Original Research Article

Spatial Assessment of Flood Vulnerability of Developed Properties in Port Harcourt Metropolis, Rivers State, Nigeria

Absttract

The study assessed the flood vulnerability of developed properties (DP) in Port Harcourt Metropolis, Rivers State, Nigeria. The study made use of DP data obtained from the open street map, and the combination of landuse/landcover map obtained from Landsat imagery of 2020, soil texture data, elevation data, and proximity to the active river channel. Descriptive statistics were used for data analysis. Findings showed that 44014 DPs were estimated in Port Harcourt Metropolis. Results showed that the spatial extent of flood lowly vulnerable areas in Port Harcourt Metropolis was 60.78 sq. km (13.22%), moderately vulnerable areas were 259.72 sq km (56.51%) and highly vulnerable areas were 139.14 sq. km (30.27%). Furthermore, 3977 (9.04%) of DP were lowly vulnerable to flood, 34754 (78.96%) were moderately vulnerable to flood and 5283 (12%) were highly vulnerable to flood in the study area. The study can be concluded that the number of developed properties in the Port Harcourt Metropolis varied based on different flood vulnerability levels as more of them were found within the moderate vulnerability levels. Based on the findings, the study recommended that all the developed properties lying in the high flood vulnerability level should be relocated to better locations or at least conform to ways of guiding against the effect of flood on the developed properties; and also periodic enlightenment of the effect of flood to the public would help a lot of preventing people from constructing their house in the highly and moderately flood vulnerable levels.

Keywords: Developed properties, Flood, Vulnerability, Open street

Introduction

Floods take a heavy toll on society, costing lives, damaging buildings and property, disrupting livelihoods, and sometimes necessitating national disaster relief, which has risen to record levels in recent years (National Research Council, 2015). Despite the rapid economic growth and urbanization witnessed in many developing nations, flooding is the major development challenge facing many of their cities. Urban flooding is intensified by dramatic changes in the impervious area, in addition to heavy rainfall and extreme climatic events (Birhanu, *et al*., 2016). High incidences of flooding could be attributed to climate change, reduction in percolation, poor environmental and infrastructure planning, poor governance, population explosion as well as rapid urbanization. The persistent migration of people from deprived areas, coupled with poor governance has put unprecedented pressure on cities' resources and infrastructure (Odufuwa, *et al*., 2012). From a vulnerability perspective, Asia and the Pacific regions have had their fair share of affecting the social and economic stability of the countries in the region, some of the worst-case scenarios for example include China when in 1998 it suffered a devastating flood that affected 223 million people, killing 3,004 people and rendering 15 million people homeless. The economic loss was over US$ 23 billion for that year (Amangabara and Obenade, 2015). Flooding has become a major hazard in Nigeria in recent years. It was estimated that Nigeria suffered combined losses of more than $16.9b in damaged properties, oil production, agriculture and other losses due to flood events in 2012 alone (Oladokun and Proverbs, 2016). Increased flood events coupled with the lack of coping capacity and high levels of vulnerability of the people have continued to put many lives and properties at risk (Oladokun and Proverbs, 2016).

According to Alaghmand, *et al.*, (2010), there is a direct relationship between urbanization and hydrological characteristics such as infiltration, runoff frequency and flood depth in an urban area. They stated that increased urbanization increases floods, both in frequency and magnitude. The effects of urbanization and global warming on floods will increase in future (due to more urbanization to accommodate increased population in cities and rises in greenhouse gas emissions) (IPCC 2013; Rashetnia, 2016). Considering this, flood vulnerability assessment is essential to identify high-risk areas and develop cost-effective flood mitigation and/or adaptation strategies. The goal of vulnerability assessment is to understand how a system will be affected by floods. Examples of possible systems could include physical structures such as houses or bridges that could be damaged or destroyed, a business or service whose supply chain could face interruption or a community that could suffer fatalities, property losses, and negative health impacts in the aftermath of a flood.

The vulnerability of the built environment to floods is referred to as physical vulnerability. An important consequence of flooding is the damage to physical structures such as buildings, bridges, roads, and public utilities. According to the World Bank (2014), 'physical vulnerability encompasses the structural and non-structural damage to buildings or building components or other infrastructure'. These damages could be direct, in terms of gradual and consistent deterioration of buildings and other infrastructure (WB, 2014; Fatemi, *et al.*, 2020). Flood damage to buildings is often extensive and deteriorates their material compositions and structures as well as their function (Blanco and Schanze, 2012). The IPCC thus indicates that vulnerability encompasses a variety of concepts including sensitivity or susceptibility to harm and lack of capacity to cope and adapt. Therefore, information on the elements at risk (e.g., people; built environment; eco-systems), the exposure (e.g. proximity to the river; elevation of the area; frequency, duration, and depth of floods), and areas' susceptibility(e.g. socio-economic capacities, coping, and recovery) are essential for assessing physical damage due to flood (Yankson, *et al*., 2017; Fatemi, *et al*., 2020). In Nigeria, several studies have been carried out on vulnerability assessment using various techniques including Remote Sensing and GIS techniques (Happy, *et al*., 2014; Eguaroje, *et al.*, 2015, Akukwe and Ogbodo, 2015; Amangabara & Obenade, 2015; Dalil *et al*., 2015; Geller *et al*., 2016; Nkwunonwo 2017; Samuel *et al*., 2017 and Chigbu et al., 2018; Afolabi et al., 2022) to ascertain the vulnerability level while a study conducted by Ugwu (2017) was able to examine the effects of incidence of flooding on property value in Port Harcourt metropolis, Rivers State. None of these studies assessed the vulnerability of developed properties. Therefore, this study is assessing the flood vulnerability levels of developed properties in Port Harcourt Metropolis, Rivers State, Nigeria.

Materials and Methods

The study was carried out in Port Harcourt Metropolis., Rivers State, Nigeria It is located on latitude 04° 42' and 04° 47'N of the Equator and longitude 06° 55'and 07° 08'E of the Greenwich Meridian (Figure 1). Port Harcourt Metropolis covers an area of 387.261000 (sq. km). Port Harcourt is the Capital City of Rivers State of Nigeria. The study area has a tropical monsoon climate with a mean annual temperature of 28^{o}C and annual rainfall over 2500mm. The relative humidity is very high with an annual mean of 85%. The relief is generally lowland with an average elevation between 20m and 30m above sea level and the geology of the area comprises basically of alluvial sedimentary basin and basement complex. The vegetation found in this area includes raffia palms, thick mangrove forests and light rainforests. The soil is usually sandy or sandy loam underlain by a layer of the impervious pan and is always leached due to heavy rainfall. The study area is well-drained with both fresh and salt water. The saltwater is caused by the intrusion of seawater inland, thereby making the water slightly salty.

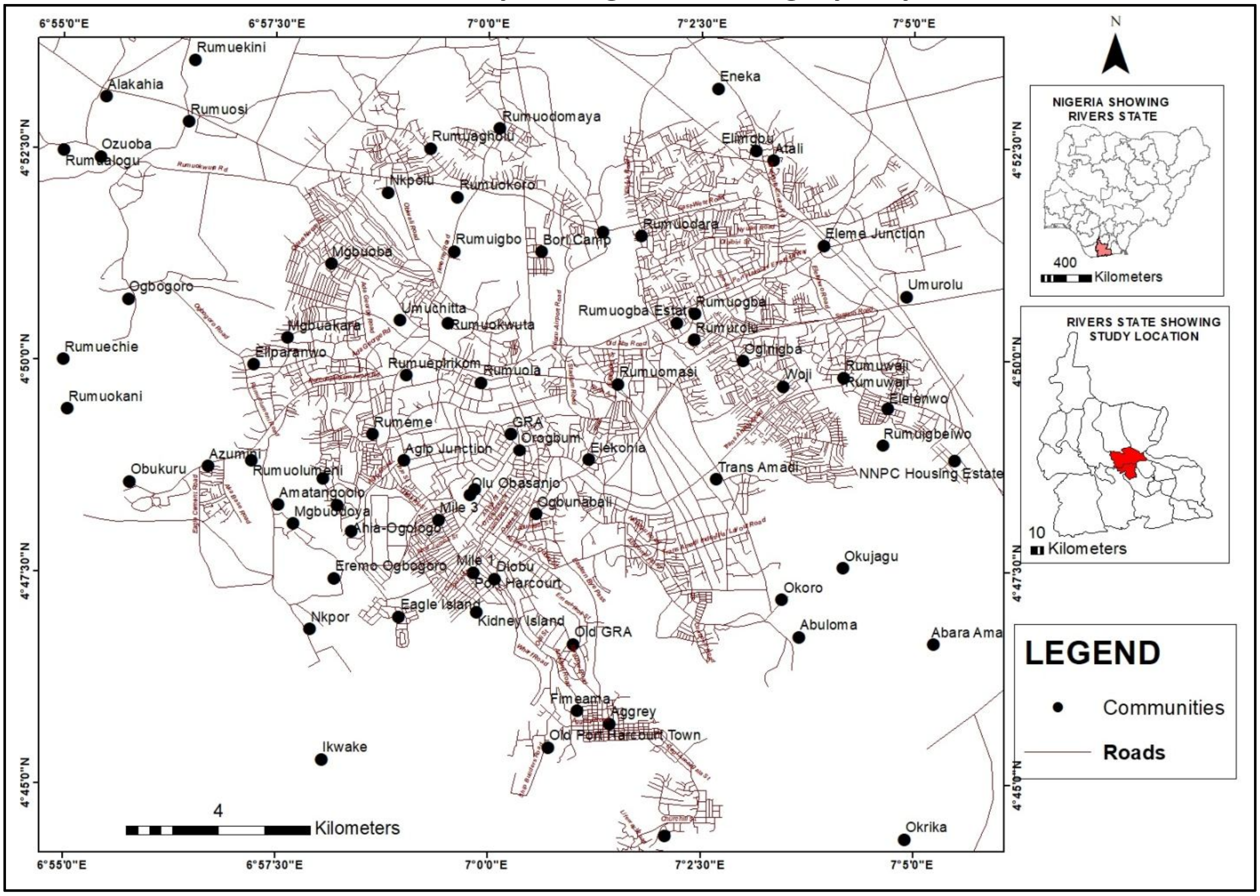

Figure 1. Port Harcourt Metropolis

This study employed the use of both primary and secondary data. The primary data included Landuse map of the capital cities acquired from the Landsat Imagery of 30m x 30m and the drainage network, road network, and communities location extracted from the topographic map of 1: 100,000 scale of the study area; and soil map derived from the FAO website. The Landsat imagery of 2020 with path and rows of 188 and 057 and sensor ID of OLI/TIRS was collected for the cities. The bands of Landsat satellite imageries of each of the study locations were combined to have composite imagery. The shapefile of each of the study locations was used to clip the composite imagery to have a definite boundary of the study area. However, the topographical map was geo-referenced to the world coordinate system (WGS 84) in ArcGIS 10.7 from where the communities and river networks were obtained while the SRTM imagery was used to determine the elevation of each of the study locations. The soil map was generated from the World Soil Map created by FAO/UNESCO (1973). The soil map supplied information on the soil dominant composition, and the textural class (1=Coarse, 2=Medium/Fine, 3=Fine). The information on developed properties was obtained from the Open Street Map website (https://www.openstreetmap.org/#map=11/4.9008/6.0796&layers=N). Thereafter Spatial Manager Desktop software was used to extract and convert the data into a shapefile and later imported into the ArcGIS environment for further analysis.

This study made use of ranking methods of the vulnerability factors which is embedded in the Analytical Hierarchy Process (AHP) proposed by Saaty (1980) and cited in Saaty (2008). AHP is a multi-criteria decision-making technique, which provides a systematic approach for assessing and integrating the impacts of various factors, involving several levels of dependent or independent, qualitative as well as quantitative information (Bapalu and Sinha, 2006). The ranking method was adopted because the criterion weights are usually determined in the consultation process with choice or decision makers which resulted in a ratio value assigned to every criterion map (Lawal et al., 2011). In the ranking method, every criterion under consideration is ranked in the order of the decision maker's preference. To generate criterion values for each evaluation unit, each factor was weighted according to the estimated significance of causing the flood.

The landuse/land cover map was generated from the satellite imageries. A supervised classification technique was adopted with the use of the MAXLIKE (Maximum Likelihood Algorithm) module to classify the imagery in the area. The area in a square kilometre of each landuse type was calculated. The drainage network which determines the proximity to river channels and communities was mapped from the topographical map. These geographic features were digitized and captured as vector data in ArcGIS 10.7. The elevation map was derived from the STRM of 2020. The boundary of each of the study locations was used to clip the imagery to have the exact delineation of the boundary. The landuse, proximity to river channels (drainage), elevation and soil texture maps were reclassified into high vulnerability, moderate vulnerability, and low vulnerability. The landuse, proximity to river channels (drainage), elevation maps and soil texture were reclassified to determine the vulnerability across the cities of the region. Spatial query in ArcGIS 10.7 was used to determine the vulnerability levels that each developed properties fall into and also used to determine the spatial extent of each vulnerability level which was categorised into high vulnerability, moderate vulnerability, and low vulnerability. Descriptive statistics involving frequencies and percentages were used in the data analysis. Data were presented in tables and maps.

Results and Discussions

Vulnerability Assessment of Developed Properties in Port Harcourt

The analysis presented in Figure 2, Figure 3 and Table 1 reveals the landuse pattern of Port Harcourt Metropolis, landuse vulnerability level to flood and the spatial extent covered by each landuse class. The analysis revealed that five major landuse patterns were identified in Port Harcourt and these included waterbodies, swamp forest/riparian vegetation, built-up area, thick vegetation and farmlands/sparse vegetation. The analysis reveals that waterbody occupied 24.71 sq km (5.39%), swamp forest/riparian vegetation occupied 64.06 sq km (13.98%) while the built-up area covered 216.91 sq km (47.35%) and thick vegetation covered 73.94 sq km (16.14%) and farmlands/sparse vegetation occupied 78.51 sq km (17.14%). Thus, the level of landuse vulnerability to flood reveals that 16.14% of the total area was lowly vulnerable based on landuse, 31.12% was moderately vulnerable and 53.74% was highly vulnerable.

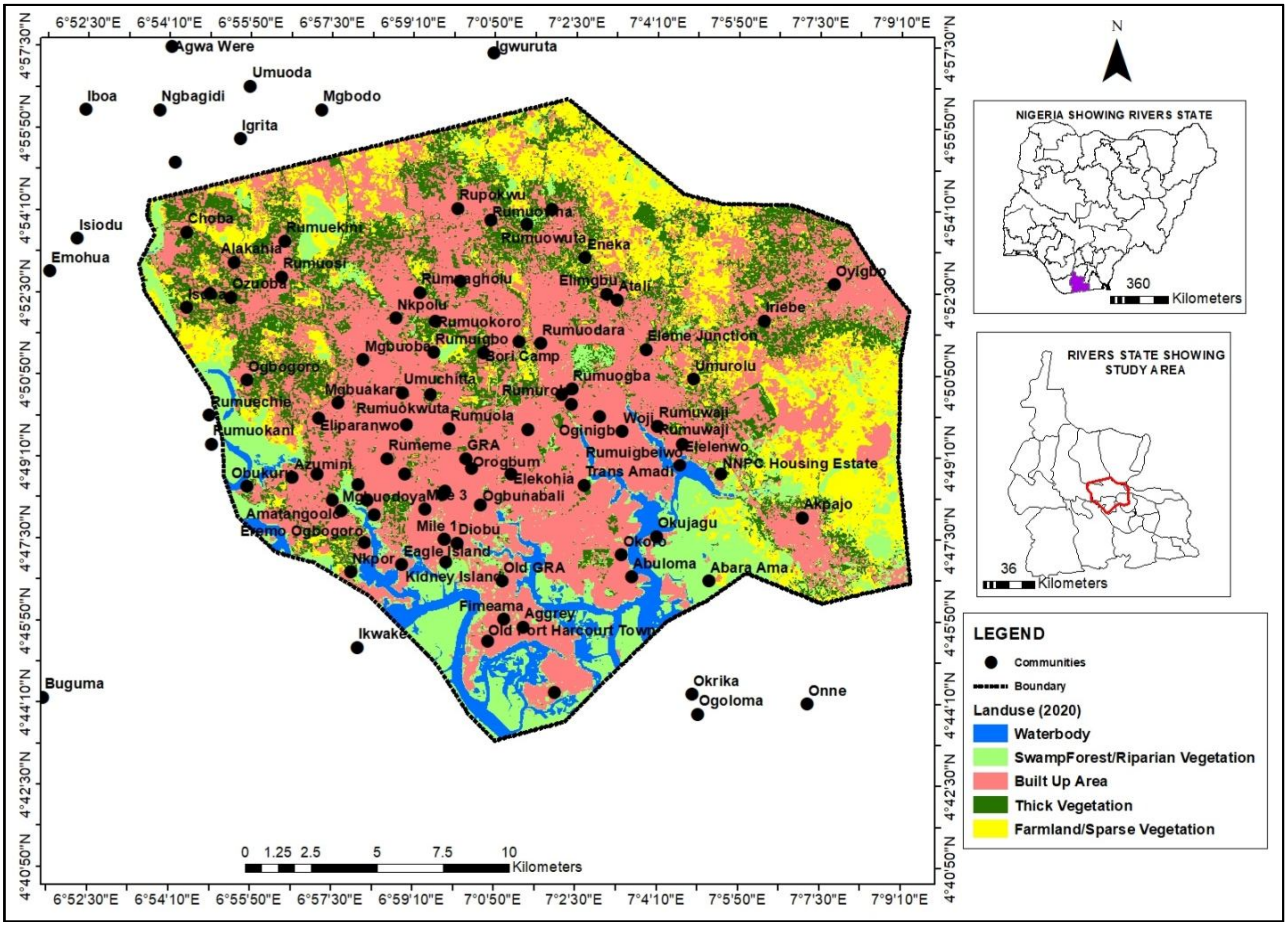

Figure 2: Landuse Pattern in Port Harcourt in 2020

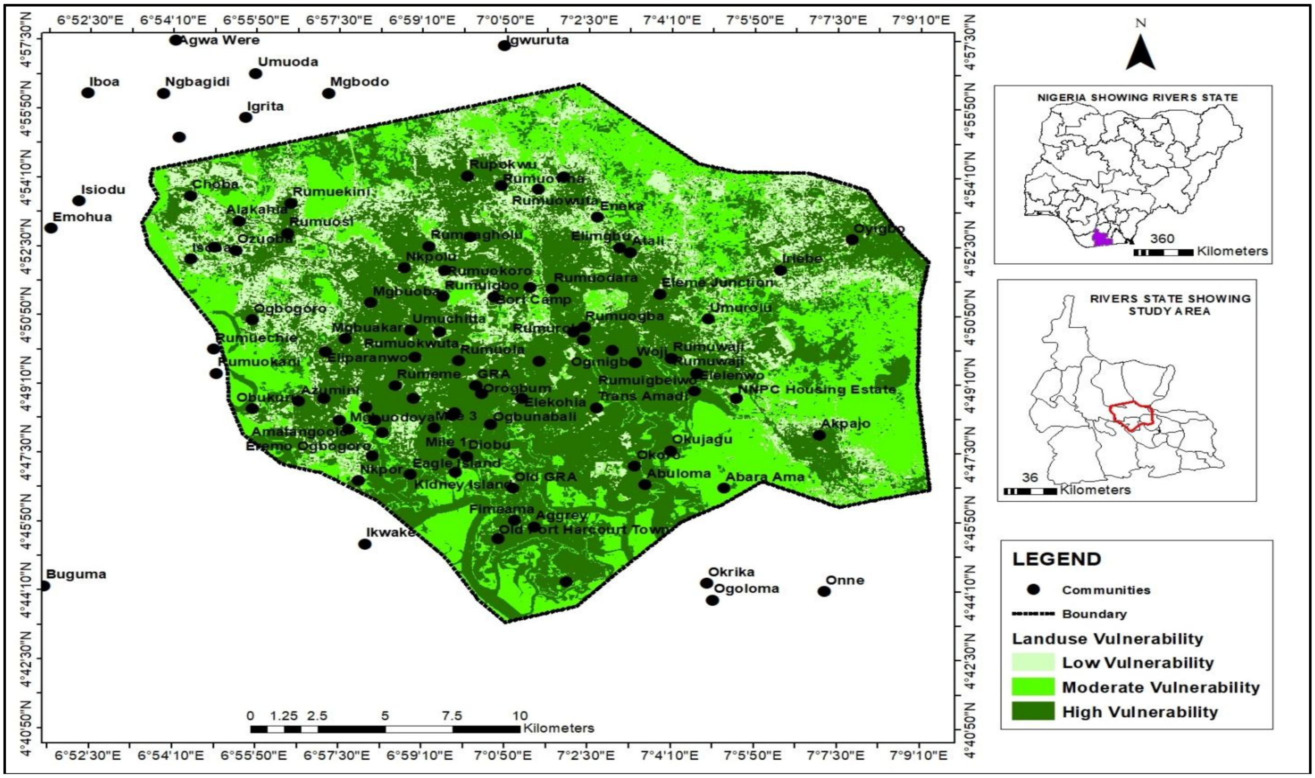

Figure 3: Landuse Vulnerability to Flood in Port Harcourt

Table 1: Landuse/Landcover Vulnerability Levels to Flood in Port Harcourt

S/n	Landuse	Spatial Extent (Km^2)	Percentage (%)	Vulnerability Assigned Values	Vulnerability Levels
1	Waterbody	24.71	5.39	3	High Vulnerability
2	Swamp Forest/Riparian	64.06	13.98	2	Moderate Vulnerability
3	Built Up Area	216.91	47.35	3	High Vulnerability
4	Thick Vegetation	73.94	16.14	1	Low Vulnerability
5	Farmlands/Sparse Vegetation	78.51	17.14	2	Moderate Vulnerability
	Total	458.13	100.00		

Proximity to River Channel (Drainage) Vulnerability Map

The analysis of proximity to active river channels is presented in Figure 4, Figure 5, Figure 6 and Table 2. It is shown that the three scenarios considered were 500m, 1000m and 1500m radius from the centre of the river. The areal extent covered by the distance of 500m which was categorized as the high vulnerability was 115.01 sq km (47.73 %), 72.55 sq km (30.11%) were occupied by 1000m distance from the active rive river channels and this was categorized to be moderate vulnerability while the low vulnerability which was 1500m distance from the river occupied 53.40 sq km (22.16%). With this analysis, it is regarded that the highly vulnerable had almost half of the total area occupied by the buffers and it was even found as the highest among other levels based on the proximity to active river channels.

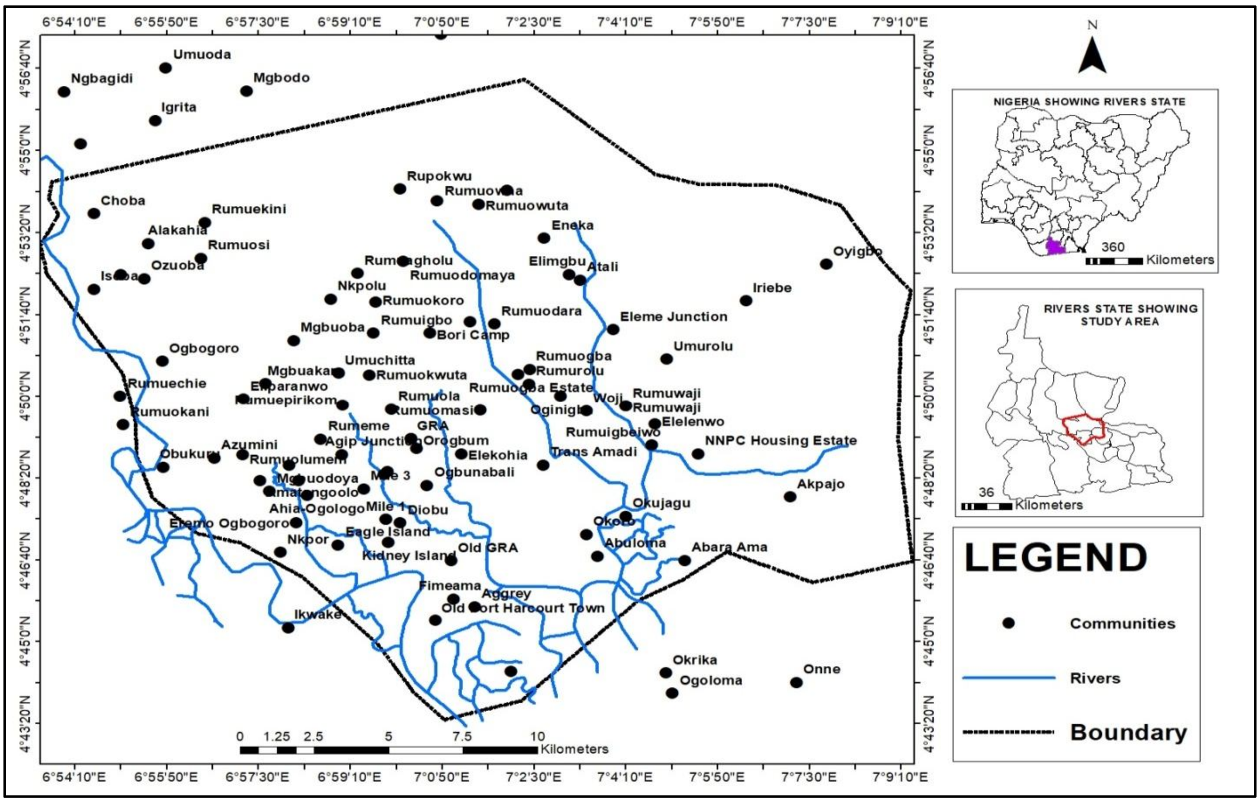

Figure 4: Active River Channels in Port Harcourt

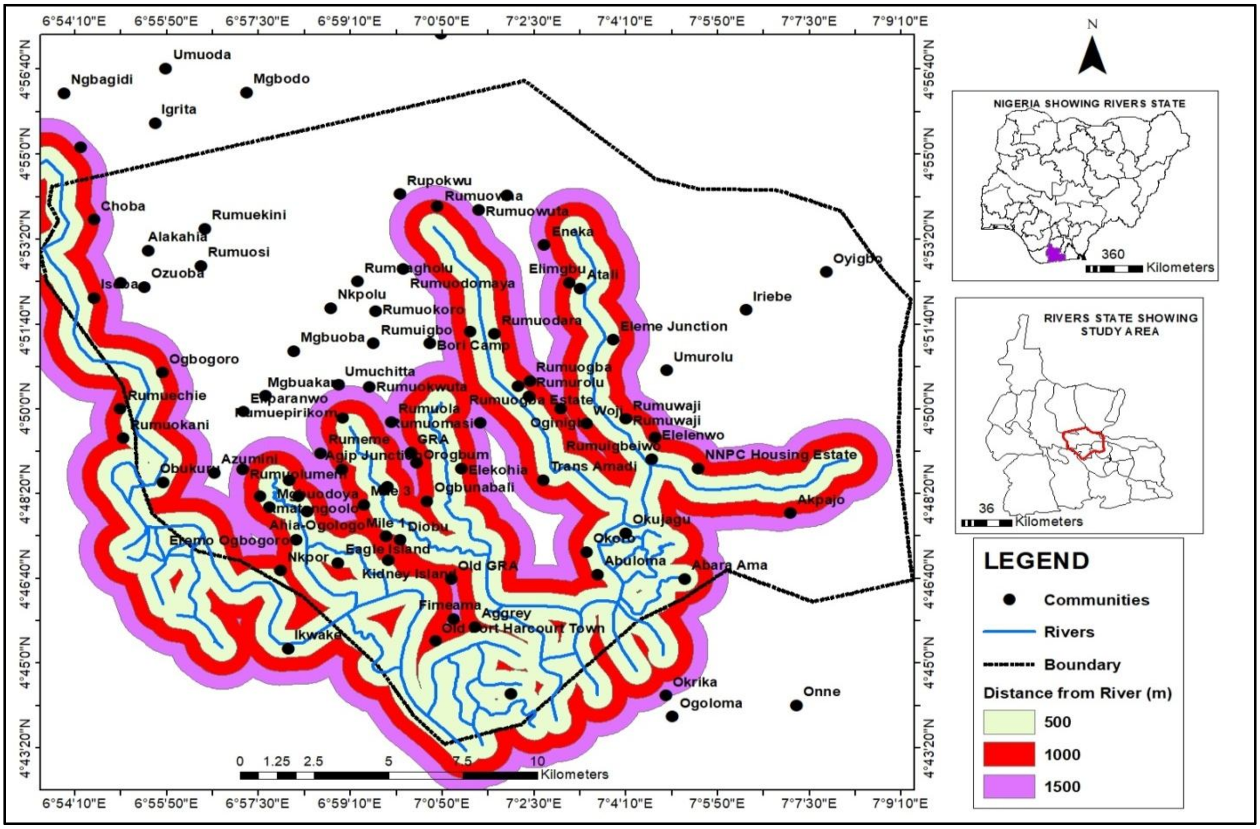

Figure 5: Buffering Analysis for Active River Channels in Port Harcourt

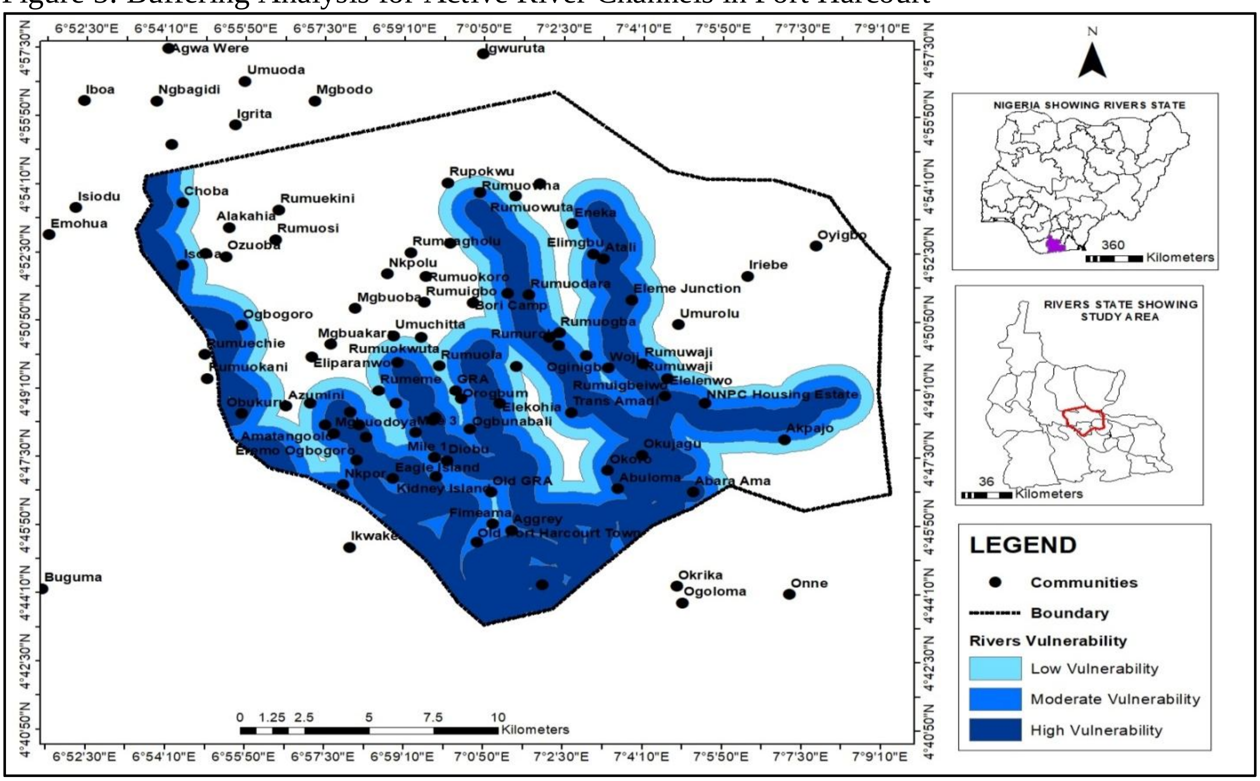

Figure 6: Proximity to River Active Channel Vulnerability to Flood in Port Harcourt

Table 2. Proximity to Active River Channel

S/n	Drainage Buffer (m)	Spatial Extent (km^2)	Percentage (%)	Vulnerability Assigned Values	Vulnerability Levels
1	500	115.01	47.73	3	High Vulnerability
2	1000	72.553	30.11	2	Moderate Vulnerability
3	1500	53.399	22.16	1	Low Vulnerability
	Total	240.96	100.00		

Soil Texture Vulnerability Map in Port Harcourt

The soil texture and its vulnerability to flooding are displayed in Figure 7, Figure 8 and Table 2. It is shown that the major soil texture identified are coarse, and fine and the spatial coverage of the highly vulnerable part of the study location was 87.15% while 12.85% was left with moderate vulnerability to flooding. Meanwhile, coarse had spatial coverage of 342.13 sq km (74.67%), and fine texture had 58.87 sq km (12.85%).

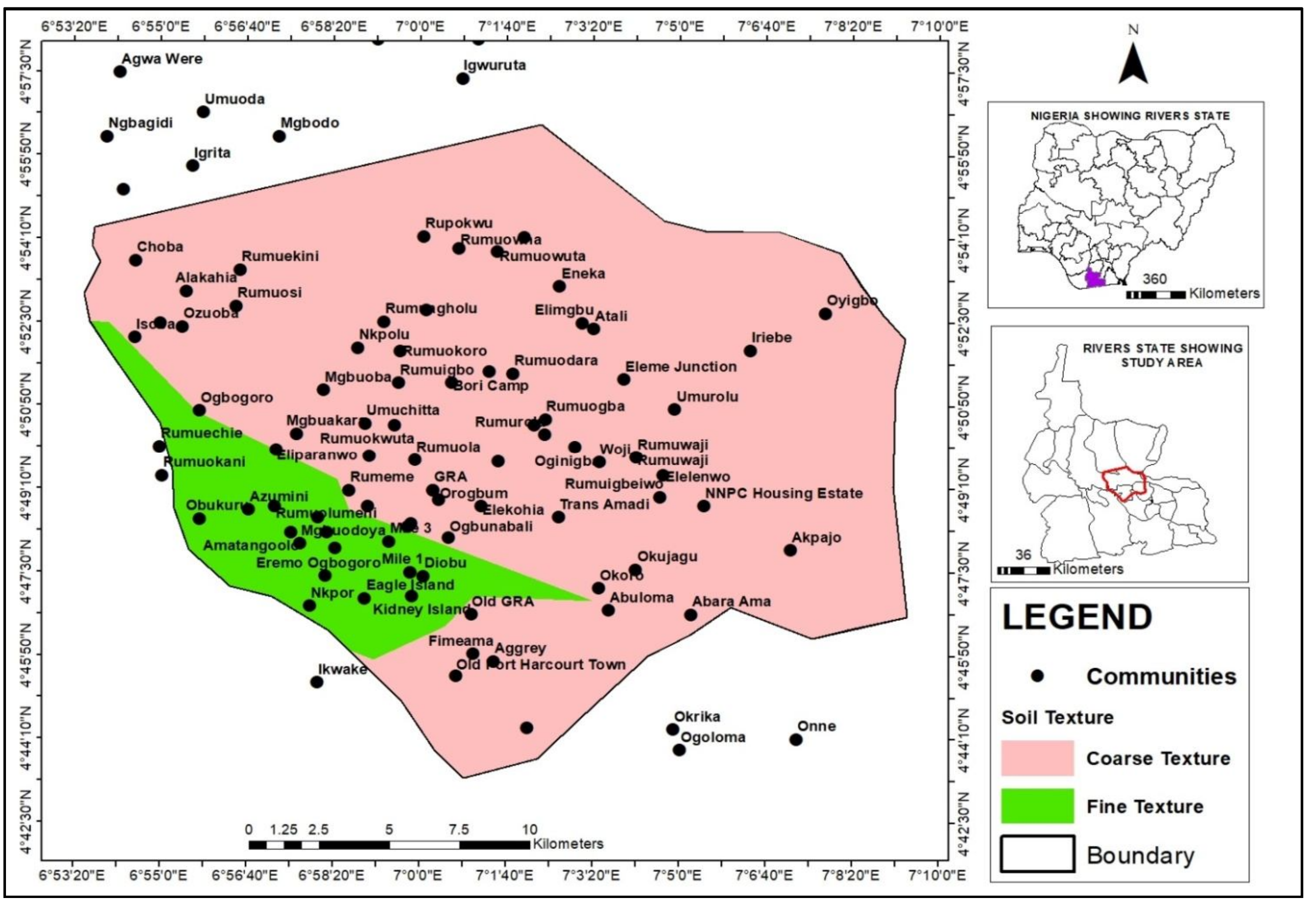

Figure 7: Soil Texture of Port Harcourt

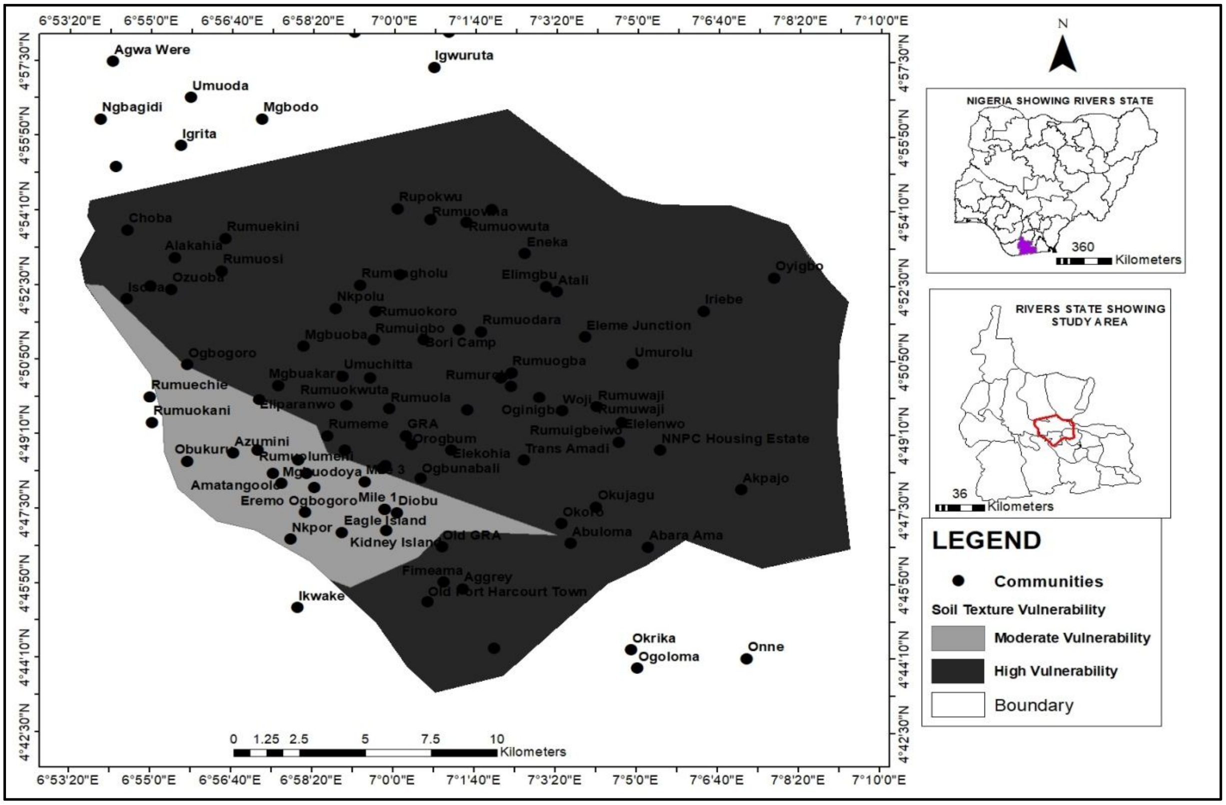

Figure 8: Soil Texture Vulnerability to Flood in Port Harcourt

Table 3: Soil Texture and Its Vulnerability to Flood in Port Harcourt

S/n	Soil texture	Spatial Extent (Km^2)	Percentage (%)	Vulnerability Assigned Values	Vulnerability Levels
1	Coarse Texture	342.13	74.67	3	Low Vulnerability
2	Fine Texture	58.872	12.85	2	High Vulnerability
3	Mixed Texture	57.197	12.48	3	Moderate Vulnerability
	Total	458.2	100.00		

Flood Vulnerability Map based on Elevation

The analysis of the elevation of Port Harcourt is displayed in Figure 9, Figure 10 and Table 3. It was discovered that the high vulnerability due to elevation covered a spatial extent of 30.9 sq km (7.77%) while moderate ranging from 8.01m to 24m had a spatial extent of 323.41 sq km (81.28%) and the spatial extent of low vulnerability was 43.62 sq km (10.96%).

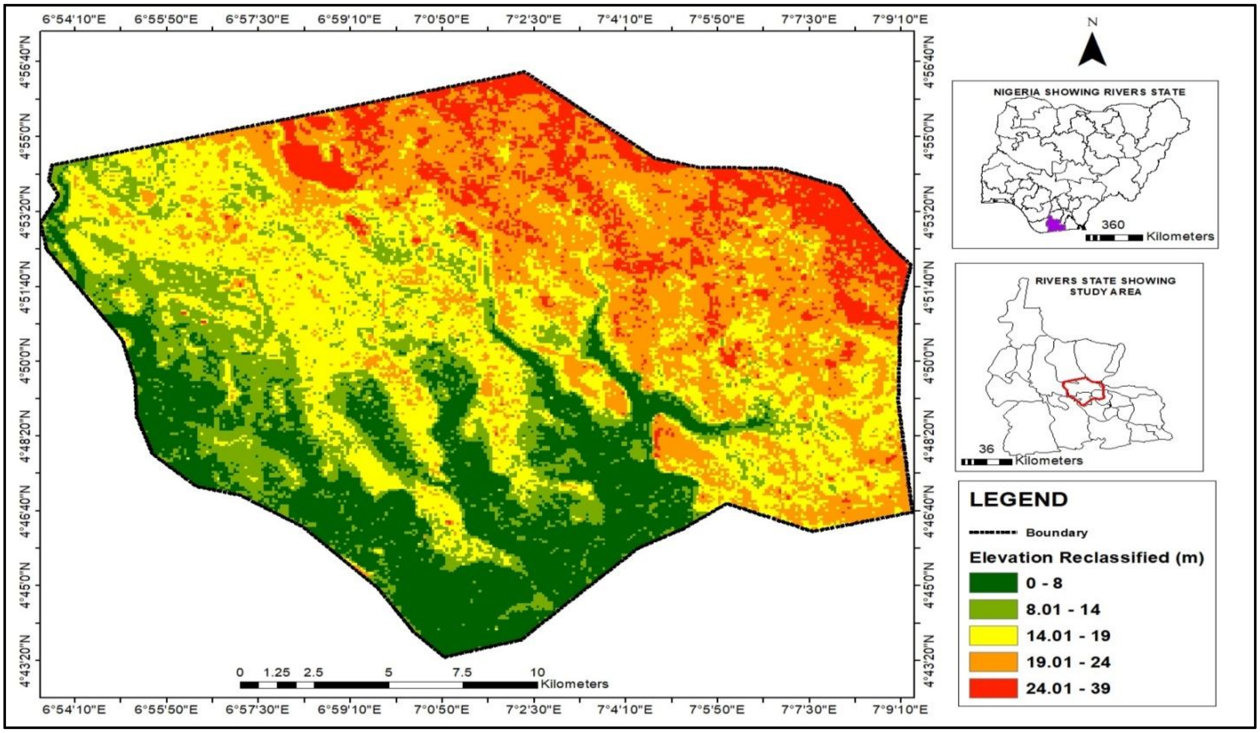

Figure 9: Elevation of Port Harcourt

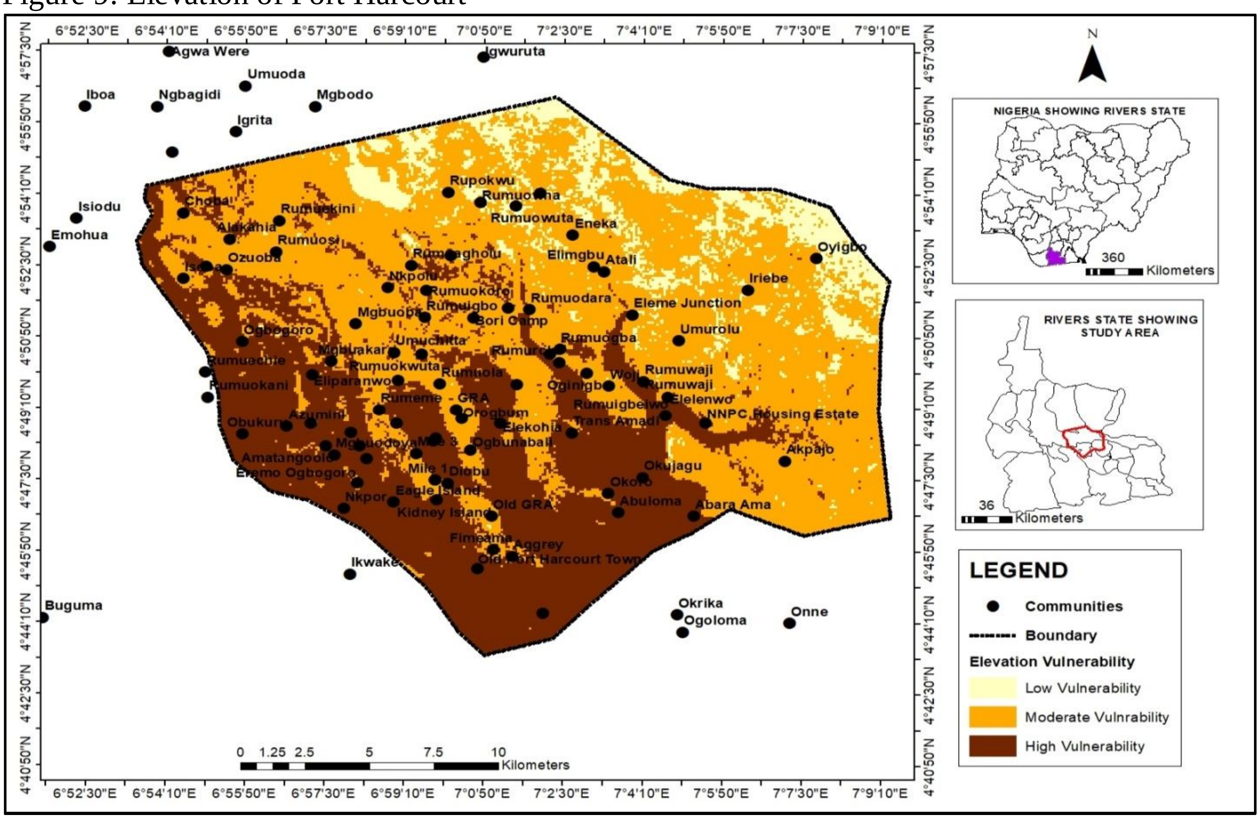

Figure 10: Elevation Vulnerability to Flood in Port Harcourt

Table 4: Analysis of Elevation Levels and Vulnerability to Flood in Port Harcourt

S/n	**Elevation Level (m)**	**Spatial Extent (Km^2)**	**Percentage (%)**	**Vulnerability Assigned Values**	**Vulnerability Levels**
1	0-8	30.9	7.77	3	High Vulnerability
2	8.01-14	73.32	18.43	2	Moderate Vulnerability
3	14.01-19	126.17	31.71	2	Moderate Vulnerability
4	19.01-24	123.92	31.14	2	Moderate Vulnerability
5	24.01-39	43.62	10.96	1	Low Vulnerability
	Total	397.93	100.00		

Flood Vulnerability Map and Developed Properties Vulnerability Levels

The flood vulnerability levels in Port Harcourt are shown in Figure 11 and Table 4 whereby it is found that the low flood vulnerability levels occupied 60.78 sq km (13.22%) while the moderate flood vulnerability occupied 259.72 sq km (56.51%) and high flood vulnerability level had a spatial extent of 139.14 sq km (30.27%). The analysis has revealed that the majority of the part of Port Harcourt is under moderate flood vulnerability but despite this, some areas are still categorized as highly vulnerable to flood.

Furthermore, the flood vulnerability levels that developed properties belonged to are displayed in Figure 12 for the lowly vulnerable developed properties, Figure 13 for the moderately vulnerable developed properties and Figure 14 for the highly vulnerable developed properties. The analysis contained in Table 5 reveals that 3977 (9.04%) of the total developed properties in Port Harcourt had a low flood vulnerability, 34754 (78.96%) had a moderate flood vulnerability and 5283 (12.00%) had a high flood vulnerability. The implication is that more than 80% of the developed properties identified in Port Harcourt are liable to be vulnerable to at least moderate floods.

Table 5: Flood Vulnerability Levels in Port Harcourt

S/n	Vulnerability Level	Spatial Extent (Km^2)	Percentage (%)
1	Low	60.78	13.22
2	Moderate	259.72	56.51
3	High	139.14	30.27
	Total	459.64	100.00

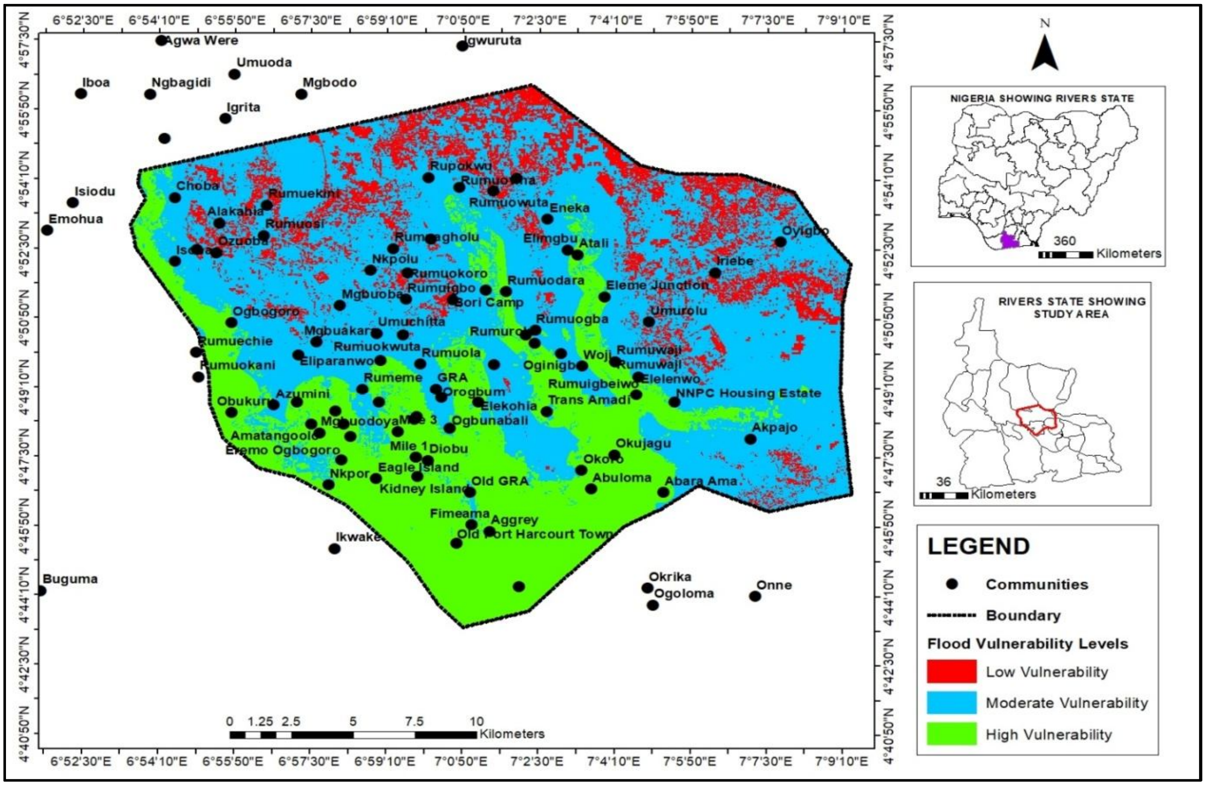

Figure 11: Flood Vulnerability in Port Harcourt

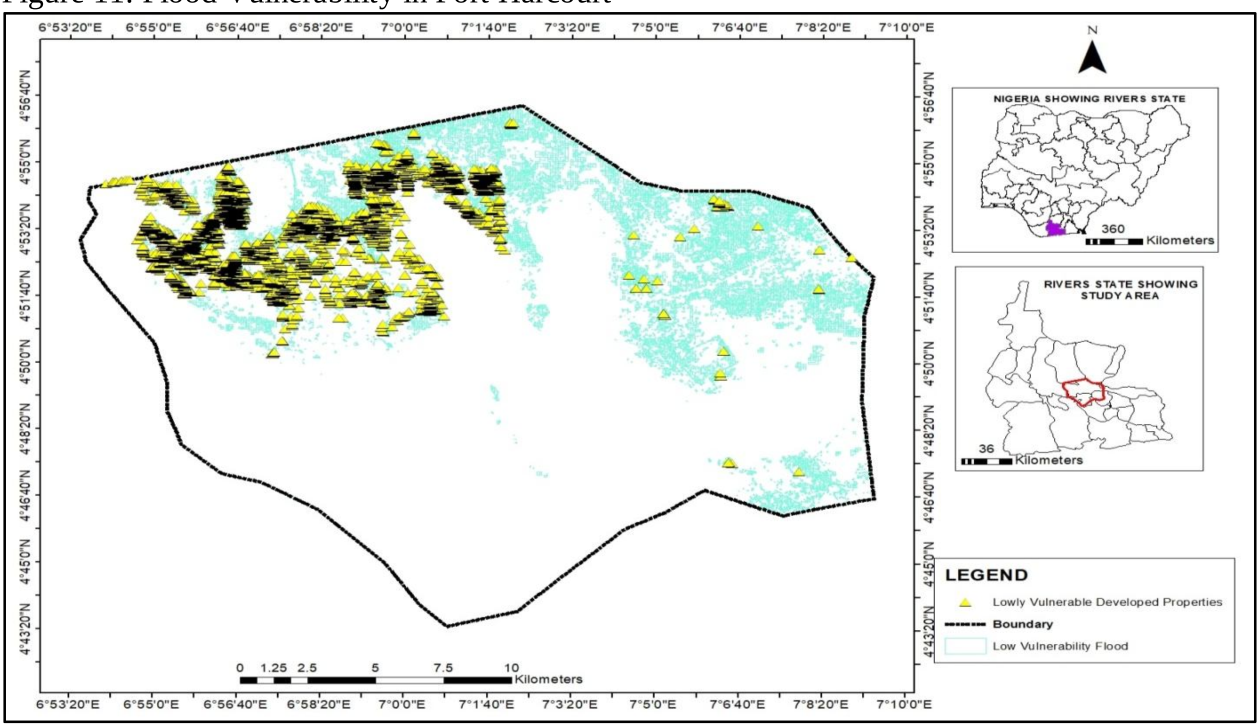

Figure 12: Developed Properties of Low Flood Vulnerability in Port Harcourt

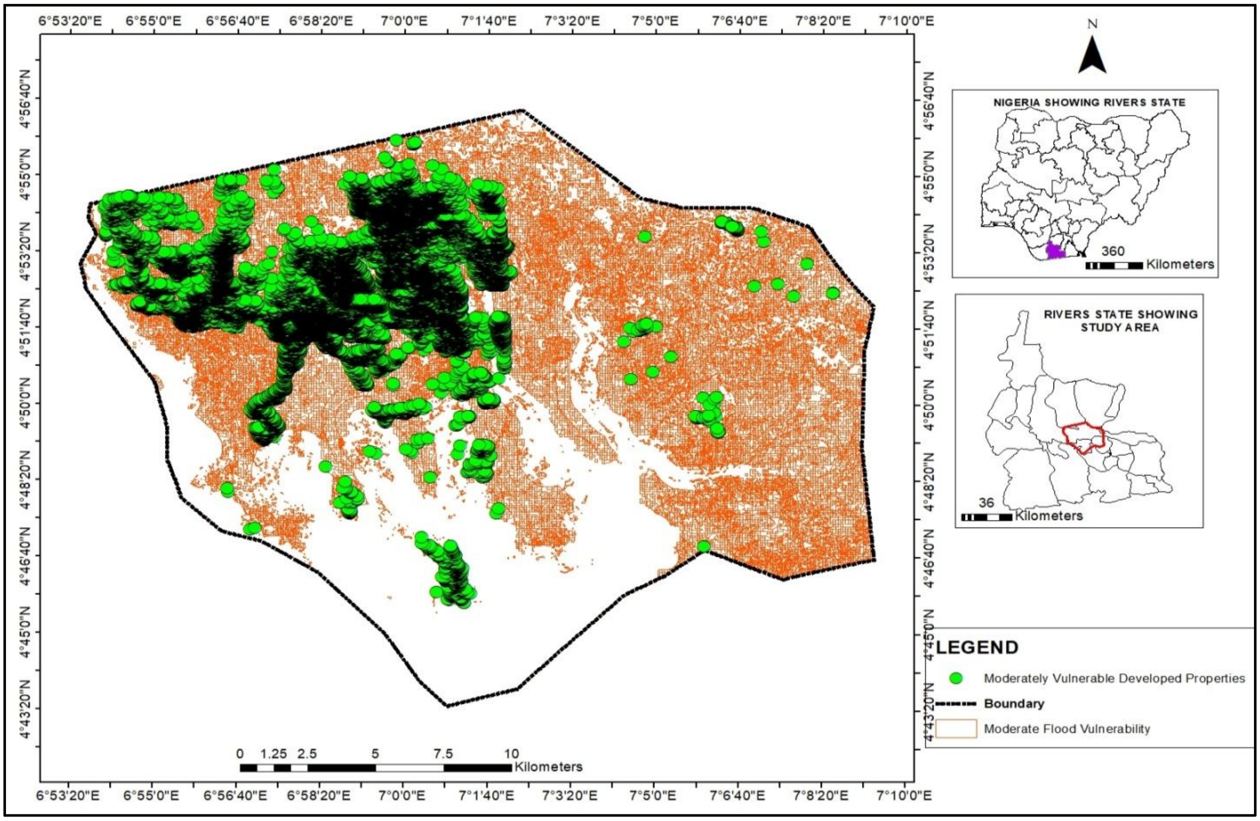

Figure 13: Developed Properties of Moderate Flood Vulnerability in Port Harcourt

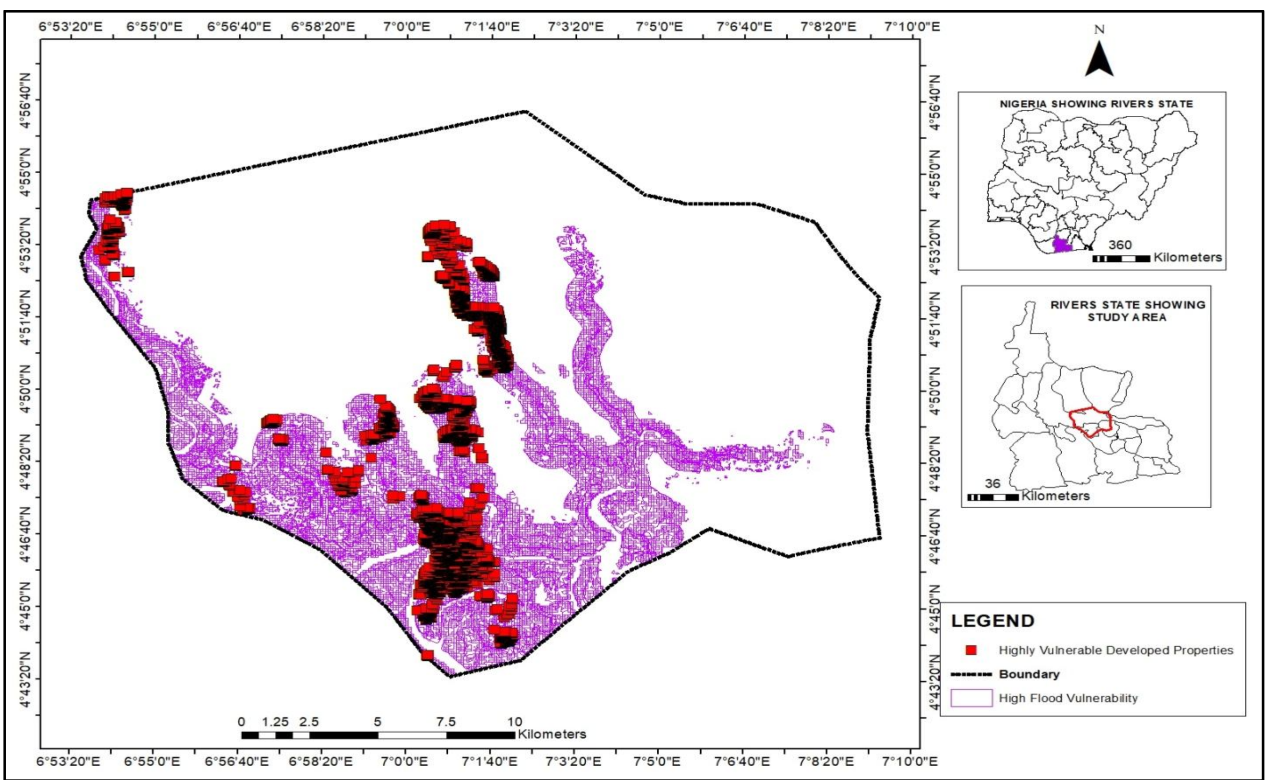

Figure 14: Developed Properties of High Flood Vulnerability in Port Harcourt

Table 6: Developed Properties Vulnerability Levels to Flood in Port Harcourt

SN	Vulnerability	Number of Developed Properties	Percentage (%)
1	Low	3977	9.04
2	Moderate	34754	78.96
3	High	5283	12.00
	Total	44014	100.00

Discussion of Findings

The flood vulnerability assessment of developed buildings showed that many of the developed are faced with moderate flood vulnerability and this may slightly affect their potential use for humankind. Floods are one of the common natural phenomena that can cause a huge danger to people and building objects located in flood plains. The particularly severe effects of such disasters are felt in heavily urbanized areas (Wilk, 2018). As a result of an increase in the flow velocity of the flood, the ground erodes, especially intense in places where obstacles are encountered, which are also construction objects. The erosion of foundations is a frequent cause of the collapse or emergency states of buildings (Wilk, 2018). Similarly, Park et al., (2021) reported that urbanization on floodplains results in a rise in property values, therefore increasing potential flood damage. Because flood damage is inevitable in floodplains, settling and investing in the floodplain contributes to a higher risk of flood damage. Other buildings are found in a low and high-flood vulnerable areas, although they are lower in number than the moderately vulnerable buildings. This is in agreement with the findings of Park et al. (2021) whereby the fuzzy values revealed the vulnerability level of each building to flood damage split into stages which included very low vulnerability, low vulnerability, medium vulnerability, high vulnerability and very high vulnerability. Kropp (2012) buttressed that the risk of flooding has always been present for buildings close to rivers or coasts, but it has been growing in recent years. Major floods all over the world over the past decade have shown that flooding is a significant environmental hazard.

Conclusion and Recommendations

The study can be concluded that the number of developed properties in the Port Harcourt Metropolis varied significantly based on different flood vulnerability levels and more of them were found within the moderate vulnerability levels. Based on the findings, the study recommended that all the developed properties lying in the high flood vulnerability level should be relocated to better locations or at least conform to ways of guiding against the effect of flood on the developed properties, and regular public enlightenment of the effect of the flood would help in preventing people from constructing their house in the highly and moderately flood vulnerable levels.

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