Geospatial Mapping and Multi-criteria Evaluation of Surrounding Flood Risk Communities of Usman Dam Abuja-Nigeria

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Abstract

There is concern of flood increase in recent decades due to its effect on human life and man's environment. This study thus mapped and analysed flood risk communities around the Usman dam in Abuja, Nigeria, using geospatial techniques. Spatial data were captured which included positional coordinates, Landsat enhanced thematic mapper (ETM), soil map, and shuttle radar topographic mission (SRTM). The factors of flooding and their effect on the area under study were identified. The results of the study revealed based on the criteria weights that, slope (0.24) and elevation (0.24) were the most important factors contributing to flooding in the study area followed by drainage proximity (0.16), land use land cover (LULC)(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 the 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 (eastern parts of the study area) in order to prevent future flood hazard.

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

INTRODUCTION

The overflowing of water onto land that is normally dry (NOAA, 2019), has adversely affected the environment in recent times. Floods can happen during heavy rains, when ocean waves come onshore, when snow melts too fast, or when dams or levees break. Flooding may happen with only a few inches of water, or it may cover a house to the rooftop. Floods can occur quickly or over a long period and may last days, weeks, or longer (Odufuwa *et al*., 2012). Floods are the most common and widespread of all weather-related natural disasters.

Increased population, climate variability, change in the catchment and channel management, modified land use and land cover, and natural change of floodplains and river channels all lead to changes in flood dynamics with direct or indirect consequence on the social welfare of humans (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 often contain permanent water bodies (lakes and channels) as well as permanent or seasonal wetlands, and these are the dominant inland waters in many regions of the world.

In Nigeria, most floods occur because of excessive rainfall leading to dams opening their spillway and dam failures. It has been estimated that more than 700,000 hectares of useful land for agricultural and human settlements are rendered useless due to annual floods (Jeb and Aggarwal, 2008).

Greentumble (2019) stated that the damming of rivers the world over is noted for economic advantages which among others are the provision of water for vast expanse of irrigable land, provision of jobs to both trained personnel and artisans alike and availability of stable water for consumption. However, there are several risks associated with the construction of dams over large water bodies. For example, the flooding of areas downstream of an embankment when the dam reservoir is filled up would necessitate the discharge of excess water to avoid dam collapse.

The flooding of communities has become a perennial problem (Kolawole *et al*., 2011) with its attendant effects on the livelihood of the inhabitants. 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), examined the magnitude, intensity and duration of floods in Bangladesh. The study revealed increase in flood incidences in the preceding few decades in the study area with flood control embankments being ineffective in reducing the damage to the environment, economy and property. Thereafter, Jansen *et al*. (2013), examined the Ringlet hydropower reservoir in Cameron Highlands, Malaysia for flood control. The study revealed from the topographic survey that the downstream river was not capable of containing the flood release from the reservoir due to the encroachment by settlers in the river reserves. Suggestions were however made for good flood management practices to mitigate the risk of flooding in both studies.

Ojigi *et al*. (2013) mapped the spatial distribution of flood disaster in the central parts of Nigeria. The study revealed that rivers Benue and Niger overflowed their banks inundating farmlands and settlements along the flood plains. The study suggested that proper planning, awareness, and enlightenment be carried out of flood prone communities. Azua *et al*. (2019), furthermore mapped flood vulnerable areas in Fagge local government area of Kano state, Nigeria using spatial multi-criteria analysis and the study identified the causative factors of flood in the study area with elevation having the most effect and rainfall the least effect. The results of the study also showed that areas in the eastern parts were extremely vulnerable to flood compared to the north-western and southern parts that were the least vulnerable. The study however suggested for the adoption of proper land use practices to mitigate flooding in the area.

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 the Federal Capital Territory (FCT), Abuja Nigeria with a view to mitigating the effects of flood. This is achieved through the identification of the factors of flood and their characteristics in the study area, and the generation of a flood vulnerability map of the study area using multi-criteria analysis.

Study Area

The study area 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 (Adakayi, 2000). However, the area under study is about 4401.7 km^2. According to Mabogunje (1976), the study area is considered the most ideal and conducive for human habitation and settlement development within the FCT. The area is characterized by a hilly, dissected terrain and is the highest part of the FCT with several peaks that are 760 m above sea level (Balogun, 2001).

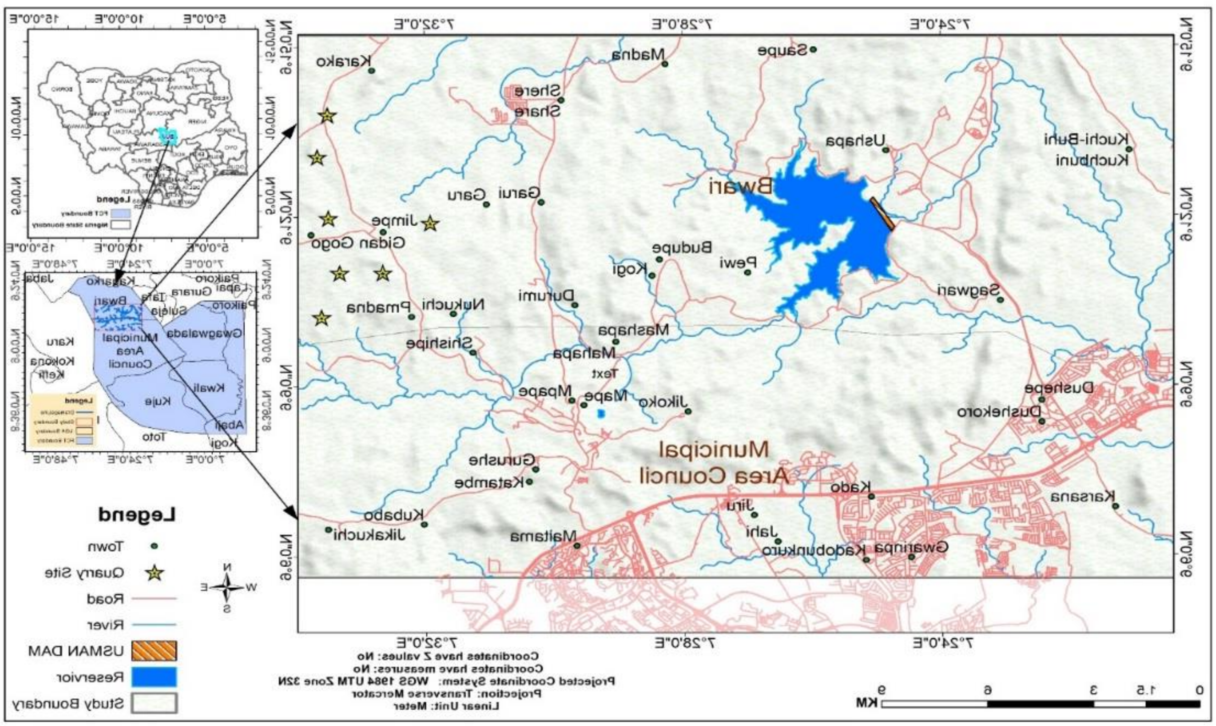

Figure 1: Study Area. Top and bottom right: map of Nigeria showing the FCT; Left: map of the study area.

The geology of the area is underlain by basement complex rocks. The annual mean temperature ranges between 25.8 and 30.2°C (Adakayi, 2000; Balogun, 2001). The soils of the study area are basically alluvial and luvisol. The climate is tropical with distinct wet and dry seasons and with annual maximum rainfall varying between 1100mm and 1600mm, while the annual minimum rainfall range from 400mm to 700mm. The geology is typically and essentially the basement complex with prominent outcrops composing mainly of granite (Adakayi, 2000).

The topography is highly undulating with isolated hills of over 600m are common while valleys can be as low as 400m. The hills are made up of granite rocks and the lower terrain is dominated by schist and gneiss. 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).

METHODS

Flooding incidents have been based on various factors or criteria which include rainfall, land use and land cover, soil type, slope, elevation, drainage (Azua *et al*., 2019) as well as unplanned urbanization, soil erosion, local relative sea-level rise, inadequate sediment accumulation, subsidence and compaction of land, riverbed aggradation and deforestation (Khalequzzaman, 2011). However, the first five of these factors apart from rainfall are adopted in this study based on the availability of data. It means therefore that, these factors must be taken into consideration when addressing the problem of flood. Figure 2 depicts the workflow diagram adopted in this study.

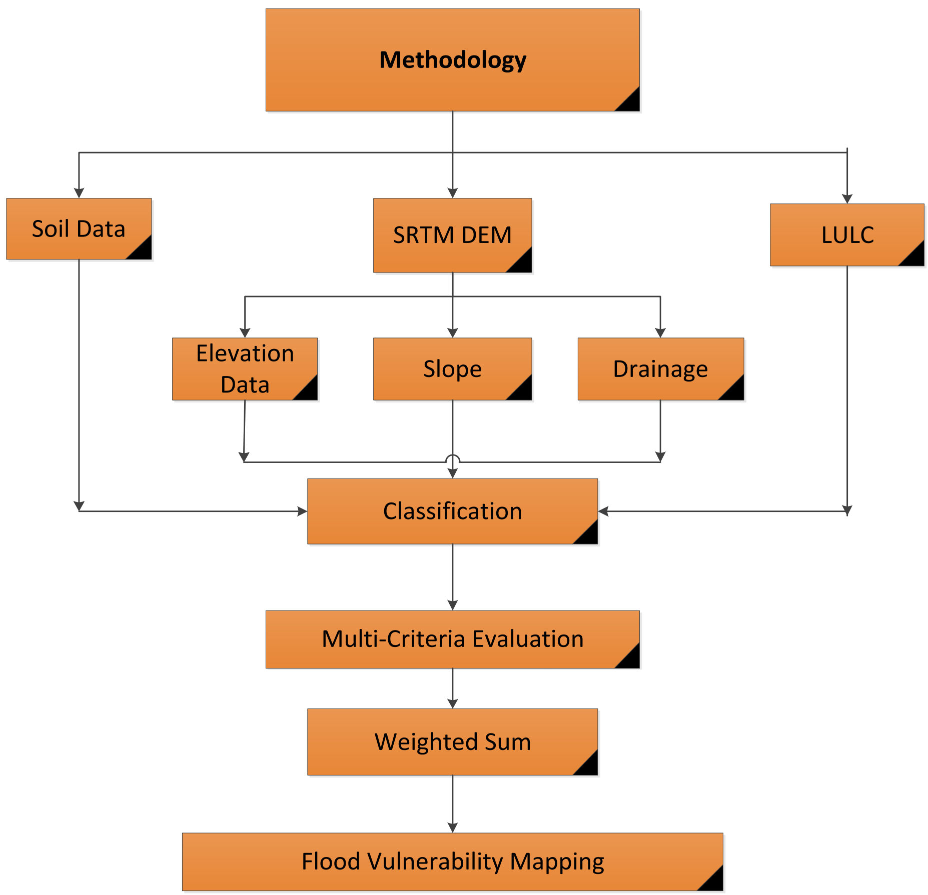

Figure 2: Workflow Diagram (modified after; Azua *et al*., 2019)

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

Data Processing

The Landsat Enhanced Thematic Mapper (ETM+) image of the study area was clipped and enhanced. 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. The accuracy assessment was carried out to ensure a high-quality classification result.

The Digital Elevation Model (DEM) data was generated from the Shuttle Radar Topographic Mission (SRTM) of the study area and then used 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.

Multi-Criteria Analysis (MCA)

Five contributing factors including 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 (Yahaya, 2008) and the availability of data for the study area as highlighted earlier. The factors were created as layers and introduced in the weighted overlay model in order to identify areas susceptible to flood in the study area. The spatial data contained in each layer was ranked based on its susceptibility 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.

RESULTS

Land Use and Land Cover (LULC)

Land cover data documents show how much of a region is covered by forests, wetlands, impervious surfaces, agriculture, and other land and water types. Water types include wetlands or open water. Land use shows how people use the landscape – whether for development, conservation, or mixed uses. 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. In flat basins large dams cause flooding of large tracts of land (that is, around 400,000 km^2 of land worldwide has been submerged due to the construction of dams), destroying local animals and habitats. People downstream have been displaced causing a change in lifestyle (Sanguri, 2019).

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 were farmland and built-up with values of 306.9 km^2 (6.97%) and 278.0 km^2 (6.32%), respectively. The classified results of land use and land cover are shown in Figure 3.

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. Water body 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.

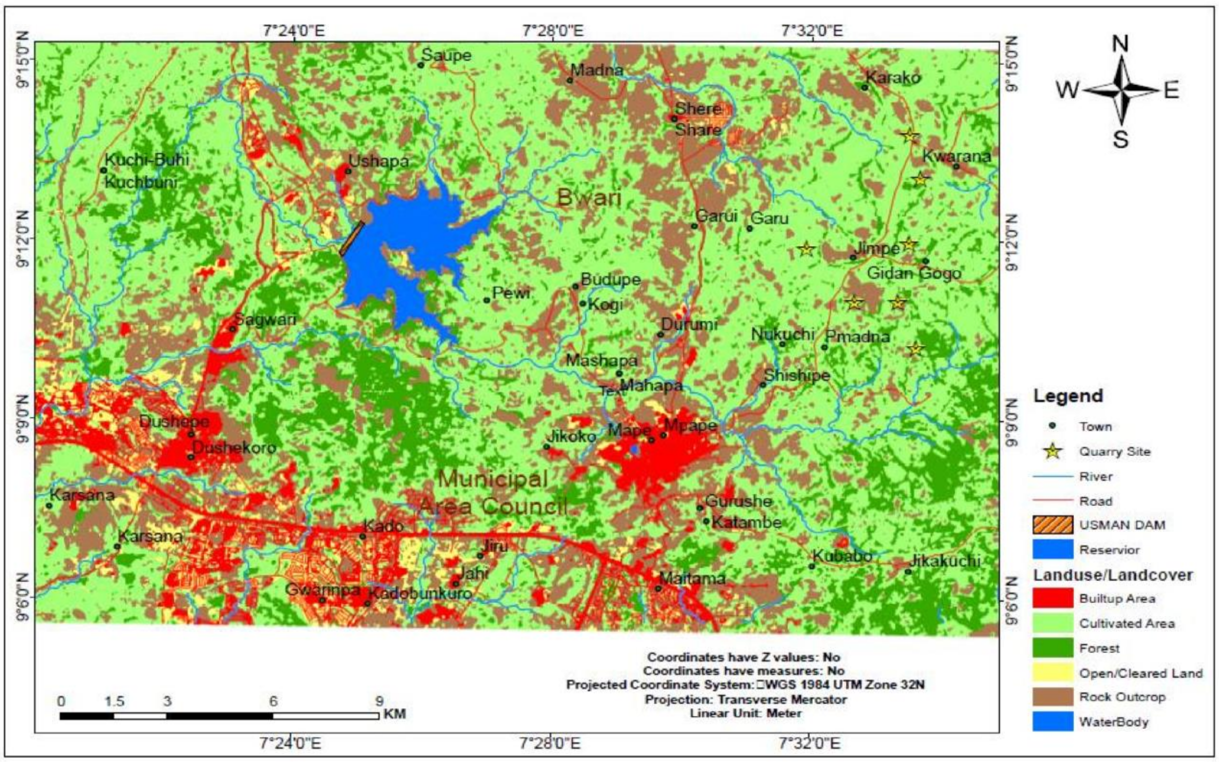

Figure 3: Land Use and Land Cover map of the study area

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

Class	Index Value	Description
Water body	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

Soil

Soil types contribute to flooding by determining the amount of infiltration as well as the surface flow in an area (Nicholls and Wong, 1990). Figure 4 depicts the soil types found in the study area.

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 is low. They were small and high contributors respectively to flooding as shown in Table 3.

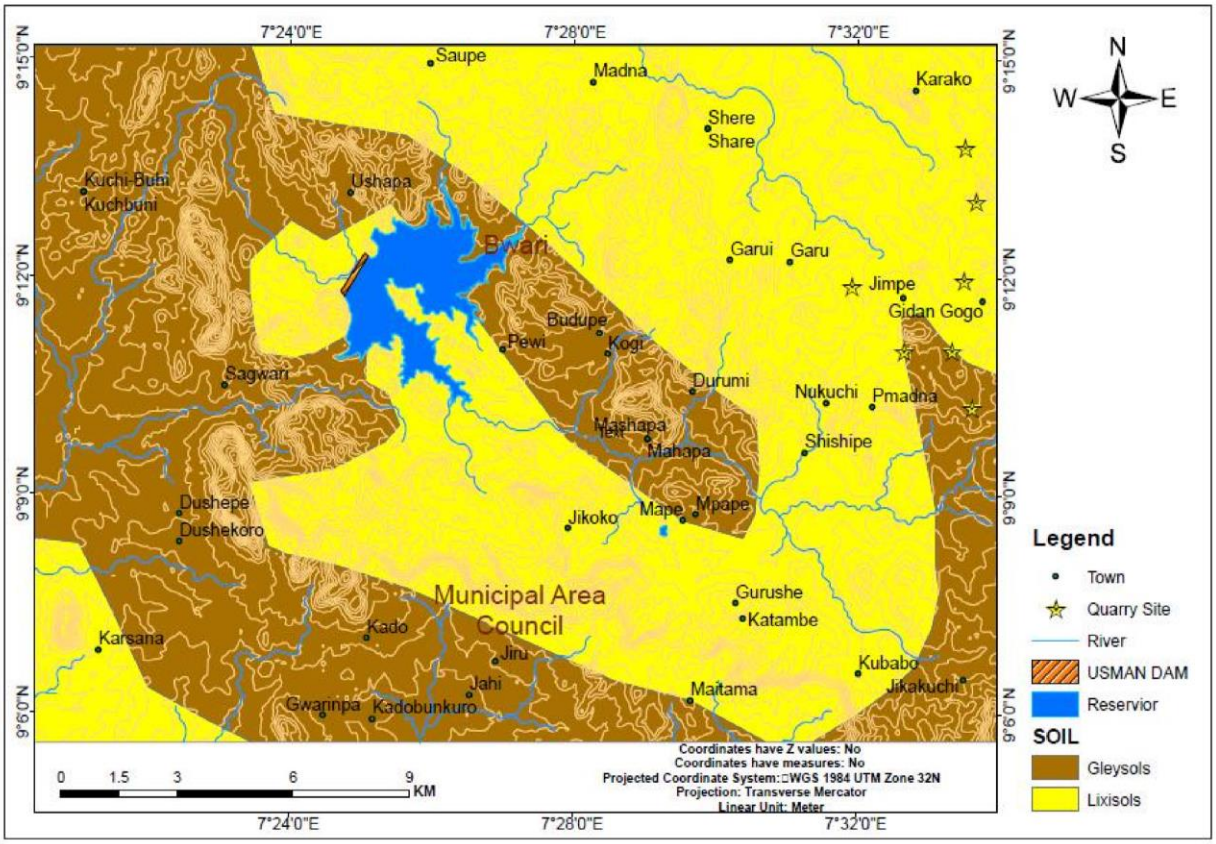

Figure 4: Soil map of the study area

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

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 elevation of the study area was generated using the DEM data as shown in Figure 5. The height values ranged from 394 to 874m as depicted in the variation of colours. Based on this result, 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).

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

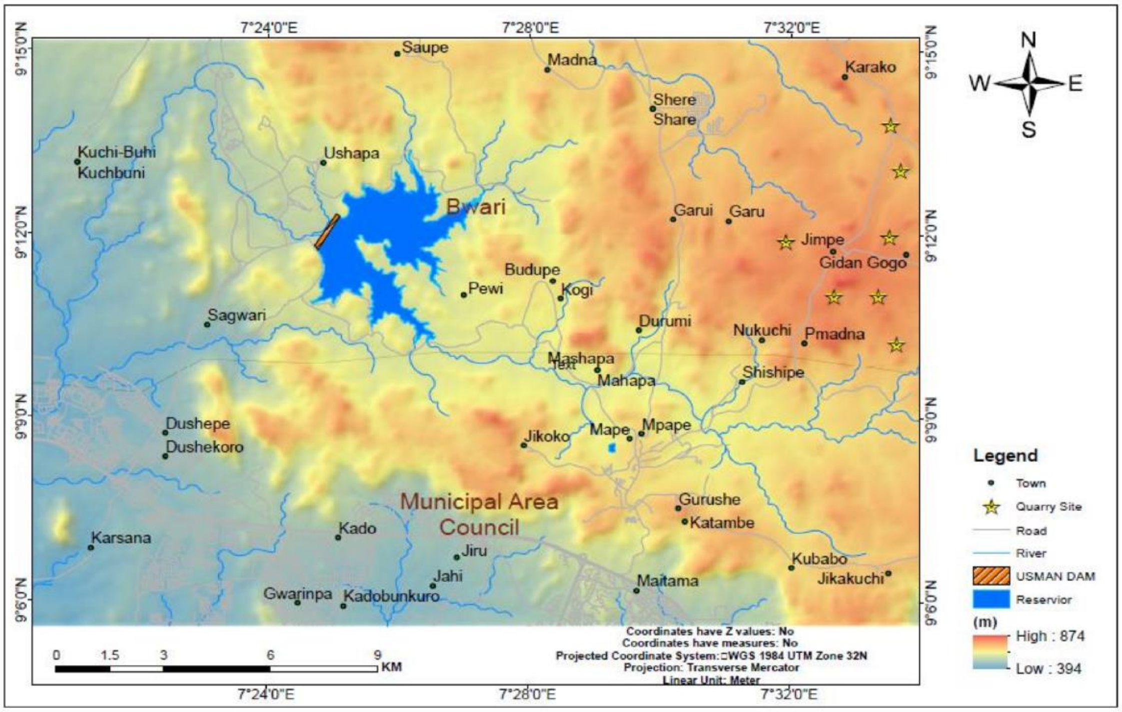

Figure 5: DEM of the study area

Slope

According to Andongma *et al.* (2017), a slope is an important element that contributes to flood 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 flood. The slope map was generated using SRTM data in the ArcHydro environment of ArcGIS 10.5 software (see Figure 6).

The slope was categorized into five classes; flat, gentle, moderate, high, and very high slopes. The slope map shows the steepness of the slopes irrespective of the direction of the slope. A greater portion of the settlements has high and very high slopes thus causing the flooding of the communities surrounding the reservoir. The slope was indexed between 0.2 and 1.0 for flat, gentle, moderate, high, and very high 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
Moderate (14 – 24%)	0.4-0.6	Moderate contributor to flood
High (25 – 39%)	0.6-0.8	High contributor to flood
Very High (40 – 115%)	0.8-1	Very high contributor to flood

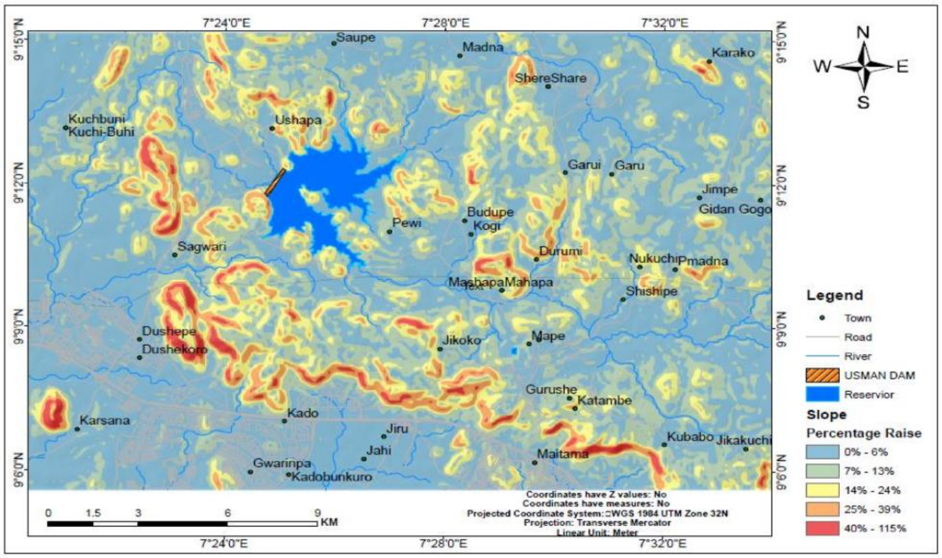

Figure 6: Slope map of the study area

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. Moreover, there can be a higher risk of flooding where settlements are near dams, reservoirs, and wetlands, which can be capitalized into house prices and lead to lower property values (Cohen *et al*., 2019). Mayomi *et al*. (2013), applied the 3km buffering to determine communities vulnerable to flooding based on the principle of proximity to river course. In this study, however, the buffer tool was used at the 500m, 1000m, and 1500m extents respectively based on (Atreya and Czajkowski, 2016; Koning *et al*., 2019) where the relationship between distance of settlement to water body and flood risk account for the housing sales prices as well as risk-based flood insurance premiums. Figure 7 shows the buffering carried out for the study area.

The settlements in the study area that appear to be at low risk of being flooded based on the results of the buffering operations include Kuchi-buni, Saupe, Madna, Garui, Garu, Jimpe, Gidan gogo, Mpape, Gurushe, Katambe, Kubabo, Jiru, Kado, and Gwarimpa respectively.

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.

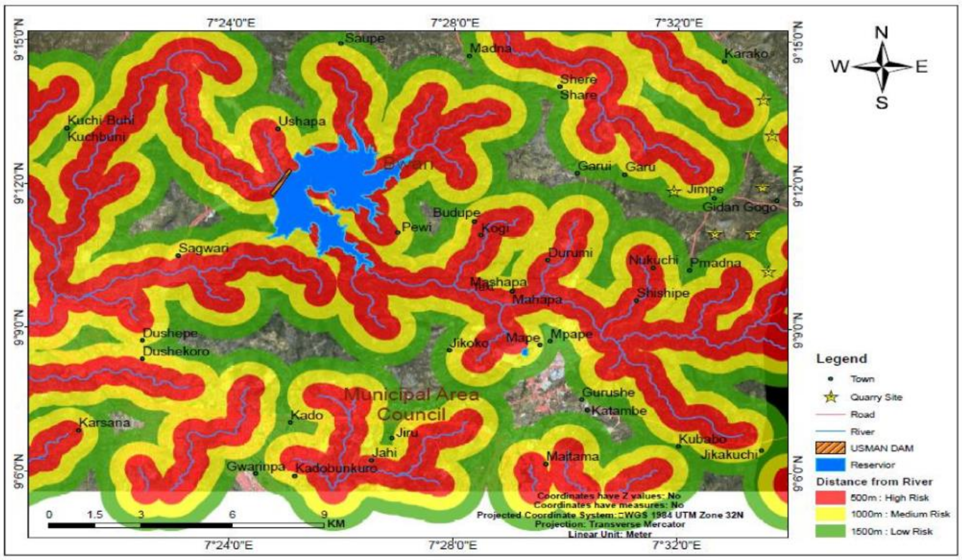

Figure 7: Drainage proximity map of the study area

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 factors responsible for flooding in 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.

Checking for Consistency

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 ≥ 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.

Flood Vulnerability Map

The flood vulnerability classes identified were low, medium and high as shown in Figure 8. It was observed that most of the settlements in the eastern part 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.

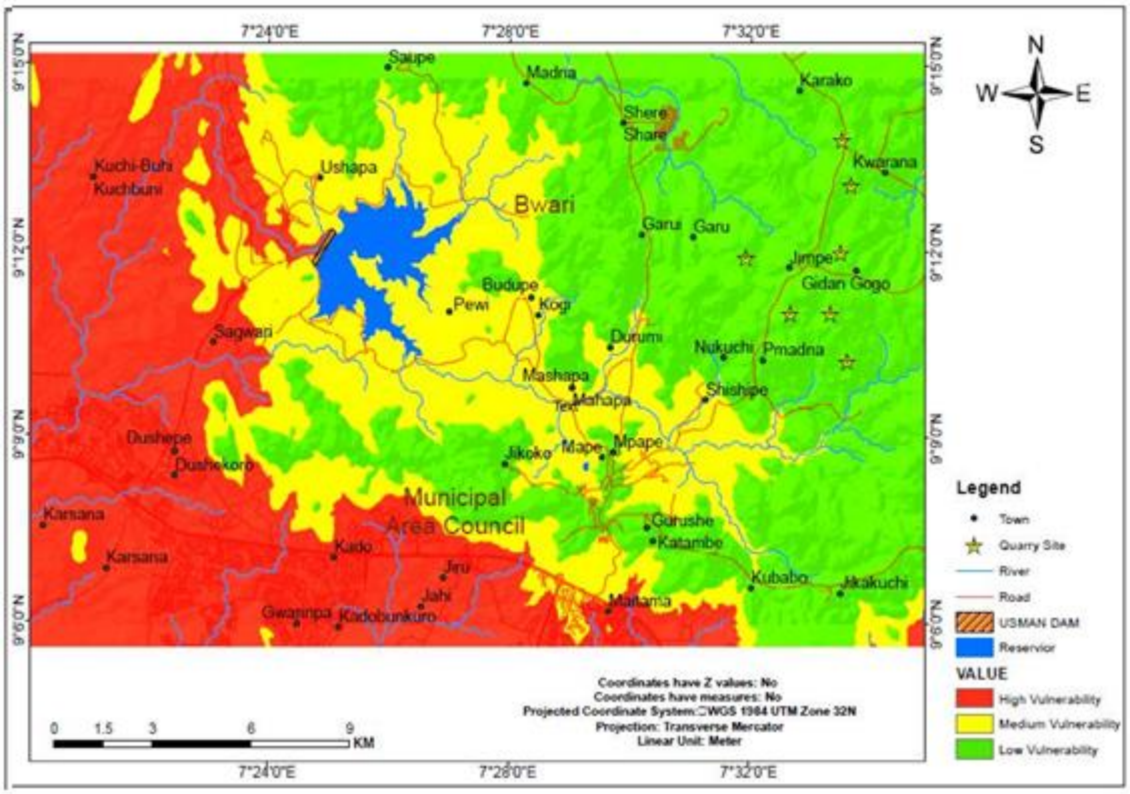

Figure 8: Flood vulnerability map of the study area

DISCUSSION

This study has revealed that among the five factors considered in the study area, slope and elevation were the most important factors of flood in the area under study (see Table 8). The majority of the settlements surrounding the Usman dam lie on the low to medium elevation and between the high and very high slopes, respectively (see Figures 5 and 6).

The proximity of settlement to drainage, LULC, and soil were other factors that contributed to flooding in the study area. Settlements close to the reservoir as well as river course were at high risks of being flooded (see Figure 7). This agrees with Mayomi *et al*. (2013), who reported similar findings in Nigeria. The soil is basically poorly drained gleysol and lixisol as highlighted in Figure 4. This helps to 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 the findings by Adedeji *et al.* (2012) and Azua *et al*. (2019), respectively.

The study shows that most settlements in the eastern parts of the study area were at low (29.57%) vulnerability to flooding. Meanwhile, most settlements in the central and western parts were moderately (64.02%) and highly (6.41%) vulnerable to flooding, respectively (see Figure 8). The implication is that settlements close to the river course and reservoir were more likely to be vulnerable to flooding with the intensity decreasing towards the eastern parts of the study area.

CONCLUSIONS

The flood risk settlements surrounding the Usman dam in Abuja, Nigeria have been assessed using the multi-criteria analysis. The results revealed based on the criteria weights that, slope (0.24) and elevation (0.24) were the most important factors contributing to flood in the study area. These were followed by drainage proximity (0.16), LULC (0.12), and soil (0.08), respectively. The results also showed that settlements in the eastern parts of the study area were the least vulnerable to flood while settlements especially close to the river course and dam reservoir in the central and western parts of the study area were more vulnerable to flood incidences.

In view of the findings of this study, it is suggested that settlements close to the river course and dam reservoir, and along the flood plains should be relocated to the low vulnerable areas (eastern parts of the study area) in order to forestall any future flood hazard.

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