29'3.259" East and latitudes 9°13'35.928" and 9°8'7.435" North. However, the area under study is about 4401.7 km^2. Planners have established that the study area is the most habitable within the FCT. Its terrain is hilly with a maximum elevation of about 760 m above sea level. The ground air temperature ranges between 25.8 and 30.2°C (Balogun, 2001) and the topography is highly undulating and varying in height with isolated hills of over 600m as valleys can be as low as 400 m. The vegetation of the area is of savannah type with patches of few types of woodland with little shrubs and grasses. The people of the study area engage in trading, farming and fishing as means of livelihood (Mabogunje, 1976).

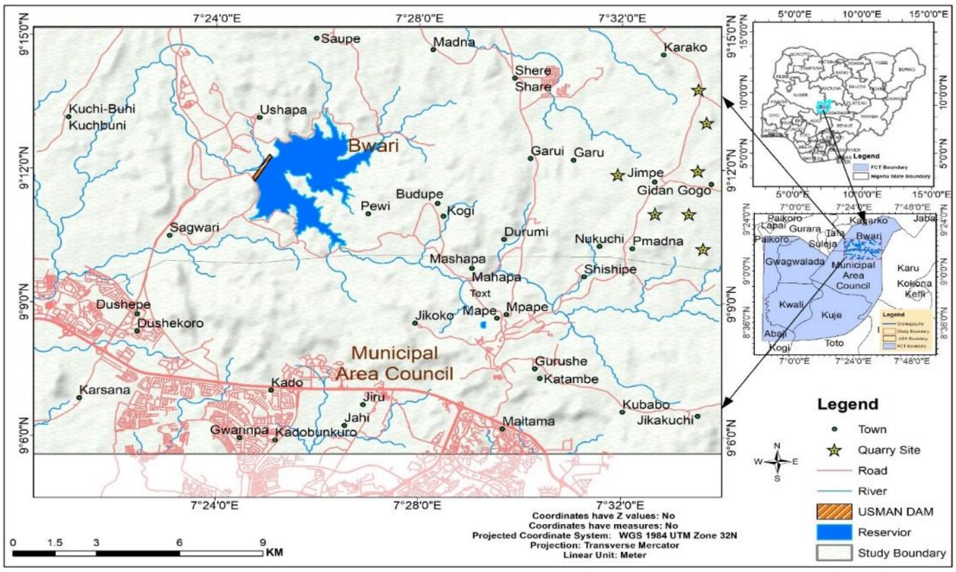

Figure 1: Study Area. Top and bottom right: map of Nigeria showing the FCT; Left: map of the study area.

2. METHODS

Flooding incidents have been based on various factors or criteria which include rainfall, land use, soil type, slope or elevation and drainage density. It means therefore that, these factors must be taken into consideration when addressing the problem of the flood. Figure 2 depicts the workflow diagram adopted in this study.

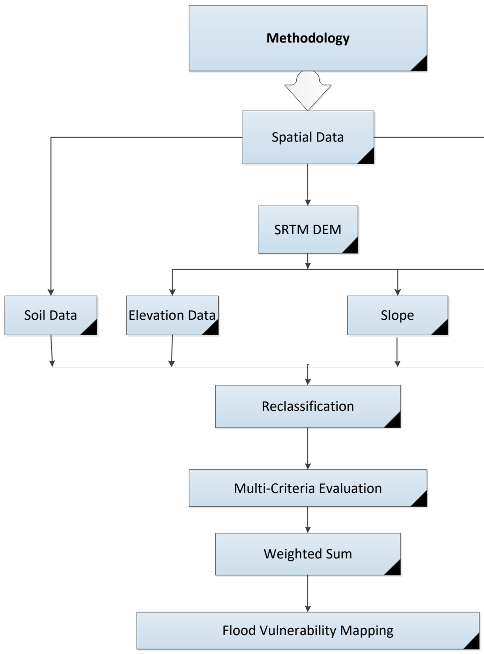

Figure 2: Workflow Diagram (modified after; Azua *et al*., 2019)

2.1 Data Sources

The details of the various datasets and their sources utilized in this study are shown in Table 1.

Table 1: Datasets and Sources

S/N	Data Type	Year	Resolution/Scale	Source
1	Landsat ETM	2017	30m	USGS (www.glovis.usgs)
2	SRTM	2016	30m	USGS (www.glovis.usgs)
3	Soil map	2000	1:100,000	Nigerian Geological Survey Agency
4	Ground truth data	2019		Field observation

2.2 Data Processing

The Landsat Enhanced Thematic Mapper (ETM) image was clipped based on the administrative boundary for the study area. It was then subjected to digital image processing using histogram equalization to enhance the image contrast and remove obscurity for proper interpretation. Supervised classification was carried out in the ENVI version 4.7 environment, to group the land uses into various classes based on their spectral reflectance characteristics. A supervised accuracy assessment was carried out to ensure a high-quality classification result.

The Digital Elevation Model (from the Shuttle Radar Topographic Mission) was utilized to determine the slope and terrain characteristics such as flow direction, flow accumulation and network order maps of the study area. The soil map of the study area was derived from the field soil surveys carried out by the Nigerian Geological Survey Agency in 2000. The classified image and maps were digitized into various layers in the ArcGIS 10.5 environment.

2.3 Multi-Criteria Analysis (MCA)

The five (5) contributing factors identified for the MCA include land use and land cover, elevation, slope, soil and drainage (proximity of settlements to drainage basin) were examined in this study for the multi-criteria analysis based on their relevance to flood vulnerability and the availability of data for the study area. The factors were created as layers and introduced in the weighted overlay model in order to identify areas liable to flood. The spatial data contained in each layer was ranked based on its vulnerability to flooding and the pixels re-classed to reflect the rankings. The five layers were weighted with each factor using numbers ranging from 1 to 5. The land use and land cover classes, however, were indexed based on their contribution to flooding.

3. RESULTS

3.1 Land Use and Land Cover (LULC)

The LULC determined the coverage extent of existing land types in the study area. The land types evaluated include forest, wetland, impervious surface, agriculture, and habitable land. The changes in land use associated with urban development especially in flood-prone areas without proper consideration for effective land use management contribute to the inundation of the areas.

The land use and land cover identified and classified in this study include built-up, farmland, forest, grassland, rock outcrop and water body. Grassland and forest constituted the largest proportions of the study area with values of 1635.8 km^2 (37.16%) and 1406.6 km^2 (31.96%), respectively. These were followed by the rock outcrop and water body with values of 387.5 km^2 (8.80%) and 386.9 km^2 (8.79%), respectively. The least was farmland and built-up with values of 306.9 km^2 (6.97%) and 278.0 km^2 (6.32%), respectively. The result of the classified land use and land cover is shown in Figure 3.

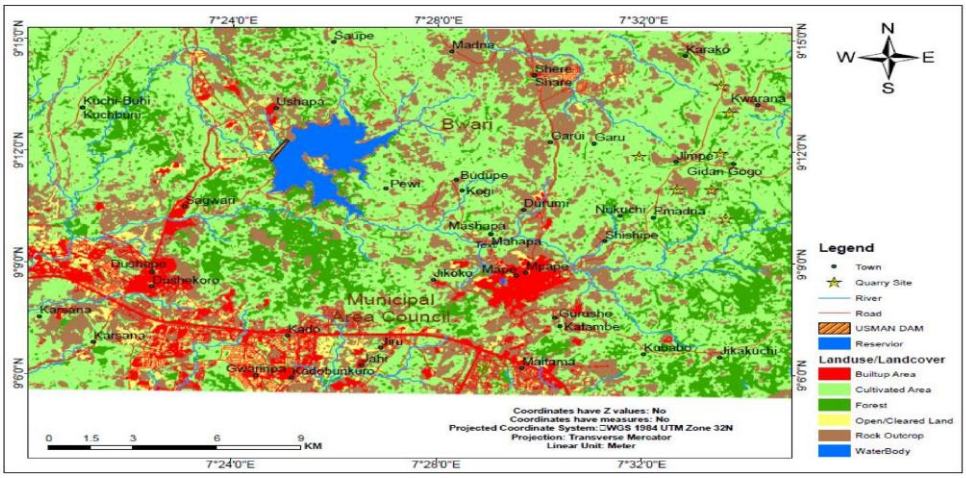

Figure 3: Land Use and Land Cover map of the study area

The accuracy assessment showed that the overall accuracy was 99.19% while the Kappa Coefficient was 98.74%. The land use and land cover classes were indexed according to their contribution to flooding in the study area as shown in Table 2. Waterbody was the highest contributor to flooding due to the fact that the overflowing river and reservoir flood surrounding settlements along the flood plains. This was followed by built-up as a result of obstruction. The least was rock outcrop with little influence as a contributor to flooding in the area under study.

Table 2: Ranking of LULC (modified after; Balica *et al*., 2012; Schroeder *et al*., 2016)

Class	Index Value	Description
Waterbody	0.8-1	Extreme high contributor to flood
Built-up	0.6-0.8	Very high contributor to flood
Farmland	0.4-0.6	High contributor to flood
Grassland	0.2-0.4	Moderate contributor to flood
Forest	0.1-0.2	Small contributor to flood
Rock outcrop	< 0.1	Very small contributor to flood

3.2 Soil

The soil type contributes to flooding by determining the amount of infiltration as well as the surface flow in an area (Nicholls and Wong, 1990). The soil type found in the study area were basically poorly drained gleysol and lixisol surfaces which contribute to flooding as the amount of infiltration are low. They were small and high contributors respectively to flooding as shown in Table 3.

Table 3: Ranking of Soil (modified after; Balica *et al*., 2012; Schroeder *et al*., 2016)

Soil Type	Index Value	Description
Gleysol	0.2-0.4	Small contributor to flood
Lixisol	0.6-0.8	High contributor to flood

3.3 Elevation and Digital Elevation Model (DEM)

The height above a specific reference point, especially above sea level (elevation) constitutes an important element of flooding because it can determine the movement of water from the upstream to the downstream. The height values ranged from 394 to 874m and the result showed that elevation was highest around the Usman dam and in the eastern part of the study area. The western and somewhat southern parts had the lowest elevation. High elevation allows easy water movement thus contributing less to flood. However, low elevation allows water to accumulate thus contributing more to flood (see Table 4 for the ranking of elevation).

Table 4: Ranking of Elevation (modified after; Balica *et al*., 2012; Schroeder *et al*., 2016)

Elevation Class	Index Value	Description
Low	0.6-0.8	High contributor to flood
High	0.2-0.4	Small contributor to flood

3.4 Slope

According to Andongma *et al.* (2017), a slope is an important element that contributes to flooding occurrence in an area. A slope that is very steep allows free movement of water along the path while an area with a flat slope will allow the gathering of water thus causing a flood.

The slope was categorized into five classes; flat, gentle, sloppy, steep and extreme slopes. A greater portion of the settlements has steep and extreme slopes thus causing the flooding of the communities surrounding the reservoir. The slope was indexed between < 0.2 and 1.0 for flat, gentle, sloppy, steep, and extreme respectively as shown in Table 5.

Table 5: Ranking of Slope (modified after; Balica *et al*., 2012; Schroeder *et al*., 2016)

Slope Class (%)	Index Value	Description
Flat (0 – 6%)	< 0.2	Very small contributor to flood
Gentle (7 – 13%)	0.2-0.4	Small contributor to flood
Sloppy (14 – 24%)	0.4-0.6	Moderate contributor to flood
Steep (25 – 39%)	0.6-0.8	High contributor to flood
Extreme (40 – 115%)	0.8-1	Very high contributor to flood

3.5 Drainage Proximity Assessment

The proximity of a settlement can determine the amount or extent of flooding experienced by the settlement, especially along the flood plains. Mayomi *et al*. (2013), applied the 3km buffering to determine communities vulnerable to flooding based on the principle of proximity to the river course. In this study, however, the buffer tool was used at the 500m, 1000m, and 1500m extents respectively. This was done to take care of any bias introduced into the buffering operation. Figure 4 shows the buffering (drainage proximity) carried out for the study area.

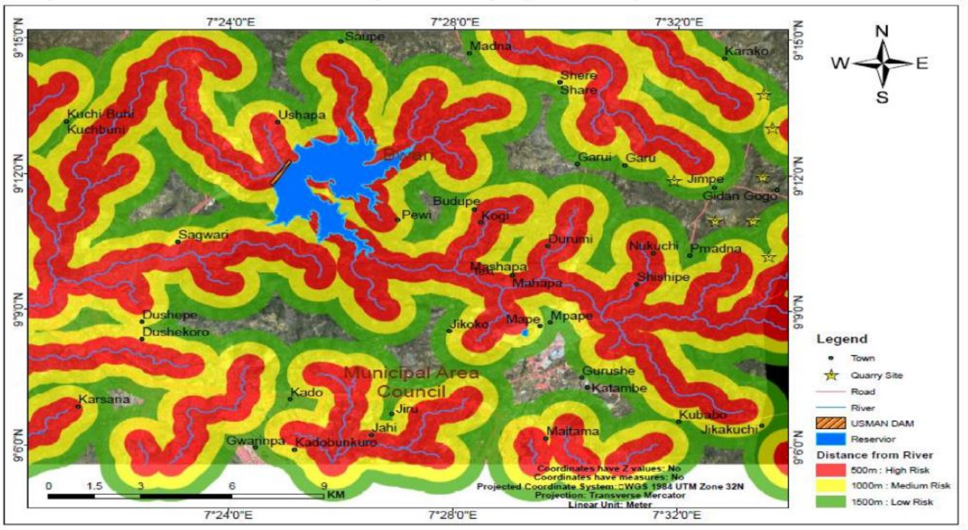

Figure 4: Drainage proximity map of the study area

The results of the buffering operations revealed settlements in the study area that appear to be at low (Kuchi-buni, Saupe, Madna, Garui, Garu, Jimpe, Gidan gogo, Mpape, Gurushe, Katambe, Kubabo, Jiru, Kado, and Gwarimpa), medium (Maitama, Shere, Budupe, Pewi, Sagwari, Dushepe, Dushekoro, Jikoko, Mape, Jikakuchi, and Kadobunkuro) and high (Karsana, Jahi, Shishipe, Nukuchi, Duruni, Ushapa, and Kogi) risks of being flooded.

3.6 Multi-criteria Analysis for Flood Vulnerability Mapping

As with all weighted overlay for multi-criteria analysis, the generated map (factor) layers were reclassified in the ArcGIS environment and utilized in the production of flood vulnerability map of the study area using the analytic hierarchical process (AHP). The AHP was adopted to assign weights and rankings to the factors (criteria) utilized in the production of a vulnerability map for the study area. A pairwise comparison matrix was first generated as shown in Table 6 which was then normalized in Table 7 to obtain the overall results consisting of the weighted average.

Table 6: Criteria Pairwise Comparison Matrix

Criteria	Drainage	Slope	Elevation	LULC	Soil	**Sum**
Drainage	1	0.77	0.67	1.3	2	**5.74**
Slope	1.3	1	1.5	1.5	3	**8.3**
Elevation	1.5	0.67	1	3	3	**9.17**
LULC	0.77	0.67	0.33	1	1.5	**4.27**
Soil	0.5	0.33	0.33	0.67	1	**2.83**
Sum	**5.07**	**3.44**	**3.83**	**7.47**	**10.5**	

Each pair of factors (see Table 6) was compared to determine which factors had the most influence on flooding based on the criteria weights (W) presented in Table 7.

Table 7: Normalized Matrix

Criteria	Drainage	Slope	Elevation	LULC	Soil	**(W)**
Drainage	0.20	0.22	0.17	0.17	0.19	0.16
Slope	0.26	0.29	0.39	0.20	0.29	0.24
Elevation	0.30	0.19	0.26	0.40	0.29	0.24
LULC	0.15	0.19	0.09	0.13	0.14	0.12
Soil	0.10	0.10	0.09	0.09	0.10	0.08
Sum	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	

The criteria weights (W) were used to rank the flood factors identified within the study area as shown in Table 8.

Table 8: Ranking of Flooding Factors (modified after; Alonso and Lamata, 2006)

Factor	Ranking	Description
Soil	4	Least important factor
LULC	3	Moderate important factor
Drainage	2	High important factor
Slope	1	Most important factor
Elevation	1	Most important factor

Table 8 highlights the fact that slope and elevation were the most important factors responsible for flood followed by drainage. The least important factor was the soil of the area under study.

3.6.1 Consistency Checking

It is important that the degree of consistency be ascertained as a result of the ranking which is expected to accept a certain level of deviations (Zhang *et al*., 2014). This is achieved through the Consistency Ratio (CR). The CR meanwhile, allows some small inconsistency in judgement and has values that are equal to or less than 0.1 (that is, if $CR < 0.1$, the rankings are consistent; if $CR \geq 0.1$, the comparisons should be recalculated). The parameters used in checking for consistency are highlighted in Table 9.

Table 9: Consistency Checking

(1/W)	{Ws}	{consis}	CI	RI (n=5)	CR
6.25	0.92	5.74	**0.01**		
4.21	1.97	8.30		**1.12**	
4.17	2.20	9.17			**0.011533**
8.46	0.50	4.27			
12.89	0.22	2.83			
		λ = 5.05			

The following expressions represent the parameters presented in Table 9 (Alonso and Lamata, 2006):

Weight Sums Vector, $\{W_S\} = [C]\{W\}$ (1)

Consistency Vector, $\{consis\} = \{W_S\} \bullet \left\{\frac{1}{W}\right\}$ (2)

Consistency Index, $CI = \frac{(\lambda - n)}{(n-1)}$ (3)

Consistency Ratio, $CR = \frac{CI}{RI}$ (4)

Where $[C]$ is the criteria comparison matrix, $\{W\}$ is the criteria weights, λ is the average of the elements of $\{consis\}$, n is the number of criteria, and RI is the random index obtainable from the random index table based on the number of criteria (n). The result of CR was computed as 0.01 indicating that the rankings were consistent based on equations 1, 2, 3, and 4.

3.7 Flood Vulnerability Map

The flood vulnerability classes identified were low, medium and high as shown in Figure 5. It was observed that most of the settlements towards the east of the study area had low (29.57%) vulnerability, while most of the central and western parts had medium (64.02%) and High (6.41%) vulnerabilities, respectively.

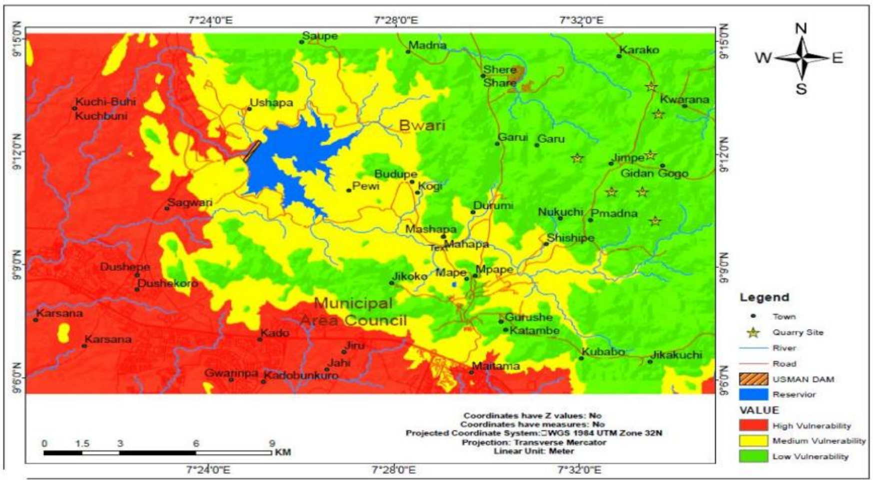

Figure 5: Flood vulnerability map

4. DISCUSSION

The multi-criteria analysis was utilized to identify and evaluate factors responsible for flood incidence in the surrounding flood-prone settlements of Usman dam in Abuja, Nigeria. The results revealed that among the five factors considered, slope and elevation as significant drivers of flood in the study area. The majority of the settlements surrounding the Usman dam lie on the low to medium elevation, and between the steep and extreme slopes, respectively. These two factors on their own could have triggered flooding and also increased the risk of erosion within the study area.

The proximity of settlement to drainage, LULC, and soil were other factors that contributed to flooding in the study area. In terms of proximity of the settlements to the river course analysis, however, the central part of the study area (especially settlements close to the reservoir) as well as other settlements close to the river course were at high risks of being flooded while other areas were at moderate and low risks of being flooded (see Figure 4). The basically poorly drained gleysol and lixisol soil surfaces in the study area support low infiltration capacity thus allowing water to gather in some areas to cause flooding. The results of the elevation, soil, and slope agree with Adedeji *et al.* (2012) and Azua *et al*. (2019), while the result of the proximity of settlements to river course agrees with Mayomi *et al*. (2013), who reported similar findings in Nigeria.

Figure 5 revealed that the study area was made up of settlements that were highly (6.41%), moderately (64.02%), and lowly (29.57%) vulnerable to flooding, respectively. The study region with low vulnerability was to the east. Additionally, most settlements in the central and western parts were moderately and highly vulnerable to flooding, respectively. The implication is that settlements close to the river course and reservoir were more likely to be vulnerable to flood.

5. CONCLUSIONS

The flood risk settlements surrounding the Usman dam in Abuja, Nigeria have been assessed using the multi-criteria analysis. The study results revealed that criteria weights slope (0.24) and elevation (0.24) were the most important factors contributing to flooding in the study area. Other ranking factors identified include drainage proximity (0.16), land use land cover (0.12) and soil (0.08) respectively. It was suggested based on the results of the study that settlements close to the river course and dam reservoir, and along the flood plains should be relocated to the low vulnerable areas (east of the study area) in order to limit the impact of future flood hazard.

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BIOGRAPHICAL NOTES

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Terwase Tosin Youngu, Ph.D., is a lecturer in the Department of Geomatics at the Ahmadu Bello University Zaria, Nigeria, where he specializes in Geo-positioning, Navigation and Geo-informatics. He has 16 years' experience in lecturing and as an analyst in the mapping of flood-prone areas, infrastructure and water utilities, groundwater prospecting sites, and farm information system for sustainable food security. Dr Youngu is a member of some professional bodies including the National Association of Geodesy (NAG), National Association of Surveying & Geoinformatics Lecturers (NASGL), Geoinformation Society of Nigeria (GEOSON), Environmental Information System – Africa (EIS-AFRICA), among others.

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