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Flood Vulnerability Assessment of a Semi-Arid Region: A Case Study of Dutse in Jigawa State, Nigeria

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Abstract

Floods occur as a consequence of overflowing water over a large area of land that is which is beyond the soils ability to absorbed the water at the receiving rate. In this study, rainfall, slope, soil type, land cover, and drainage network were analyzed as causative factors of flooding. Furthermore, Landsat satellite images was used to assess land use and land cover (LULC). Flood vulnerable areas are were analyzed using the multicriteria evaluation process (MCE). A flood vulnerable areas map was generated after overlaying the maps of the major parameters responsible for flooding in GIS environment. The results show that the vulnerable areas are not confined in one area alone, however, the southmost part, the upper north and some part of the central accounting for about 25% are very vulnerable and high to flooding thanks to accumulations of multiple factors. Similarly, the result indicated that 53 %, 19% and 3% of the area were characterized as moderate, low and very vulnerable areas respectively. This research will help environmental managers and policy makers toward sustainable management of flooding affecting the area. This work will assist policy makers and environmental managers in identifying the major areas that are more at risk of flooding, thus, the little available resources can be allocated to these areas for better management practices and sustainable development.

1. Introduction

Among all-natural disasters, flood is considered as most dangerous natural tragedies associated with wider geographical areas, responsible for damaging infrastructure, properties, causing people's displacement and even loss of human lives and ecosystem in many parts of the world (Dano, et al., 2019; Pal & Singha, 2022). Flood is a natural and persistent overflow of voluminous amount water which happens due to heavy rainfall beyond the absorption capacity of the geographical area and its features (Swain, Singha, & Nayak, 2020). Research has shown that, more than one-third of the world's land area is susceptible to flooding, thus affecting nearly 82% of the world's population (Dilley, 2005).

In the last thirty years, the many countries in the world were significantly experienced upsurge in loss of lives and properties due to flooding events (Osei, Ahenkorah, Ewusi, & Fiadonu, 2021). It has been established that, worldwide over $40 billion losses were documented during 1998 and 2010 while about 178 million people were affected by flooding in 2010 alone (Leskens, Brugnach, Hoekstra, & Schuurmans, 2014). This is even more severe in developing countries due to their lack of standard infrastructure, ill equipped and limited financial and technical resources to handled such devastating events (Echendu, 2020). In sub-Saharan region of West Africa, rainfall variability is believed to be responsible for the region's frequent vulnerability to floods and droughts (Asare-Kyei, Forkuor, & '', 2015). This region has experienced tremendous increase in flood events particularly in the last three decades, causing catastrophic impacts in human lives, and environmental consequences such as loss in biodiversity among others (Braman, et al., 2013). The west African region is believed the have experienced an increased in runoff believed to had been caused by the land clearing mostly for agricultural activities and other land use changes which has been taking places since the past four decades (Mahé, et al., 2013; Nka, Oudin, Karambiri, Paturel, & ", 2015). This is mostly attributable to increase in population which aggravates even more pressure in food demand and development of newer settlements (Marchant, et al., 2018; Maja & Ayano, 2021).

Many states in Nigeria are increasingly being affected by flooding which is the most common disaster in the whole country annually during the rainy seasons attributable to precipitation increased associated to climate change (Echendu, 2020).Most flooding events in Nigeria are originated from intensive and prolong rainfall, catastrophic damages of infrastructure (such as dam failure) and blockages along the drainage systems (Jeb & Aggarwal, 2008). For example, in 2008, Makurdi received a devastating rainfall that led to loss of many lives and properties and rendered many people homeless, (Mmom & Ayakpo, 2014). Similarly, the year 2012 was considered one of the worst flooded years in Nigeria (Nkeki, Henah, & Ojeh, 2013) affecting 33 state which led to death of 363 people and the displacement of more than 2.3 million people (Adekola & Lamond, 2018) as well as directly affecting the livelihood of 16 million people with economical loss of over US$16.9 billion (Adekola & Lamond, 2018; Echendu, 2020). Some of the worst affected States include Kano and Jigawa in the northwestern part of the country, Bauchi and Adamawa in the northeast, Niger, Kogi and Benue in the northcentral and many others in the southern parts of Nigeria (Mmom & Ayakpo, 2014). This necessitates the need for more research to come up with management strategies for sustainable development.

Researchers all over the world employed Geographic information systems (GIS) to develop flood vulnerability (Jeb & Aggarwal, 2008; Kourgialas & Karatzas, 2011; Mmom & Ayakpo, 2014; Asare-Kyei, Forkuor, & ", 2015; Khosravi, Nohani, Maroufinia, & Pourghasemi, 2016; Osei, Ahenkorah, Ewusi, & Fiadonu, 2021). This is because GIS have the ability to manipulate, analyse, store, complex sets of data especially for environmental related studies. Moreover, GIS is a very suitable tool studies that involves the multi-dimensional phenomenon like such as flooding (ShafapourTehrany, Pradhan, Mansor, & Ahmad, 2015). With the current environmental challenge of climate change, its believed that intensity in flood intensity and frequency will continue to affect the lives of many people in the possible future (Echendu, 2020). This study therefore examined GIS as a useful and important technique to predict flood vulnerable areas in Dutse Local Government Area (LGA) of Jigawa state.

2. Materials and Methods

2.1 Study area

Dutse the capital of Jigawa State (Figure 1) is situated at lat.11 42’ 04” and 9 20’ 31” E. with an estimated population of about 431,800 according to national population commission (Gazetter., 2006). The Geology of Dutse has a rocky topography that is generally noticeable across the city. The climate of Dutse is semi-arid type defined by a long dry season of mostly eight months. The raining season falls between the months of June to September with an annual rainfall of 900 to 1000 mm (Barau, 2015) and 80% of this is received between July to September (Buba, 2000).

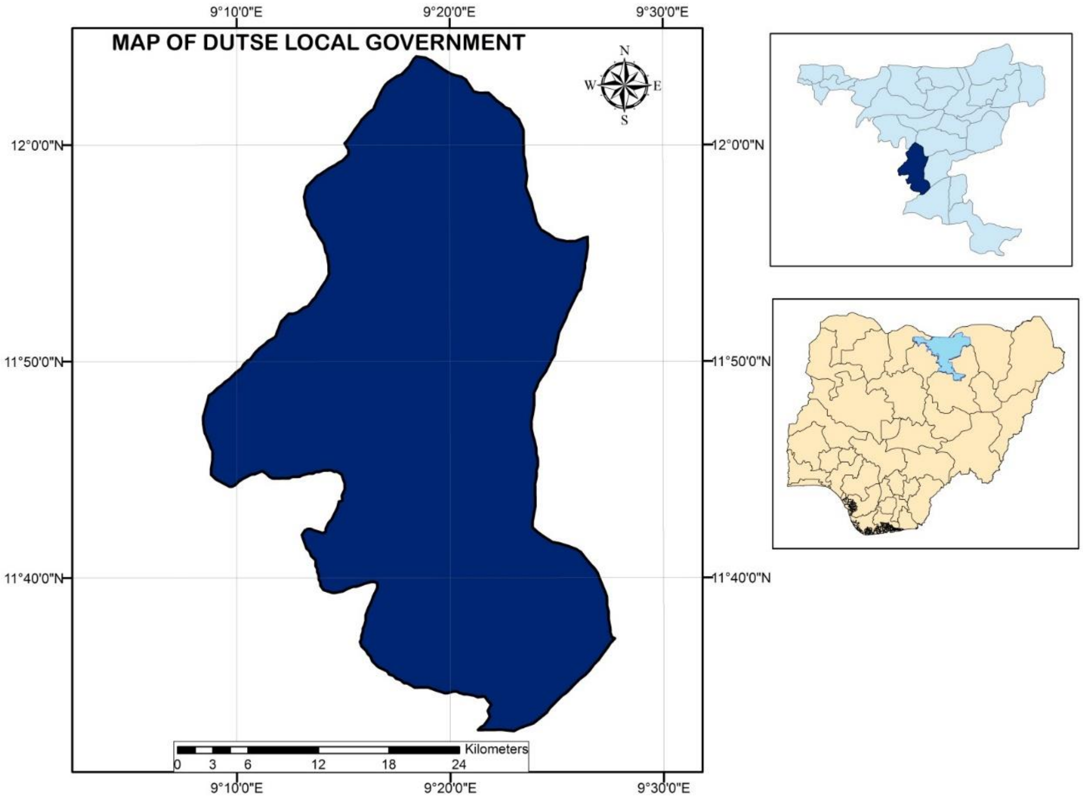

Figure 1: Map of the study area, Dutse/ Jigawa state and Nigeria

2.2 Data set and approaches

The data set consist of satellite imagery of 2020 Landsat satellite (Landsat 8) and Digital Elevation Model (DEM) data acquired from the United States Geological Survey (USGS) database at (http://earthexplorer.usgs.gov/). These data sets were used to produced Land-use map of Dutse, Slope map (DEM), Elevation map and Drainage network map. Other data used in the research is Soil map, and all were analyzed in the GIS environment and overlayed to produced vulnerability map of the area (Dano, et al., 2019).

2.3 Flood model

The multicriteria decision method MCD utilized in this study to determine the areas that are more vulnerable to flooding based on pre-allotted rating and weighted to the model parameters subject to the state and nature of each parameter (Table 1) (Kourgialas & Karatzas, 2011). The rating ranges from 1 to 10 reflecting lesser potential effect to higher potential effects respectively (Shaban, Khawlie, & Abdallah, 2006). The weight values ranging from 1 to 5 will then be assigned to the rated parameters pending on the significance of each individual parameter in its impact or contribution to flooding (Khosravi, Nohani, Maroufinia, & Pourghasemi, 2016). After that each factor was multiplied by its percentage weight (Gemitzi, Petalas, Tzihrintzis, & Pisinaras, 2006):

$$\mathrm{S} = \sum \mathrm{W}_i * \mathrm{X}_i \; \ldots\ldots\ldots\ldots \; (1)$$

where *S* is the final map of hazardous areas, *wi* is the weight of factor *i* (percentage) and *xi* is the rate of the factor *i*. The resulting maps from the five MCD index parameters were then overlaid in a GIS environment to create the final vulnerability map following (equation 1).

2.4 Parameters

2.4.1 Elevation: Another important factor that influenced flooding is the elevation. Lower altitude are more prone to flooding as compared to higher altitude. This is due to gravitation; flow accumulation and naturally water runoff from high areas to low areas. Thus, flat areas at low altitudes are more likely to flood rapidly than areas at higher altitudes with sharper slopes (Dano, et al., 2019).

2.4.2 Slope: The slope is an important parameter in flood analysis as it helps to dictate which direction the water flows and which area the runoff stagnates. The tendency of flooding increases with the decrease in slope steepness (Cabrera & Lee, 2019).

2.4.3 Soil: Soil type is a significant factor in defining the water holding and infiltration capacity of a given area and therefore affects flood vulnerability (Ali, et al., 2020). Soils that are porous in nature such as sandy soil are have higher infiltration capacity compared to soils that are characterized with low porosity such as clay soil. This is because the earlier allow the water to pass through easily while the latter retain the water (Slater, 2007), thus creating stagnation and then flooding (Ibrahim, et al., 2018).

2.4.4 Land-Use: the changes in land use is a very vital parameter when it comes to flooding, this is due to the fact that different land use entails how much water stays or flow through an area (Hussein, Alkaabi, Ghebreyesus, Liaqat, & Sharif, 2020). For example, forested areas with many trees are known to be less susceptible to flooding because first, the trees serve as protective cover, the roots also penetrate the soils thereby allowing water to infiltrate easily while bare lands have no protective cover and no infiltration ability, such areas tend to be compacted and can create runoff so easily (Dammalage & Jayasinghe., 2019). The case is similar with built-up areas, since cements and roofing prevented the water to infiltrate the soils, then it will accumulate and if there is no good sizeable drainage system that can accommodate such water, it can easily become flood (Emam, Mishr, Kumar, Masago, & Fukushi, 2016).

2.4.5 Drainage system and buffering: The fact that all water collected at a given watershed would eventually find its way to a river, stream or any drainage network, means that areas closer to such features are more susceptible to flooding since if the water overflow the drainages. the nearest niobous are the most likely alternative areas the water will flow through. Therefore, the closer an area is to drainage network the higher the tendency of it being affected by flooding and the further away it is from the drainages, the less likely it is to flood (Cabrera & Lee, 2019).

It's worth mentioning that, rainfall is also a very important parameter in flood study (Arnell & Gosling, 2016; Dano, et al., 2019) but this area receives more or less same amount of rainfall due to its limited size, as such it will not make an impact in this study.

Table 1 Cataloging: standardization based on ratting and weighting of the factors affecting flood (modified from (Kourgialas & Karatzas, 2011)

Model parameters	**Range**	**Rating**	**Weight**
Elevation (m)			5
	550	3	
	500	4	
	450	6	
	400	8	
	370	10	
Slope			4
	20–100	1	
	15–20	3	
	10–15	4	
	5–10	7	
	0–5	10	
Soil media			3

	Sand	3	
	Sandy Loam	5	
	Loamy sand	7	
Land use			5
	Vegetation	2	
	Rock	4	
	Bare land	5	
	Buildup area	7	
	Water bodies	10	
River (buffers) (m)			5
	1500	2	
	750	4	
	500	8	
	250	10	

3. Results And Discussions

The elevations result of Dutse (Figure 2) shows that only less than 7% of the area is between 450 to 500 altitude which is the highest elevation in the area and thus the list expected to be affected by flooding (Ali, et al., 2020). While 52% of the area is within the altitudes of 400 to 450 meters above sea level, mostly in the central to southern part of the area. The result also indicated that 41% mostly northern and south-south part of the area falls within 370-to-400-meter altitude. These areas are the likely to be affected based on altitude as it’s the lowest part of the study area. Thus, when runoff accumulates, this is the area it will all flow to thereby putting it more at risk to flooding (Cabrera & Lee, 2019).

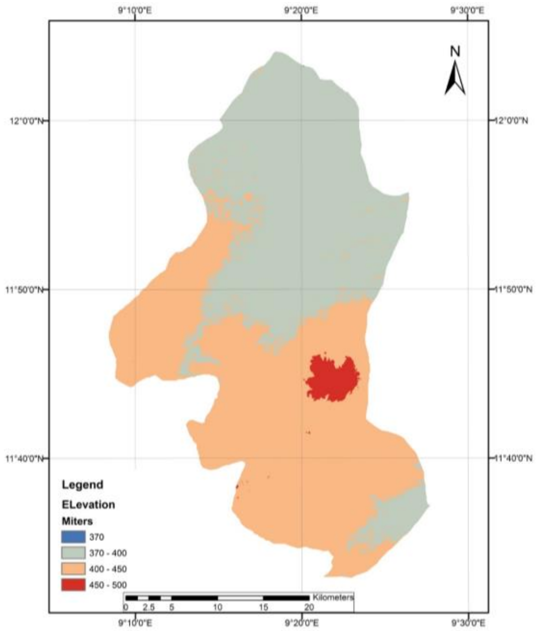

Figure 2: Elevation map of the study area.

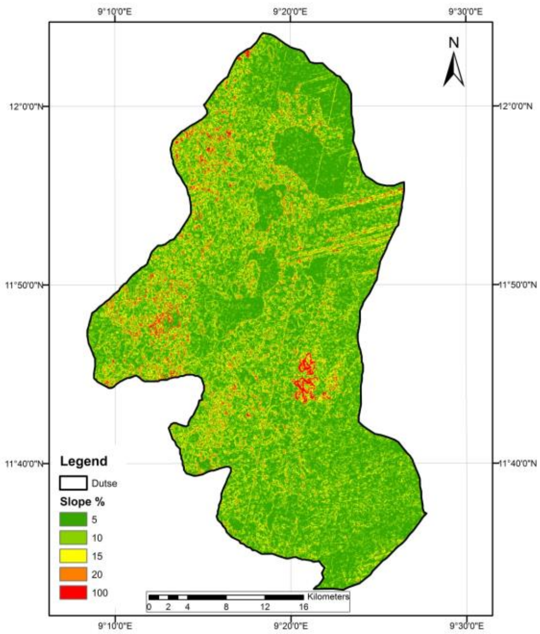

Figure 3: Slope map of the study area. Source (Geographic Information System) DEM amp of Nigeria

Slope help to dictate directions which the water flows and volume of water to be retain by area (Dano, et al., 2019). The slope map (Figure 3) shows that about 49% of Dutse is more susceptible to flooding because it falls within the flattest part of Dutse 5 to 10 % slope making more likely retain water (Khosravi, Nohani, Maroufinia, & Pourghasemi, 2016) spatially distributed all over the area, this is then followed by 10 to 15% slope which covers 35% of the area. The remaining area most fall above

15 % are less likely to be flooded due to slopy nature of such area (ShafapourTehrany, Pradhan, Mansor, & Ahmad, 2015).

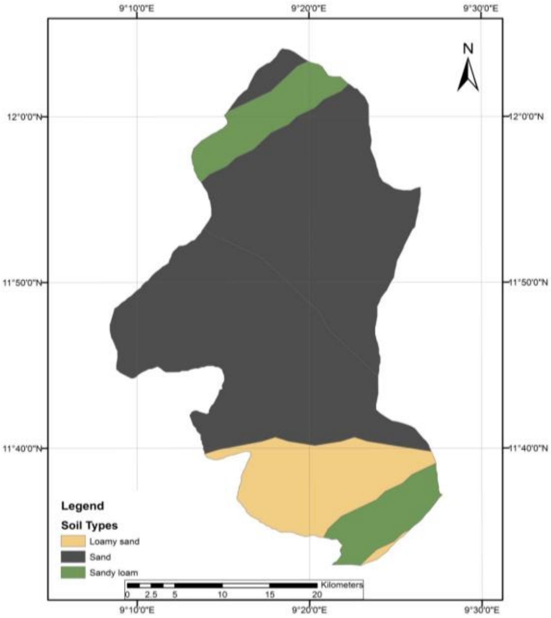

Figure 4: Soil Type map of the study area. Source (Geographic Information System) topographic soil data map of Nigeria.

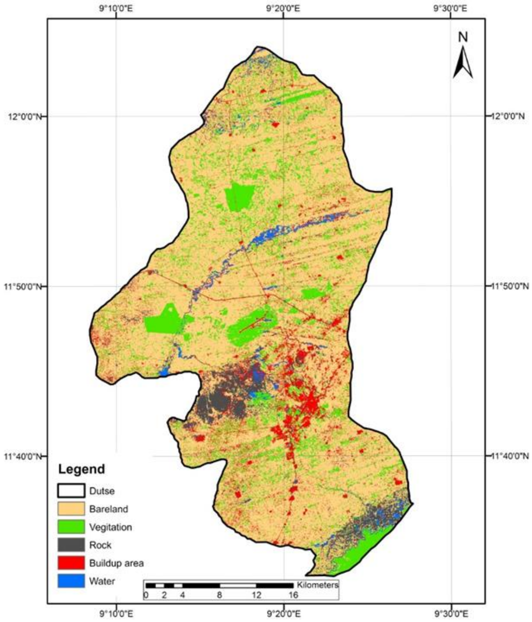

Figure 5: Land use land cover map for the year 2020

The soil map (Figure 4) shows that nearly 74% of the area is covered by sand, this soil is known to have very high hydraulic conductivity, 45 m/day, meaning water pass through it easily, thus such area is less susceptible to flooding based on soil parameters (Ernst, 2000). The two other soil types are loamy sand and Sandy loam covering 14% and 12 % respectively. Compared to sandy soils, slower infiltration capacity, hence are more likely to retain water which eventually could lead to flooding (Anderson & Woessner, 2002).

From the maximum likelihood supervised classification made in this research the land use land cover change classified into five factors (Figure 5), which water was 1.7 %. This is always the first land use to be overwhelmed runoff since its usually the lowest part and the receiving end of all runoffs (Braman, et al., 2013). The built-up area covers 8.4 %, this is also susceptible to flooding due to quite number of reasons, such as poor infrastructural plan and development (Barau, 2015), blockage of drainage networks, and the fact that roofing and cemented areas prevent water from infiltrating to the ground among others (Echendu, 2020). The bare land class of land use accounts for 68.3 % of the total area. The fact that this area has no protective cover , makes it at risk of not only flooding but also other environmental problems like land degradation , drought (Buba, 2000), soil erosion and so on (Adeoye, Ayanlade, & Babatimehin, 2009; Braman, et al., 2013; Hussein, Alkaabi, Ghebreyesus, Liaqat, & Sharif, 2020). The vegetation area accounts for 16.70 % of the total land, which is less vulnerable to flooding. This is because plant roots help in creating more infiltration ability of a soil thereby weakening the tendency of flooding (Arnell & Gosling, 2016; Cabrera & Lee, 2019).while rocks account for 4.7% of the land cover mostly hilly and therefore not vulnerable to flooding.

The drainage system of Dutse is densely and spatially distributed all over, however some areas are more likely to be affected by flood than others. For example, area closer to major river network like the southmost and central parts the area (Figure 6) are highly likely to be affected by flooding, and the closer the area to such the more likely it will be affected than those further away from the major drainage networks (Dano, et al., 2019). Meaning areas that falls within 250 m from the drainage network are more susceptible to flooding that those at 500m away (Emam, Mishr, Kumar, Masago, & Fukushi, 2016).

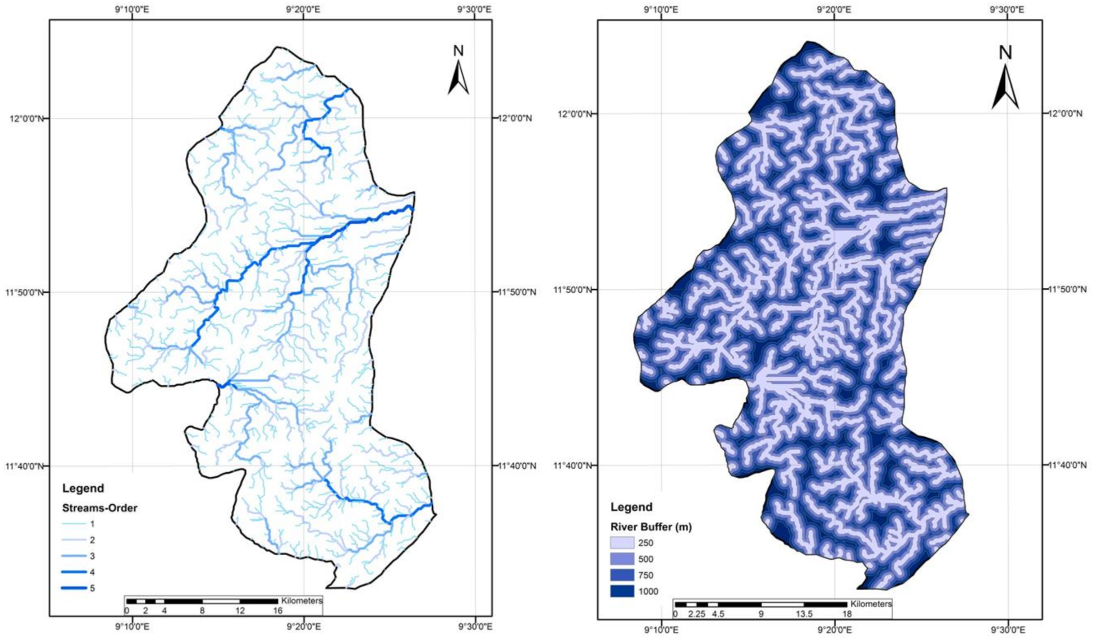

Figure 6: Drainage Network (a) and buffer (b) maps of the study area.

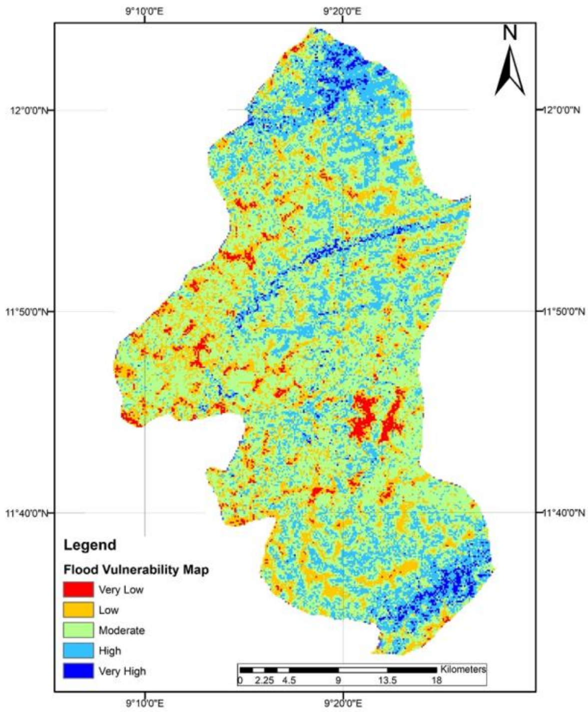

Figure 7: Vulnerability Map of the study area. Source (Geographic Information System) overlay of the factors.

All individual parameter (Figure 2 to 6) were overlaid in GIS environment to produce the final map of vulnerability to flooding (Figure 7). The result shows that, though the vulnerable area is not too distinctive much to a one area alone, but the south most part, the upper north and some part of the central covering almost 25% are very vulnerable and high to flooding due to accumulation of multiple factors (Ali, et al., 2020; Pal & Singha, 2022). While 53 %, 19% and 3% of the area were characterized as moderate, low and very vulnerable areas respectively.

4. Conclusion

Flood vulnerability assessment of Dutse was carried out to determine areas that are more susceptible to flood within the capital of Jigawa State using MCD technique. The land use land cover map was generated from Landsat imagery of 2020, while the evaluate, slope and drainage maps were generated from DEM. These parameters along with soil map were super imposed in the GIS environment to create the vulnerability map. The resulting outcome shows that about 25 5 of the area mostly south most, central and norther parts of Dutse area the most vulnerable are. thus, the policy makers and environmental managers should prioritize energy and resources in these particular areas to minimize the problems of flooding within the state capital of Jigawa State. Similarly, restriction should be imposed along other best management practice like tree implantations to help minimize the effects of flooding within the area in question.

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