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AN ASSESSMENT OF FLOOD VULNERABILITY IN SELECTED URBAN CATCHMENT: A CASE STUDY OF PORT HARCOURT METROPOLIS, NIGERIA

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Abstract:

Flooding occurs due to increase in global temperatures high rate of precipitation and increase rate of runoff and increase rate of urban flooding. The aim of study is to determine the flood risk assessment of selected urban catchment in Port Harcourt, Nigeria. The study adopted correlational research design where secondary data was generated from Landsat Imageries of the study area. The digital elevation model of the area was used to determine the water shed pattern, land use / land cover and inundation level using supervised classification of land use in the area. The study also adopted Geographic Information System (GIS) aided computer simulation of the storm water been generated through enhanced DEM to determine storm water level and inundation based on land use/land cover change. Data generated was analyzed using hydrological models and techniques which include storm water generation assessment, inundation modeling, assessment of land cover and level of inundation and evaluation of flash flood vulnerability using modeled inundation. Findings showed that Port Harcourt has a number of streams of different flow lengths which was higher in Port Harcourt 'The study also revealed that Port Harcourt has about 654 sub basins. The total runoff in Port Harcourt was higher (0.74) inches ,Also the rate of change of catchment behaviour like the catchment precipitation, node flooding and runoff in both study areas continued to increase with time of the day, and the rate of change of volume of runoff varied slightly in Port Harcourt,. The width of hydrograph in Port Harcourt was wider as the areas prone to moderate and high flood in Port Harcourt was higher (95.03%) Based on these findings, the study recommends that better planning of the cities is required to regulate the effect of flooding in the study area. The area liable to moderate and high flood vulnerability should be well monitored and guarded to minimize the destruction of lives and properties.

Keywords: Flood, vulnerability, urban, catchment, metropolis

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INTRODUCTION

The increase in global temperatures, seasonal shifts, and high rate of precipitation which lead to increase rate of run-off increases the rate of urban flash flood (Sunnin, Saro, Moung-Jin and Hung-Sup, 2018). Heavy rains, typhoons, floods and other meteorological conditions cause variation in the hydrological system and increase the pressure on drainage systems, water works,, and sewage facilities in urban areas (Muneerudeen, 2017). In addition, low lying areas and flood plain areas as well as increase in impermeable surfaces such as building and roads can lead to an exponential increase insurface flow by decreasing the absorption and storage of rainwater below the surface (Muneendeen, 2017). Subsequently, with a higher concentration of rainwater in rivers, flooding risks increase substantially. Flash flood is generally defined as a rapid onset of flood with a short duration and a relatively high peak discharge (Ismail, 2015). Flash flood occurs rapidly, generallywithin one hour of rainfall and sometimes accompanied by landslides, mud flows, bridge collapse, damage to buildings, and facilities (Hapuarachichi, Wang & Pagano, 2019).In most recent years, a flood occurrence can be forecasted by applying hydrologic and hydraulic models, which needed large-scale data that are not accessible. Aneesha, Shashi and Meshapam (2019), have noted that the utilization of Geographic Information System (GIS) based tools for flood risk and hazard evaluation was uncommon before 2000.Therefore, it is of high importance for city and urban planning professionals to map and manage the natural risk cause by flash floods for future planning. With the advent and development of computer, disaster management and mitigating authorities can now predict where flood will occur and how severe they are likely to be with an amazing accuracy. So far and in recent times, many studies have been done to map flood in different countries to determine the level of flash flood and the inundation level to produce the flood hydrographs and flood maps to show the level of hazard as a result of the run-off as in the United States (Mastin, 2009), China (Liang, Yongli, Hongquan, Daler, Jingmin and Juan, 2011), Egypt (El Bastawesy, White and Nasr, 2009; Ghomein, Arnell and Foody, 2002), Saudi Arabia (Sand, 2010; Dawod, Mirza & Al-Ghandi, 2011), India (Bhatt, Rao, Manjushree and Bhanumurthy, 2010) & Ghana (Forkuo, 2011).

Geographic Information System (GIS) and remote sensing provide a broad range of tools for determining area affected by flood and for determining or forecasting areas that are likely to be flooded due to high water level/run-off either in a low land area, flood plains or a river channel. GIS can be extensively used to assemble information from different maps, aerial photographs, satellite images and Digital Elevation Model (DEM). The central task will be to delineate flash flood zones and the level of inundation, the level of storm water, the amount and level of rainfall – run-off and watershed as well as the land use land cover change and the preparation of flood hazard risk maps for the vulnerable areas. Flood hazard mapping is a vital component for appropriate land use planning in flash flood – prone areas. This is because it creates easily read, rapidly accessible charts and maps, which facilitates easy identification of areas of risk and priorities their mitigation/response efforts.

Flood simulation models have wide variety of approaches that are available to compute the water surface elevation associated with flood events. Some of these models use a one Dimensional approach (ID), others use a two-Dimensional (2D), and there are others that allows the use of integrated ID and 2D simulation. However, in 2015, the US Army Corps of Engineering Hydrologic Engineering Center (HEC) released HEC-RAS version 5.0.3 which perform ID steady and unsteady calculation as well as 2D and unsteady flow calculation to determine flash flood using the HEC-RAS model. Other models that are used to examine flood hazards include HEC-HMS model, Digital Elevation Model (DEM) and land satellite images across urban centres.

In the Niger Delta region of Nigeria like other deltaic regions of the world, flash flood is a common hazard. This is because most places in the region lie below sea-level. The deltaic nature of the drainage basin in the region, and the fact that the entire area lies within the flood as well as the increasing urban population pressure on the urban landscape of the area without proper land use planning has made the region flash flood prone. In the wake of increased land use and land cover change, increased human developmental activities and intense rainfall and the high rate of runoff there is serious concern to examine the incidence of flash flood in the area. Given the above, this study on flash flood risk assessment in Niger Delta cities is carried out in selected urban centres in the area. Basically, Port Harcourt metropolis and Uyo metropolis are selected for this study because of the fact that these two cities have gluts of swampy basins cross-crossed by myriad of rivers and creeks (Amangabara and Obenade, 2015 and Eyinlaand Ukpo, 2006) which laze directly in the wet equatorial climatic belt. Bonny and New Calabar River Systems and various associated creeks and streams drain the Port Harcourt region while the Qua River, the Ibeno River and the Itu River and other creeks and streams drain the Uyo metropolitan area (Amangabara & Obenade, 2015).

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Secondly, Port Harcourt metropolis was chosen for this study because of their high urban population size which make these cities vulnerable to flash flood. The National Population Commission (NPC) (2019) puts the population figures of Port Harcourt metropolis in 2019 as 2,873,000, Uyo in 2019 as 1,773,000, Yenegoa in 2019 as 470,800, Benin city in 2019 as 1,676,000, Calabarin 2019 as 555,000, Asaba in 2019 as 407,126 and Warri in 2019 as 814,000. Therefore, Port Harcourt metropolis which often experienced flash flood has been a source of worries to urban planners.drainages. These have caused the tremendous changes experienced in our natural earth system. Also, there have severe coastlines and shorelines inundation, increased paved surfaces and devastating human impact on the hydrological cycle. The continued deforestation of the urban buffer zone vegetation and the increased global climate change have all accelerated the spate of torrential rainfall, thereby increasing the runoff and storm water generation rate which consequently result to flash flood. This has resulted to increase level of vulnerability resulting to loss of property, destruction of arable lands, loss of thousands of lives and displacement of millions of people.

The lack of proper delineation of potential flash flood and inundation area to produce flash flood and inundation area to produce flood maps to show the actual extent of inundation of flood plain is a serious problem. The issue of poor land use control and improper urban planning, lack of knowledge of land use and land cover changes and dearth of expertise in the application of GIS in modeling flash flood risk assessment also exacerbate the problem. Thus, in the era of computer simulation, it becomes imperative to assess the risk associated with flash flood prone areas using the state-of-the-art technology with a view to proposing remedial measures to combating urban flash flood. This study therefore seeks to determine flash flood risk assessment in selected urban centres of Port Harcourt in the Niger Delta region of Nigeria as flash flood occurrences are frequently experienced in these cities due to high population concentration and topographical structure.

Flash flood in recent time has caused devastating effect in urban areas resulting to loss of lives, destruction of property and displacement of millions of people. Current evidence and observation have shown that the occurrence of urban flash flood is as a result of increased urbanization, land use and land cover changes, uncontrolled development, human attraction and encroachment of flood plains and wetlands, and the blockage river channels, divides and drainages. These have caused the tremendous changes experienced in our natural earth system. Also, there have severe coastlines and shorelines inundation, increased paved surfaces and devastating human impact on the hydrological cycle. The continued deforestation of the urban buffer zone vegetation and the increased global climate change have all accelerated the spate of torrential rainfall, thereby increasing the runoff and storm water generation rate which consequently result to flash flood. This has resulted to increase level of vulnerability resulting to loss of property, destruction of arable lands, loss of thousands of lives and displacement of millions of people.

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To facilitate the attainment of the goal of this study, the following research questions are put forward:

1. How does storm-water generation vary across each of the study area under consideration?
2. What is the potential level of inundation due to flash flood across the study area?
3. How does land use and cover affect the inundation levels across the study area?
4. What is the pattern of flash flood vulnerability across the study area?

1.4 Aim and Objectives of the Study

The aim of the study is to determine flood vulnerability of selected catchment of Port Harcourt Metropolis in Niger Delta, Nigeria. The specific objectives are to:

1. Model the variation in storm-water generation within each of the city in the study area
2. Model potential level of inundation of flash flood within the city of the study area
3. Analyze the level of inundation of flash flood on land use /cover within the metropolis under consideration.
4. Model the vulnerability of selected urban catchment to the pattern of flash flood in the area.

Conceptual framework

The DPSIR Framework

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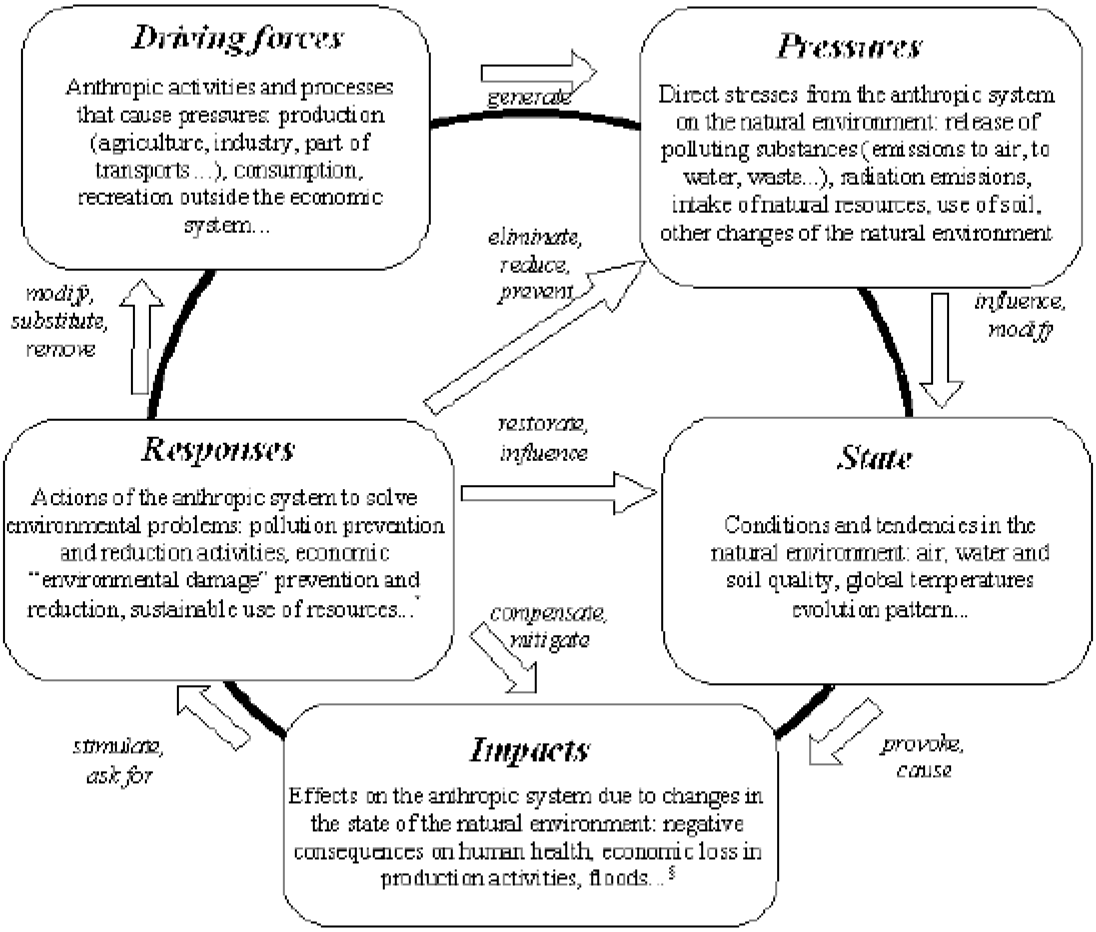

Fig. 1: The Drivers – Pressures – State – Impact Response (DPSIR) Model / Framework for flash flood risk assessment
Source: Adapted from United Nations, 2009

CONCEPTUAL FRAMEWORK

Water Cycle

The water cycle also known as the hydrological cycle or hydrologic cycle, describes the continuous movement of water on, above and below the earth's surface, a perpetual movement of water throughout the various components of the earth's system. The water in the earth system is stored in the oceans, in the atmosphere, including on the earth surface as well as under the earth/land surface. Panago and Soroshian (2002), have observed that the mass of water in the earth system remains fairly constant over time but the partitioning of the water into the major reservoirs of ice, fresh water, saline water and atmospheric water and underground water is variable depending on a wide range of climatic variables. In this cycle, water moves from one reservoir to another, such as from river to ocean, or from the ocean to the atmosphere, by the physical processes of evaporation, condensation, precipitation, infiltration, surface run off, and subsurface flow, as such, the water goes through different forms; liquid, solid (ice) and vapour (Fig. 2).

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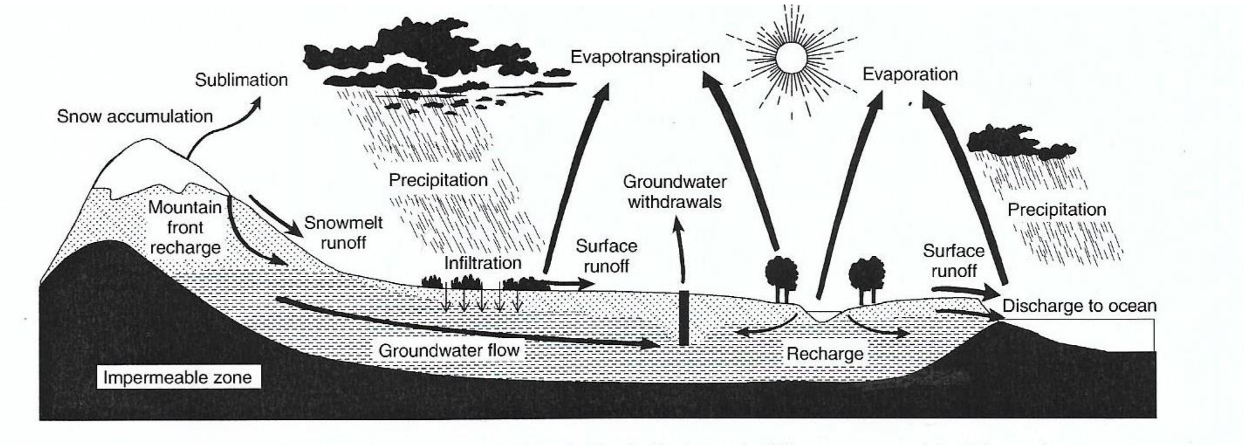

Fig. 2: A schematic diagram of various fluxes within the hydrologic cycle

METHODOLOGY

Study Area

Physical Location

The study area for this research comprises of Port Harcourt metropolis located within the vicinity of latitudes 4°45[1] N to 4[0]55[1] N of the equator and longitude 6[0]55[1]E to 7[0]05[1] E of the Greenwich meridian (Census, 2006). Port Harcourt is the capital of Rivers State (Fig. 3)

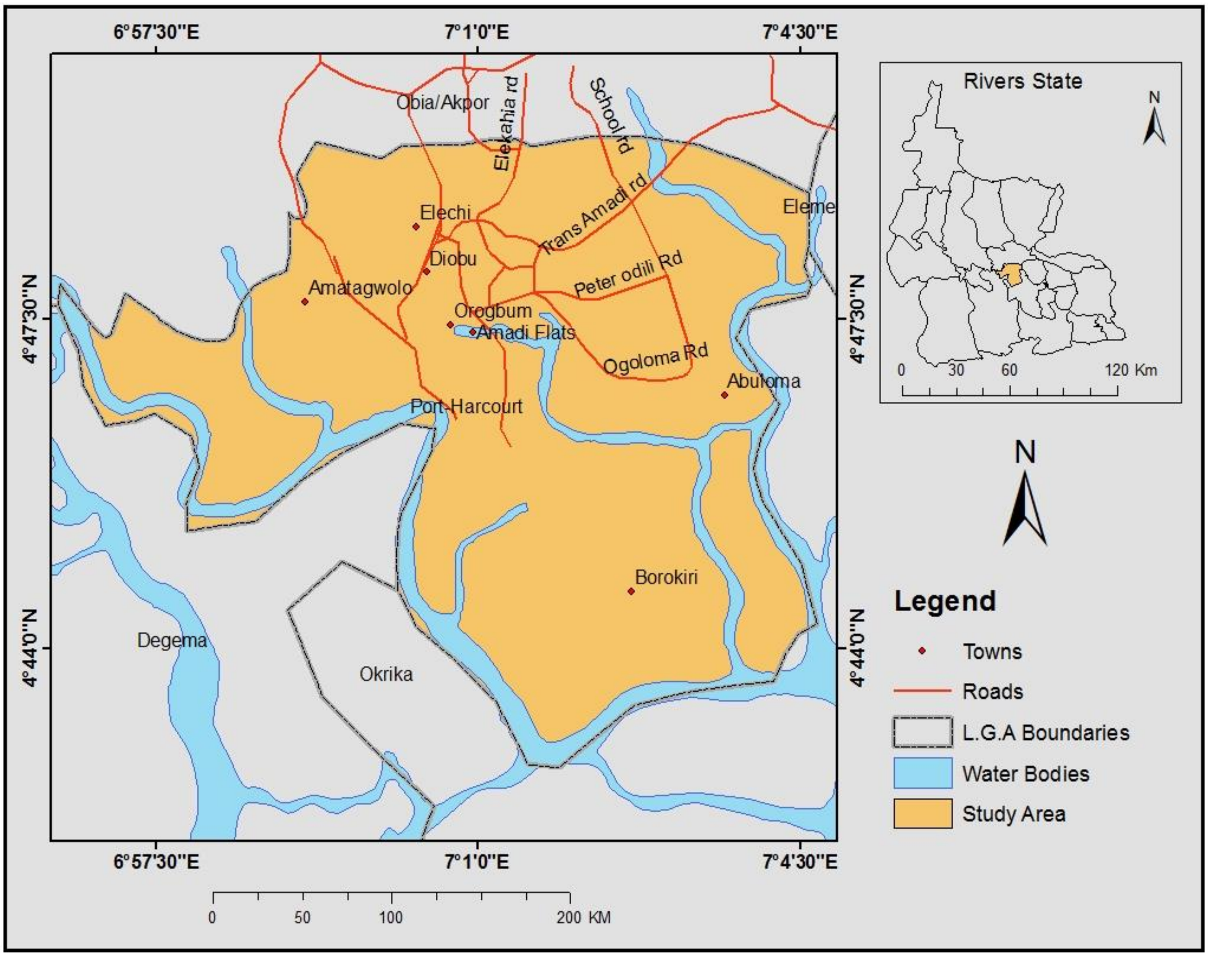

Fig. 3: Port Harcourt Metropolis and Environs

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Climate

Port Harcourt metropolis has a unique tropical climate. The climatic condition of Port Harcourt average has an annual temperature of 26.4ºC and the precipitation is within 2708mm annual rainfall averages 2509mm (Oyegun, 1994).

Relief and drainage

The relief of the study is such that the area falls within the coastal belt dominated by low lying coastal plains which structurally belong to the Agbada and Akata formations. The area is low lying thereby making the flow of water and surface run-off to have hitches in its flowing pattern. The monotonously flat landscape comprises of coastal plains criss-crossed by a labyriath of swamp, creeks and water ways, indicating a relatively scarcity of firm and extensive land mass. The Bonny river, new Calabar and Andoni rivers not only received the intricate network of creeks and waterways from the region but also serve as major in lets of the water of the Atlantic ocean into the area.

Soil and Geology

The soil of the area consists of various types of super final deposits overlying thick tertiary sandy and clayey deposits which are over 100m thick in places. The consistently high rainfall and temperature of the area encourage intense chemical weathering of the rocks, which result in the formation of clay minerals that are ubiquitous in the region (Oyegun, 1994). The area is made of two broad groups of soil derived from the sediments and those formed on younger quaternary and recent alluvium.

Economy

The major economy of the area is predominantly farming, fishing, trading, craft making, canoe carving, and mineral exploration and production as the area is blessed with abundance oil mineral resources. The numerous sea pots and petrochemical plants provide huge economic benefits to the area and this attract large population of immigrants into the area thereby increasing the spate of growth of these urban centres leading to increased flooding.

The data for this study shall be the secondary data. These data shall be generated from Landsat imageries of the study area showing the digital elevation of the area and the water shed pattern, the land use and land cover maps for a supervised classification of land uses in the areas.

METHODS OF DATA COLLECTION

The data for this study shall be collected using Geographic InformationSystem (GIS) aided computer simulation from United States Geologic Survey (2020). The storm-water shall be generated across the study area through enhanced DEM developed for the area to show the level of inundation based on land cover. Water shed delineation and partitioning shall be done also to capture the vulnerability level of the inundated area.

METHOD OF DATA ANALYSIS

The data for this study was analyzed using hydrological models and modeling techniques to achieve the objective of the study.

1. Storm water Generation Assessment: To model storm water generation across the small catchments, the flood hydrograph modeling was done using these steps:

i) Get the DEM data for the study areas
ii) Run a model using the DEM data on a GIS software (Sensitinel-2) to show the storm water generated.
iii) Weigh and overlay the DEM data in the principle of pair-wise comparison of storm water runoff against rainfall intensity and terrain pattern using multi criteria evaluation techniques.
iv) Produce the volume of the runoff which is plotted to show the flood hydrograph.

Thus, the enhanced Digital Elevation Model (DEM) developed for the small catchment across cities was used. This technique was adopted by Araro et al (2019) in assessing flash flood risk in urban environment of Taibah and Islamic University Campuses of Kingdom and Lian et al, (2017) on flash flood vulnerability assessment for small catchment with material flow approach to show the relationship between exposure, sensitivity and adaptive capacity in a smallcatchment. Adopting the procedure of Amro et al (2019) and Lian et al, (2017), a flood hydrograph for the small catchment across the cities of Port Harcourt and Uyo will be generated using enhanced DEM to be developed as shown in the steps above. This was used to determine and model the approachof runoff/storm water generated.

2. Inundation Modeling

Watershed/catchments modeling was used to delineate the catchment/watershed and carry out hydrological modeling using soil, climate, elevation, drainage data for the study area in order to measure the potential level of inundation of flash flood across cities. The AQUAVO water shed modeling system (WMS) will be used to model rainfall runoff across the study area. In this current study, the WMS software as adopted by Amro et al (2019) and Lian et al, (2017), will be applied to delineate the catchments across the cities. This will show the inflow of flood and runoff simulation and potential level of inundation in the study area.Also, a component of the level of inundation across the catchments/segments of the cities based on land cover combination was also be carried out.

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3. Assessment of Relationship between Land Cover and level of Inundation

The following steps were taken:

1. Get the land cover of the cities
2. Recreate inundation level of material flow to land covers.
3. Compare inundation level based on land cover.
4. Then ANOVA was used to compare inundation level to land cover. The ANOVA techniques consists of obtaining two independent estimates of samples of variables, that is, between sample variance or between sample sum of square (BSS), and the other based upon variability (difference) within sample, that is, within sample variance or within sample sum of squares (WSS). The variables for ANOVA include: (i) slope and layer derived from 30m x 30m resolution DEM data (ii) Soil layer (iii) Land use/land cover type (iv) Land shape factors (terrain pattern).However, the most recent land cover data was drawn from satellite imageries and the dominant land covers across different areas would be extracted and level of inundation compared.

4. Evaluation of Flash Flood Vulnerability using Modeled Inundation

Vulnerability assessment will be carried out using Jenk's classification based on the level of inundation modeled. Areas would be classified into 5 groups: Very High (VH), High (H), Moderate (M), Low (L) and Very Low (VL) vulnerability classes. The cities would be partitioned into hydrological segments. Each hydrological unitwould be partitioned into small catchments/watershed units and the catchments/watershed units will be partitioned into hydrological response unit (HRUs) and proportions of different land use and land cover will be derived. This was adopted by Woubet and Belachew (2011) to assess flood hazard and risk assessment using GIS and remote sensing in Fogera Woreda, northwest Ethiopia.

RESULTS AND DISCUSSION

This chapter involves the results presentation and discussions of findings in the study areas.to be presented in the light of the study aims and objectives which involves to analyze the probability and occurrence/variation of stormwater generation across the cities in the study area, to examine the severity of occurrence and the potential level of inundation of flash flood across the cities in the study areas, analyze the level of inundation of flash flood on landuse/landcover across the cities under consideration, to examine the probability/severity patter of flash flood matrix across the study areas based on the study of Amro et al[2010] and Lian et al [2017] on Flood risk assessment on selected urban catchments in Taibah and Islamic Universities campus in Saudi Arabia, also the result and findings is based on the study of Luminin et al [2018] on spatial assessment of urban flood suspectability using Data mining and Gistools. Also the results and findings is also based on the study of Hayder and Husan[2013] on Maximum likelihood for Landuse/land cover mapping and change detection using Landsat satellite imagery of South Johor .and finally the study of Mohammed et al[2016] on spatial distribution pattern and terrain analysis of urban flash flood and inundated areas in Maiduguri, Nigeria which used Digital Terrain Model [DTM] generated from the Shuttle Radar Topography Mission to generate hydrological parameters to show areas liable to flooding and inundation from a 3- dimensional DTM of the area, but failed to model stormwater generation in the area ,model the level of inundation and also failed to evaluate the level of vulnerability of elements at Risk to Urban flash flood in the study area, the testing of hypothesis is also involved (Table 1).

Table 1: Stream Parameters

Stream Parameters	Port Harcourt
Total Stream Length (m)	339991.67
Average Stream Length (m)	1086.24
Number of Streams	313
Standard Deviation	886.39
Minimum (m)	46.08
Maximum (m)	5771.86
Highest Flow Length (m)	0.17

Storm-water generation in Port Harcourt Metropolis

The description of stream parameters in Port Harcourt Metropolis is shown in Table 4.1. In Port Harcourt, the analysis showed that the total length of streams was 339991.67m and the mean length was discovered to be 1086.24m. In total, there were 313 streams in Port Harcourt Metropolis and the highest flow length was 0.17m. In Uyo Metropolis, the total length of streams was 312894.25m and the average length was 1246.59m. There were 251 streams that were found in Uyo Metropolis and the highest flow length was 0.14m. From the analysis, it can be deduced that there are more streams in Port Harcourt Metropolises than that of Uyo Metropolis but the average length of streams was higher in Uyo than Port Harcourt.

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The sub-catchment analysis in the study areas revealed that Port Harcourt had more basins than Uyo Metropolis. Port Harcourt had 654 sub basins while Uyo had 21 sub basins (Table 2, Figures 4.2, 4.3, 4.7). The total area of basins in Port Harcourt was 446101922.54 sq m while in Uyo, it was 248746367.20 sq m. In Port Harcourt, the area ranged between 5456.12 sq. m to 68591447.12 sq m with the mean value of 1388006.17 sq.m, whereas in Uyo Metropolis the area of sub basins ranged from 1187688.18 to 92699584.59 sq m with the mean value of 11845065.10 sq m.

Table 2: Sub Basin Parameters

Sub Basin Parameters	**Port Harcourt**
Total Number of Basins	654
Total Area (Sq. m)	446101922.54
Minimum (Sq. m)	5456.12
Maximum (Sq. m)	68591447.12
Average Area (Sq. m)	1388006.17
Standard Deviation (Sq. m)	4246555.79

Source: Researcher's Analysis, 2020

The digital elevation model of Port Harcourt was found to range between -6m to 39 m in Figure 4 and there are quite sub basins of varying sizes in Port Harcourt Metropolis (Figure 5). The flow length of streams in Port Harcourt Metropolis ranged from 0m to .174054m (Figure 6). On the other hand, the digital elevation model of Uyo ranged from 11 m to 77m (Figure 7). This shows that the topography of Uyo is higher than that of Port Harcourt. The sub basins in Uyo Metropolis are also of different sizes as some are significantly large especially at the centre of the metropolis (Figure 7). The flow length of streams in sub basins ranged from 0m to 0.144281 (Figure 8). Thus the flow length of streams in Uyo sub basins is lower than that of Port Harcourt Metropolis.

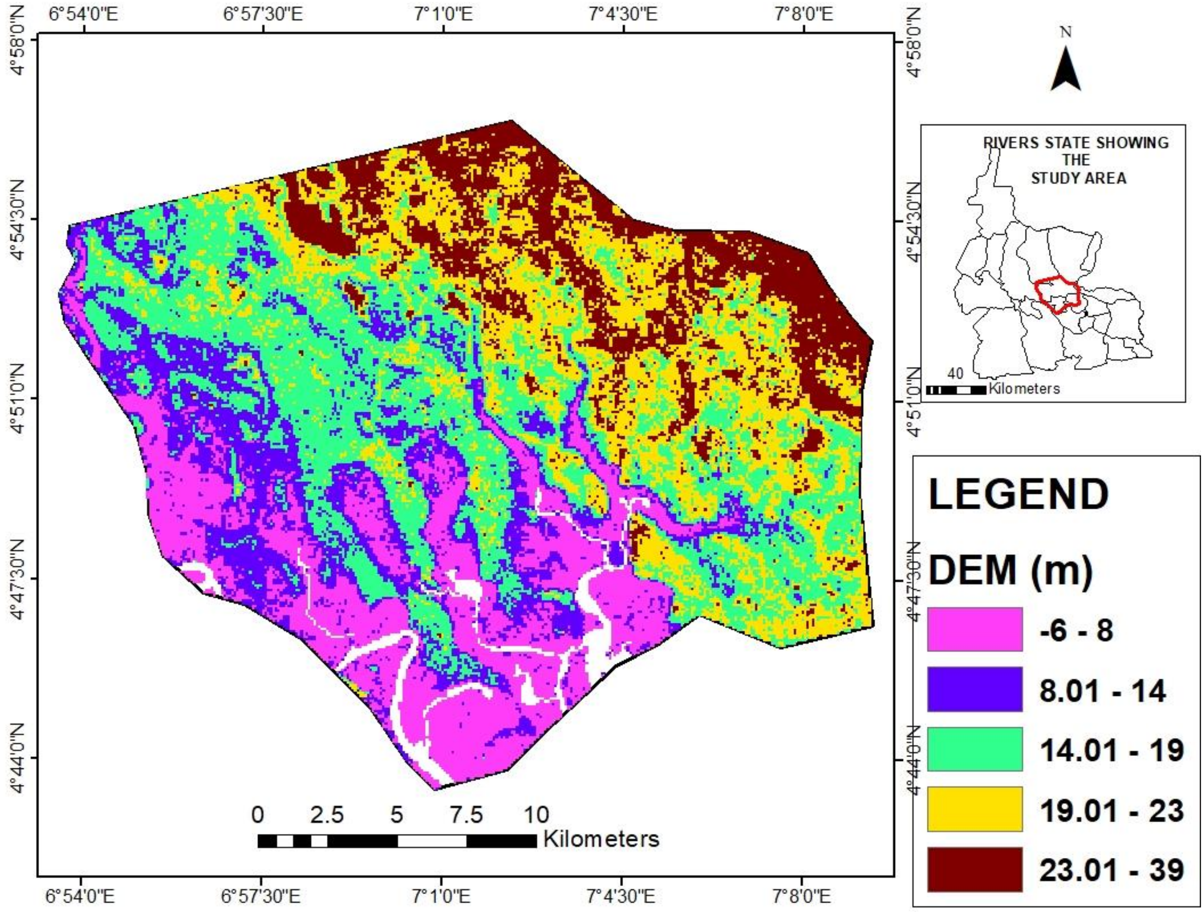

Fig. 4: DEM of Port Harcourt Metropolis

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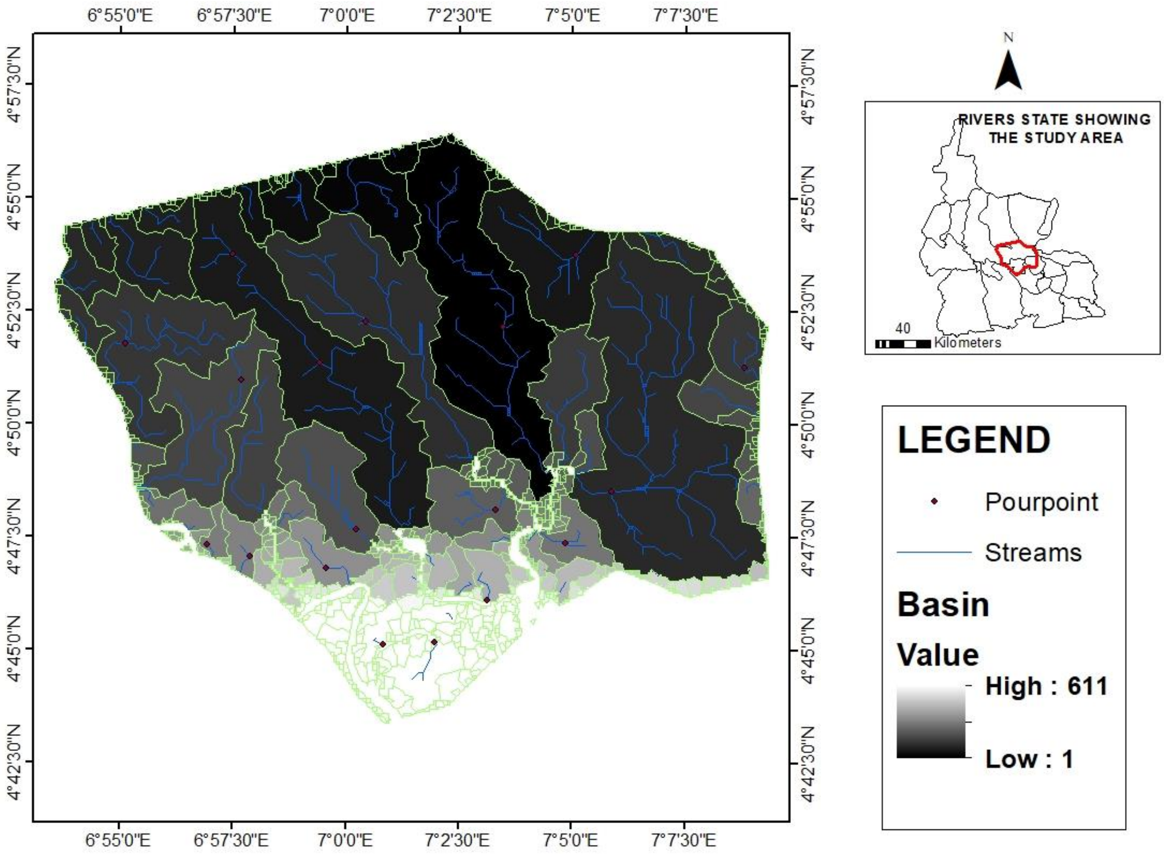

Fig. 5: Basins and Streams in Port Harcourt Metropolis

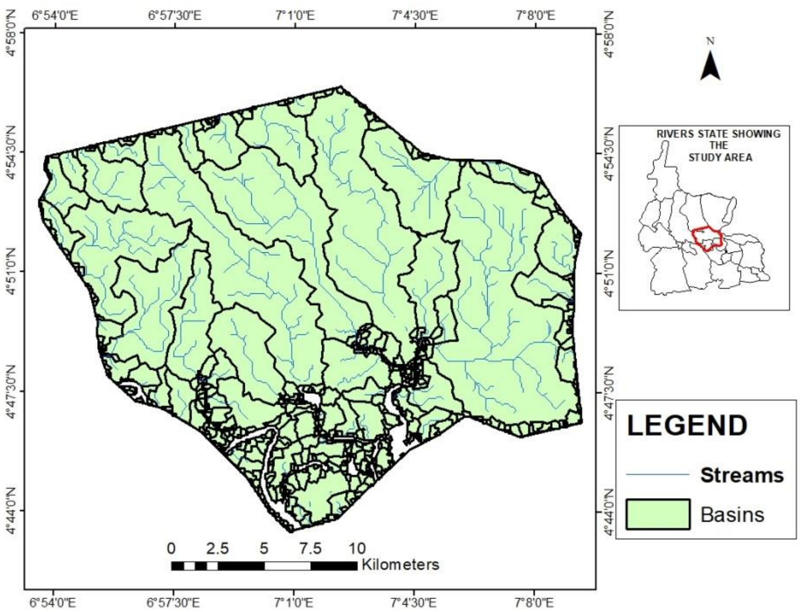

Fig. 6: Basin Polygons and Streams in Port Harcourt Metropolis

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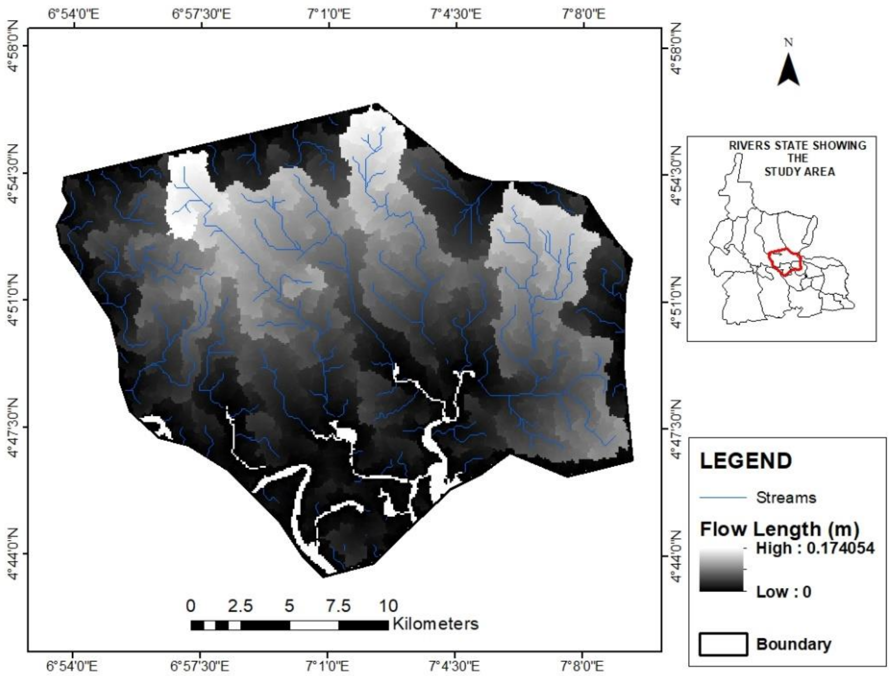

Fig. 7: Flow Length of Stream in Port Harcourt Metropolis

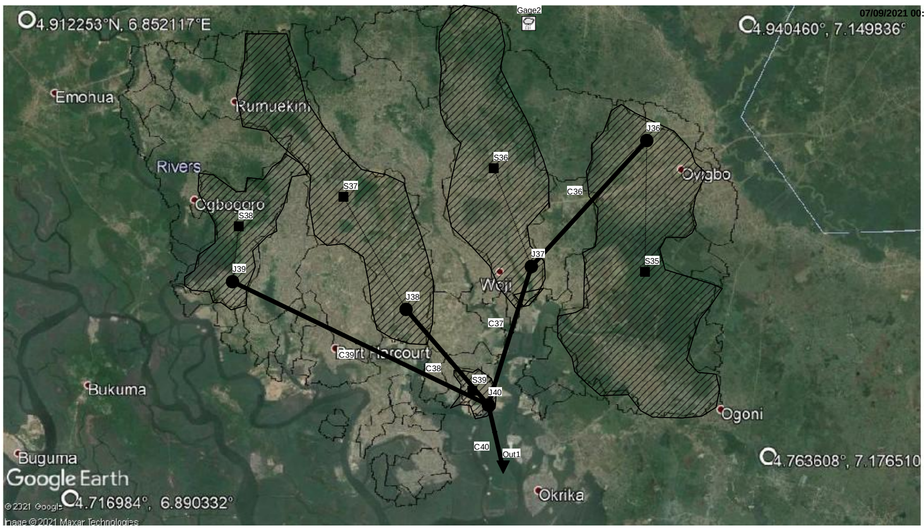

Fig. 8: Delineated Sub catchments, Links and Nodes in Port Harcourt Metropolis

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Table 3: Sub-catchment Runoff in Port Harcourt

Sub catch ment	Total precipitation (in)	Total Runon in	Total Evaporation in	Total Infiltration in	Impervious Runoff in	Pervious Runoff in	Total Runoff in	Total Runoff 10^6 gal	Peak Runoff CFS	Runoff Coeff
S35	1.57	0	0	0.79	0.74	0	0.74	0.08	0.73	0.472
S36	1.57	0	0	0.79	0.74	0	0.74	0.08	0.73	0.472
S37	1.57	0	0	0.79	0.74	0	0.74	0.08	0.73	0.472
S38	1.57	0	0	0.79	0.74	0	0.74	0.08	0.73	0.472
S39	1.57	0	0	0.79	0.74	0	0.74	0.08	0.73	0.472

Table 4: Link Flow in Port Harcourt

Link	Type	Maximum Flow (CFS)	Day of Maximum Flow	Hour of Maximum Flow	Maximum Velocity ft/sec	Maximum/ Full Flow	Maximum Full Depth
C36	CONDUIT	0.73	0	6:00	3.56	0.07	0.14
C37	CONDUIT	1.46	0	6:00	5.26	0.11	0.18
C38	CONDUIT	0.73	0	6:00	4.22	0.06	0.11
C39	CONDUIT	0.73	0	6:00	3.92	0.06	0.12
C40	CONDUIT	3.64	0	6:00	9.35	0.18	0.26

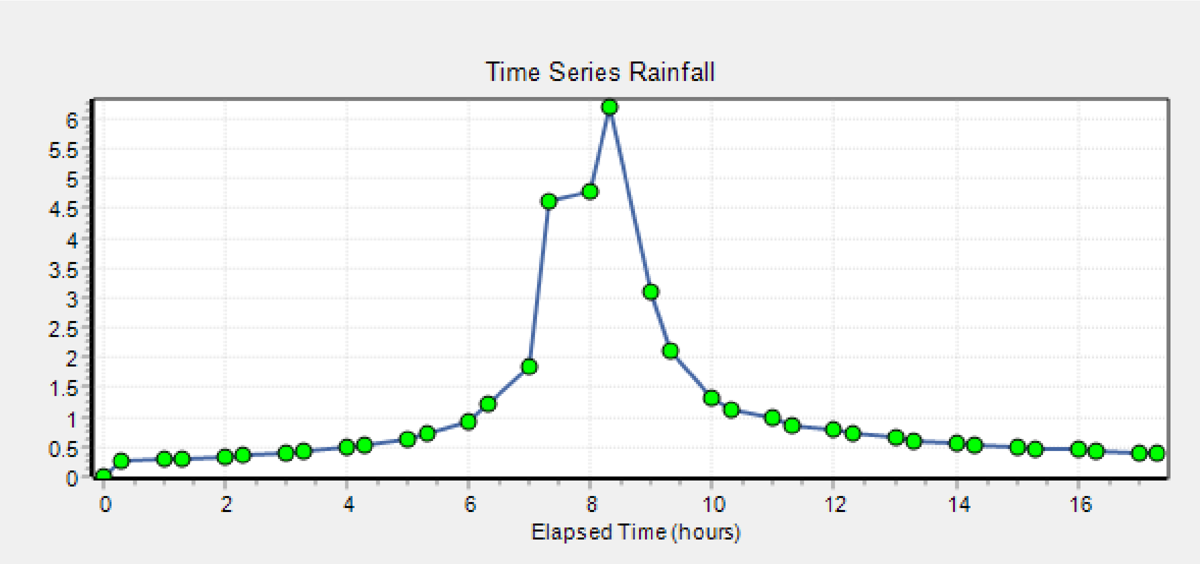

Fig. 9: Time Series of Precipitation Data in Port Harcourt

Table 5: Summary of the Sub Catchment Precipitation, Node Flooding and Link Volume in Port Harcourt Metropolis

Time (Hr)	Sub Catchment Precipitation (in)	Node Flooding (CFS)	Linking Volume (ft^3)
0:00	0	0	0
0:15	0.01	25	100
0:30	0.02	25	100
0:45	0.02	25	100
1:00	0.28	75	100
1:15	0.28	75	100

1:30	0.28	75	280
1:45	0.28	75	280
2:00	0.29	75	280
2:15	0.29	75	280
2:30	0.29	75	280
2:45	0.29	75	280
3:00	0.29	75	280
3:15	0.29	75	280
3:30	0.31	75	280
3:45	0.31	75	460
4:00	0.31	75	460
4:15	0.33	75	460
4:30	0.33	75	460
4:45	0.33	75	460
5:00	0.36	75	460
5:15	0.36	75	460
5:30	0.36	75	460
5:45	0.36	75	460
6:00	0.39	75	460

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Table 6: Land use/Land cover Vulnerability Levels to Flood

S/n	Land use	Spatial Extent (m^2)	Percentage (%)	Vulnerability Assigned Values	Vulnerability Levels
1	Water bodies	49815513.54	10.87	3	High Vulnerability
2	Wetlands	41171466.91	8.99	2	Moderate vulnerability
3	Farmlands/Sparse Vegetation	96199667.97	21.00	2	Moderate vulnerability
4	Built Up Area	185250584.42	40.43	3	High vulnerability
5	Thick Vegetation	85710458.96	18.71	2	Moderate vulnerability
	Total	458147691.8	100.00		

Source: Researcher's analysis, 2021

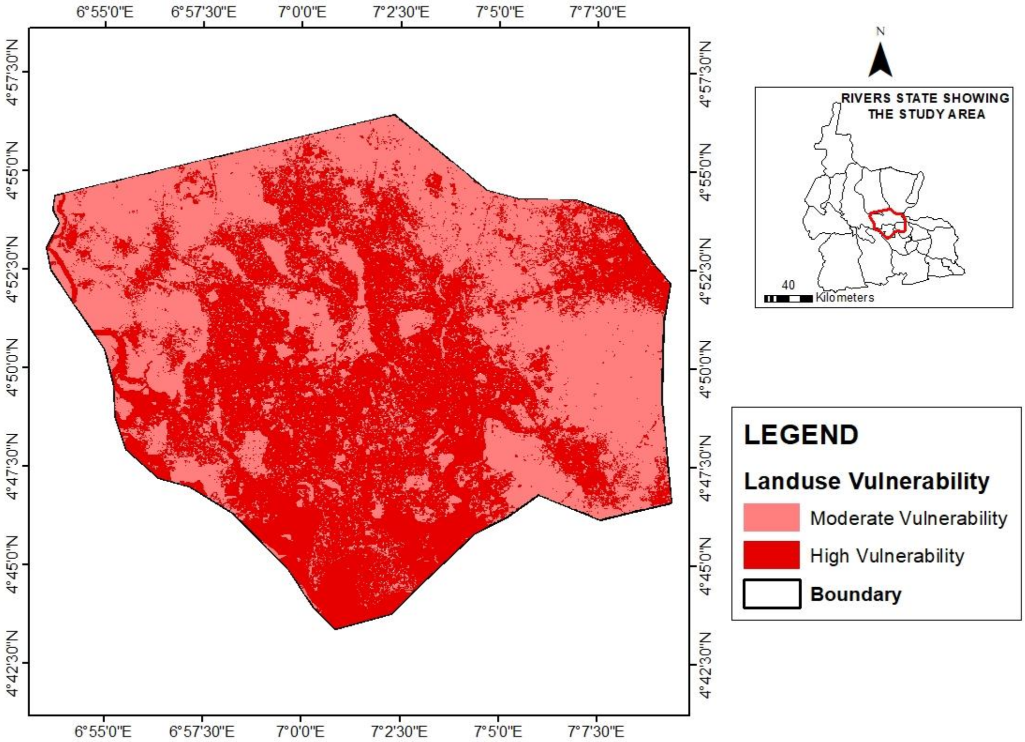

Fig. 10: Landuse/Land cover Vulnerability Map to Flood in Port Harcourt Metropolis

Storm water attributes in the Study Areas

Storm water attributes in the Port Harcourt

Based on the study aims and objectives which involves to analyze the occurrence and variations of stormwater generation across the study areas.

Table 4.3 summarized the simulated sub catchment runoff in Port Harcourt Metropolis whereby 4 sub catchments were used for the runoff generation (Figure 4.8). It is vividly shown that the total precipitation in each of the sub catchment is similar which was 1.57 inches while the total infiltration read 0.79 inches. The total runoff was 0.74 inches and 0.08 x 10^6 gallons.

The link flow analysis through the conduit or pipe as shown in Table 4.4 reveals that the range of maximum flow of the conduit was from 0.73 CFS to 3.64 CFS while hours of flow was 6 hours. It is thus observed that the conduit C36, C38 and C39 having similar maximum flow still exhibited different rates of maximum velocity. Thus, C36 had 3.56 ft/sec, C38 had 4.22 ft/sec while C39 had 3.92 ft/sec. The other two conduits namely C37 and C40 with higher flow maintained higher velocity as they had 5.26 ft/sec and 9.35 ft/sec respectively. It is equally discovered that the maximum full flow was higher in the conduits with higher flow velocity. The maximum full depth of the conduit appeared to range from 0.11 ft (C38) to 0.26 (C40). Generally, it is shown that flow; velocity of flow, full flow and full depth of conduit followed almost the same pattern against each of the conduit (Figure 4.9).

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The nodes or junctions of inflow in Port Harcourt Metropolis in Table 4.5 were seen to have equal maximum of lateral inflow of 0.73 CFS. It is however discovered further that the maximum total inflow ranged from 0.73 CFS in J36, J38 and J39 to 3.64 CFS in J40. The Outfall was also having 3.64 CFS total inflow. Although the lateral inflow volume in all the nodes was similar (0.0796 x 10^6 gal) but the total inflow volume of the nodes varied and ranged from 0.0796 x 10^6 gal to 0.396 x 10^6 gal; whereas the outfall had 0.394 x 10^6 gal. It could be deduced from the analysis that total inflow is proportional to the total inflow volume in the nodes or junctions (Figure 4.10).

The node depths in Port Harcourt Metropolis are given in Table 4.6 had varying depths ranging from 0.12 ft in J38 to 0.27 ft in J40 and Out1. The maximum depth among the nodes was highest in J40 and Out 1 (0.39 ft) while the minimum was found in J38 (0.17 ft). The maximum HGL ranged from 13.39 ft in J40 to 23.2 ft in J36. The maximum HGL in Out 1 was 3.39 ft.

The outfall loading shown in Table 4.7 revealed that the flow frequency was 82.36% while the average flow was 2.97. The maximum flow was 3.64 CFS and total volume of storm water was 0.394 x 10^6 gal in Port Harcourt Metropolis.

Sub Catchment Runoff, Node Flooding, and Linking Volume

The sub catchment runoff, node flooding and linking volume of Port Harcourt Metropolis is observed here. The situations at different times of the day are shown in Figures 4.20 (0.00-01.00mins), 4.21 (01.15-01.30mins), 4.22 (01.30mins-01.45mins), 4.23 (01.45mins-05.15mins), and 4.24 (05.15mins-06.00mins) in Port Harcourt Metropolis. In Table 4.15, the analysis revealed that the catchment runoff, node flooding and linking volume increased with increasing time of the day. The sub catchment runoff ranged from 0 in to 0.73 in; node flooding ranged from 25 to 100 CFS while link volume ranged from to 100 ft^3 to 460 ft^3. The simulation of the sub catchment runoff, node flooding and linking volume was not deduced.

Nature of Water Elevated Profiles/Hydrographs in the Study Area

The nature of water elevated profiles or hydrographs though the conduit between different nodes and the outfall in the study area are discussed in this section. In Uyo Metropolis, three different water elevated profiles were generated while two were generated Port Harcourt Metropolis. For Port Harcourt Metropolis, the water elevation profile included from Node 36 to Out 1 (Figure 4.31); and that of Node 38 to Out 1 (Figure 4.32). The one from Node 36 to Out 1 was increasing in elevation with increasing distance to the Outfall while the one for Node 38 to Out 1 continued to decrease. The water elevation profile in Uyo Metropolis included the Node 1 – Out 1 (Figure 4.33), Node 6 to Out 1 (Figure 4.34), Node 7 to Out 1 (Figure 4.35). All of them continue to decrease in elevation with increasing distance to Outfall except the one in Node 6 to Out 1.

Flood Vulnerability in Port Harcourt

Landuse Map Vulnerability

The landuse map vulnerability to flood was determined according to the vulnerability levels assigned to each landuse identified in the study area. Table 4.18, Figure 4.36 and Figure 4.37 explain the types of landuse discovered and the spatial extent of each of them. The built up area had the highest spatial extent (185252584.42 m^2), followed by farmlands/sparse vegetation having 96199667.97 m^2. The analysis also revealed that wetland recorded 41171466.91m^2 while waterbodies had 49815513.54 m^2 and the thick vegetation had 85710458.96 m^2. The built up area covered 40.43%, farmlands/sparse vegetation covered 21% while waterbodies, thick vegetation and wetlands covered 10.87%, 18.71% and 8.99% respectively. The analysis further showed that the spatial extent of the area for moderate flood vulnerability was 48.7% while high flood vulnerability was 51.3%.

Flood Vulnerability Map based on Elevation

The flood vulnerability level based on elevation is shown in Table 7, Figure 11 and Figure 12. It shows that the high vulnerability zone based on elevation was between -6m and 8m while the moderate vulnerability was between 8.01m and 23m. The high and low vulnerability zone which includes; Elekahia housing estate, Olu-obasanjo road, Mile 3 Market, Mile 1 Market Isaac Boro park, Eastern bye pass, Old GRA/Owuru Creek/Ntawogba creek, Education Bus Stop Diobu, Marine Base, Azikiwe Road, Industry Road, Port Harcourt Township/Dock yard, Creek road sandfill areas, Borikiri and Amadi flat was between 23.01m and 39m. The analysis also revealed that the high, moderate and low vulnerability covered 63559551.04 m^2 (14.24%), 303466356.41 m^2 (67.98%) and 79399875.83 m^2 (17.79%) respectively.

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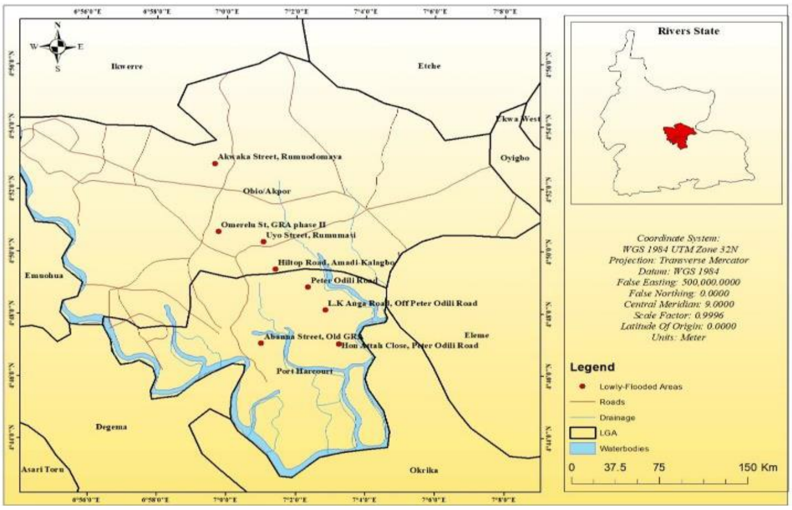

Fig. 11: Lowly Flooded Areas in Port Harcourt Metropolis

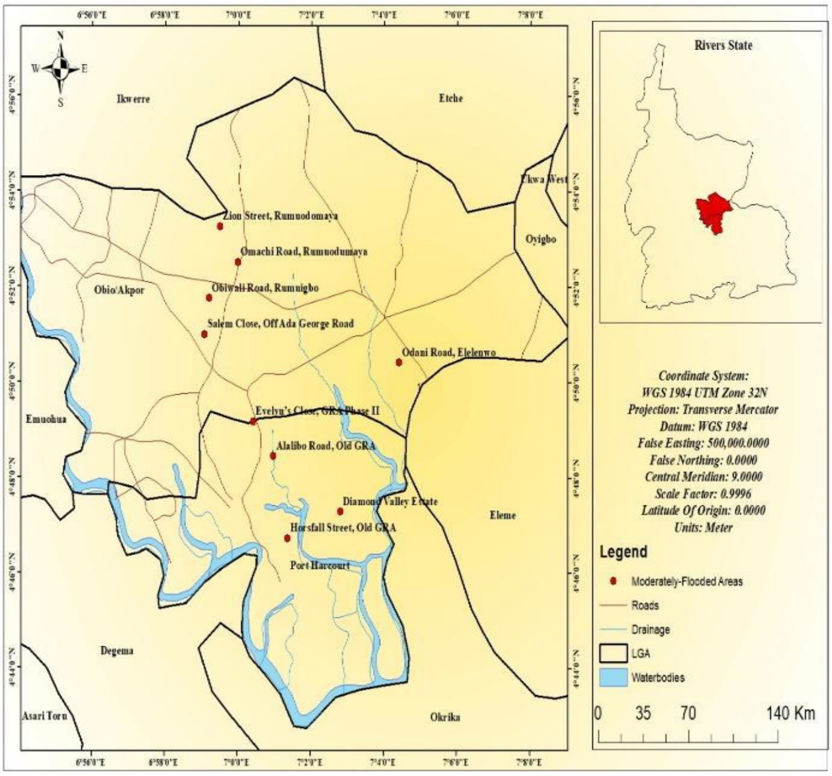

Fig. 12: Highly Flooded Areas in Port Harcourt Metropolis

Table 7: Elevation data of Port Harcourt Metropolis

S/n	Elevation (m)	Spatial Extent (m^2)	Percentage (%)	Vulnerability Assigned Values	Vulnerability Levels
1	-6-8	63559551.04	14.24	3	High vulnerability
2	8.01-23	303466356.41	67.98	2	Moderate vulnerability
3	23.01-39	79399875.83	17.79	1	Low vulnerability
	Total	446425783.3	100.00		

Source: Researcher's analysis, 2021

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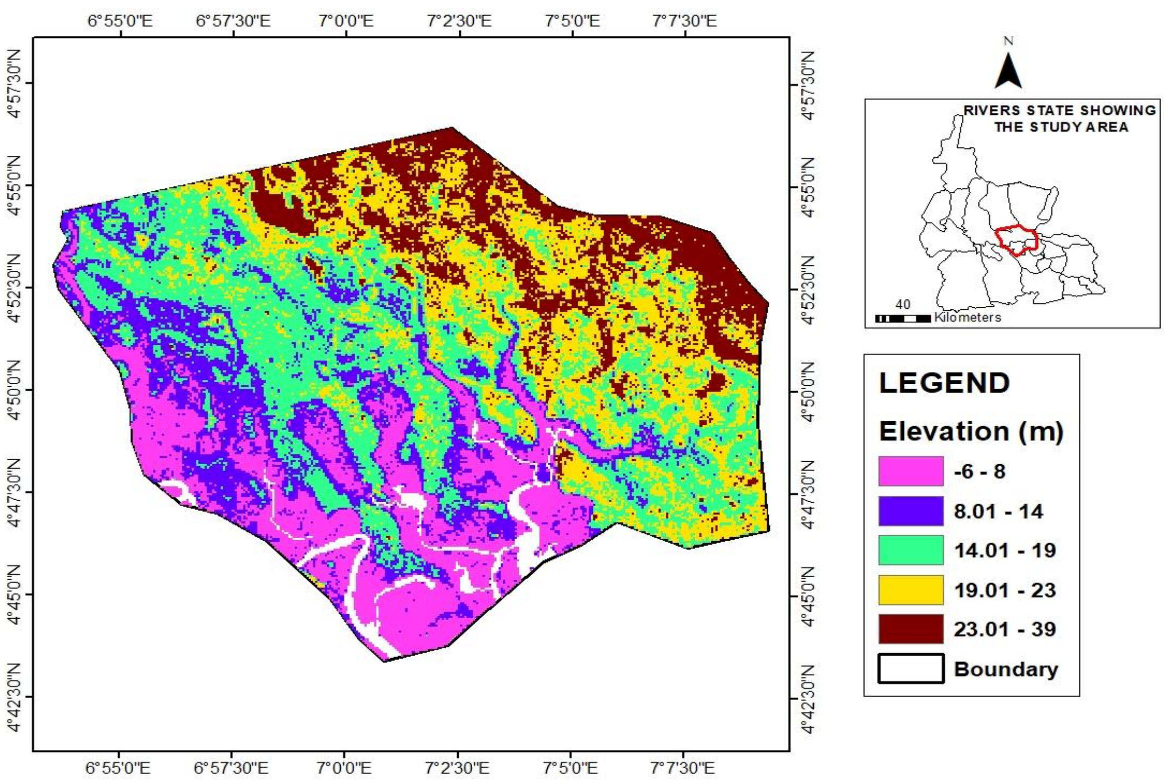

Fig. 13: Elevation of Port Harcourt Metropolis

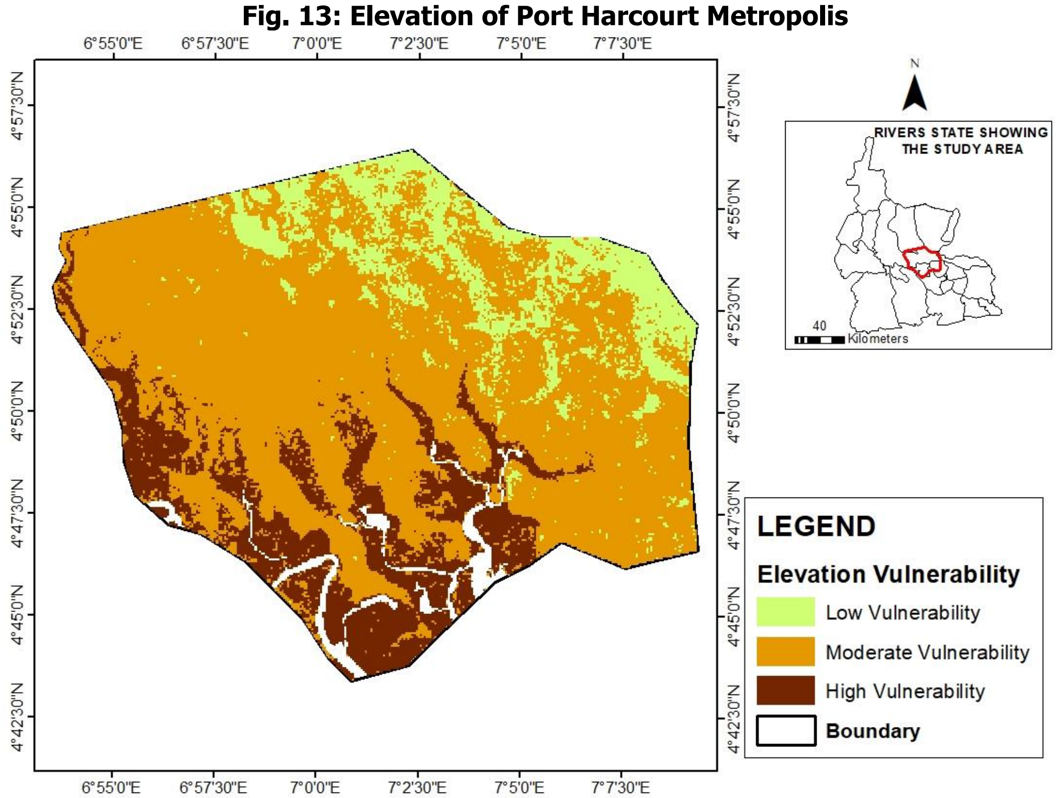

Fig. 14: Elevation Vulnerability of Flood in Port Harcourt

Elevation Vulnerability of Flood in Port Harcourt Soil Texture Vulnerability Map

Table 8 and Figures 15 and 16 describe the soil texture vulnerability to flood of Port Harcourt Metropolis. The analysis showed that the coarse texture covered 400857580 m^2 while fine texture covered 57242676.32 m^2. This shows that 87.5% and 12.5% was for high vulnerable and low vulnerable respectively.

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Table 8: Soil vulnerability of flood in Port Harcourt Metropolis

S/n	Soil	Spatial coverage (m^2)	Percentage (%)	Vulnerability Assigned Values	Vulnerability Levels
1	Coarse Texture	400857580	87.5	3	High vulnerability
2	Fine Texture	57242676.32	12.50	1	Low vulnerability
Total	Total	458100255.9	100.0		

Source: Researcher's analysis, 2021

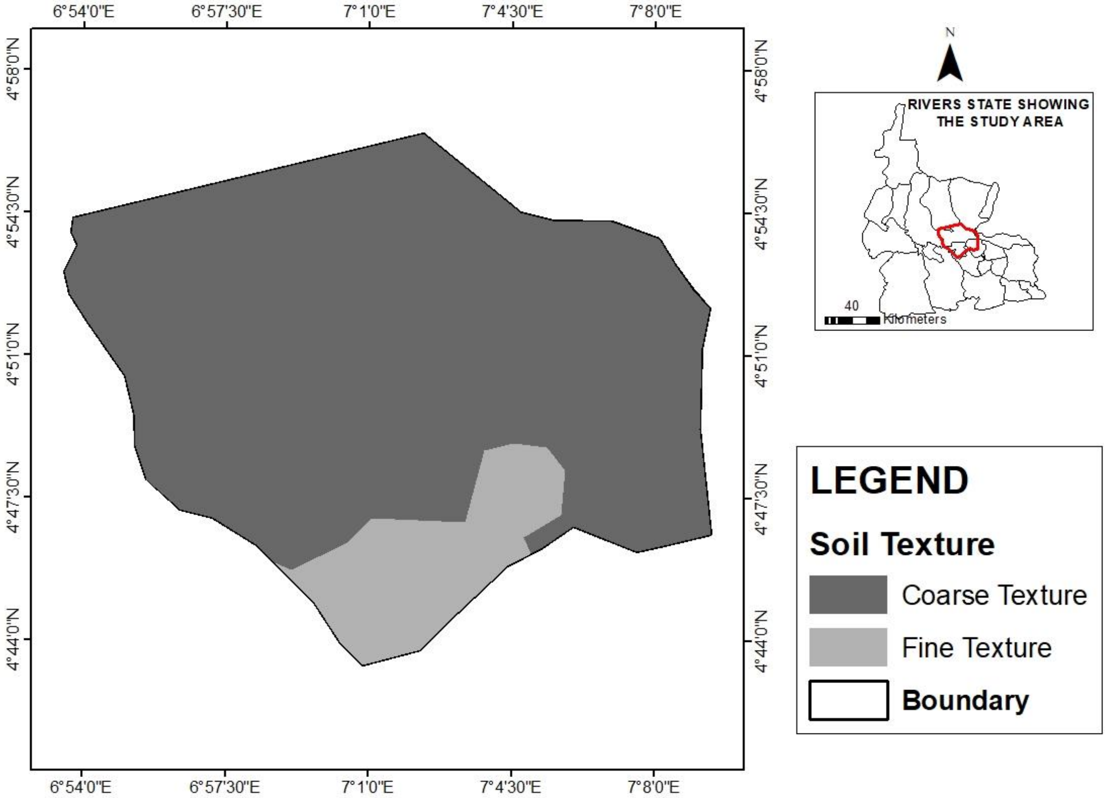

Fig. 15: Soil Texture of Port Harcourt Metropolis

Proximity to River Channel (Drainage) Vulnerability Map

Table 9 and Figures 15 and 16 describe the drainage buffering and drainage vulnerability maps of Port Harcourt Metropolis respectively. The results show that the buffer of 200m from the rivers (i.e. high flood vulnerability level based on the proximity to active channel) covered a spatial extent of 112016821.05 m^2 (36.21%); the buffer of 400m which was regarded to be moderate vulnerability covered 104640095.29 m^2 (33.82%) while the buffer of 600 m known to be low vulnerability covered a spatial extent of 92714238.86 m^2 (29.97%).

Table 9: Drainage vulnerability of flood in Port Harcourt Metropolis

S/n	Buffer Scenarios (m)	Spatial coverage (m^2)	Percentage (%)	Vulnerability Assigned Values	Vulnerability Levels
1	0-200	112016821.05	36.21	3	High vulnerability
2	200-400	104640095.29	33.82	2	Moderate vulnerability
3	400-600	92714238.86	29.97	1	Low vulnerability
Total		309371155.20	100.0		

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Source: Researcher's analysis, 2021

Flood Vulnerability Map and Communities Vulnerability Levels

Table 10 and Figure 16 present the flood vulnerability levels of Port Harcourt Metropolis. The analysis showed that the areas that have low vulnerability to flood were 22842973.93 m^2 (4.97%) of the entire area. The moderate vulnerability areas covered a spatial extent of 342355833.48 m^2 (74.56%), while high vulnerability areas covered 93979859.22 m^2 (20.47%). This implies that areas with moderate and high vulnerabilities covered 95.03% of the entire Port Harcourt Metropolis, which means major part of the study area was prone to flood considering the above factors.

Table 10: Final Flood Vulnerability in Port Harcourt Metropolis

S/n	Vulnerability Level	Spatial coverage (m^2)	Percentage (%)
1	Low	22842973.93	4.97
2	Moderate	342355833.48	74.56
3	High	93979859.22	20.47
Total	Total	459178666.6	100.0

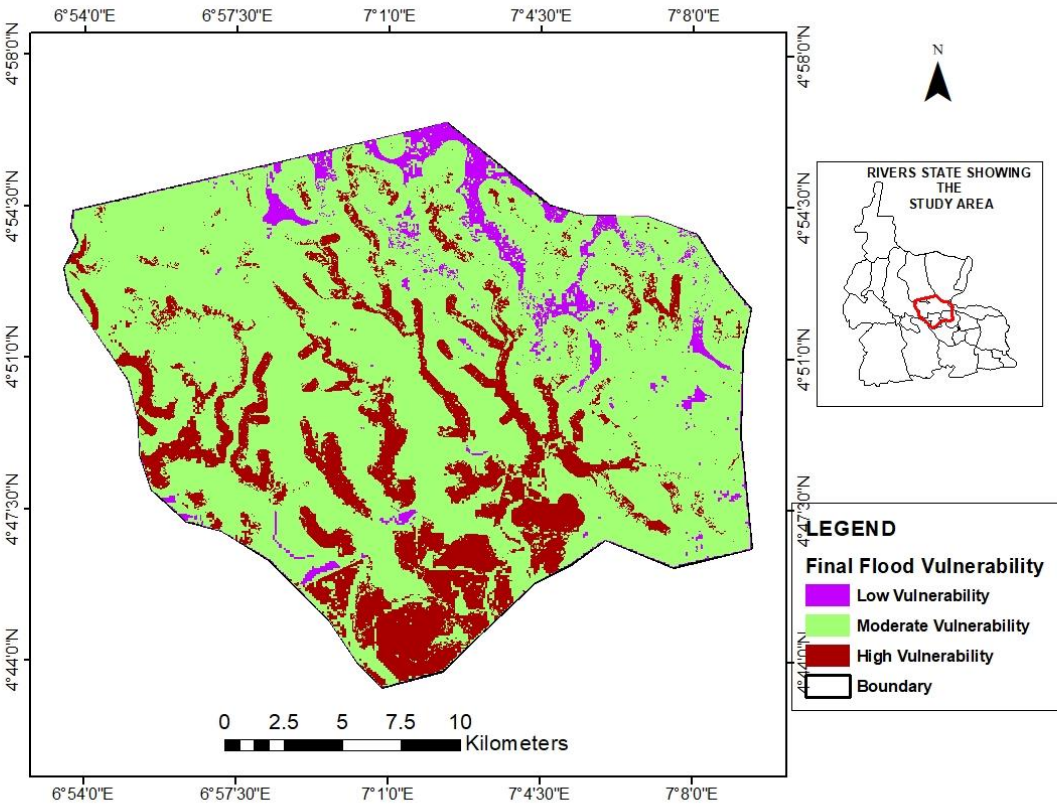

Fig. 16: Flood Vulnerability Levels of Port Harcourt Metropolis

DISCUSSION OF FINDINGS

The study compared the storm water generation and flood vulnerability between Port Harcourt. Due to devastating effect in Urban areas resulting to destruction of Property and displacement of millions of people, sporadic urbanization, human attraction, Land use / land cover changes. uncontrolled development, encroachment of floodplains which occurs as a result of flash flood, blockage of river channels, drainages. Shoreline inundation, devastating human impact on the hydrological cycle, The Findings of the study showed that Port Harcourt the total stream length, number of streams and the flow length was higher in Port Harcourt. However, the average stream length was higher in Port Harcourt Metropolis. Considering the number of sub basins in the study area, findings showed that Port Harcourt had more (654) sub basins.

The sub catchment runoff, Node flooding and link velocity of both Port Harcourt metropolis as presented in Table 4.16, figure 4.25 (0.00 mins – 01/15mins), figure 4.26 (1.15mins – 1.30 mins) and figure 4.27 (1.30mins – 6.00mins) present the sub catchment runoff, Node flooding and link velocity a Port Harcourt metropolis. Similar to other analysis and findings, the runoff, and flooding increased with increasing time of the day while the velocity increased from 0.01ft/sec to 2ft/sec at 1.30mins, and begin to reduce and stayed at 1ft/sec. The analysis/findings in figure 4.28/0.00mins – 03.30mins, 4.29 (03.30mins – 0.400mins) and 4.30 (04.00mins) – 06.00mins indicated three different major changes during the simulations in any of the combined parameters (runoff, flooding or velocity).

Table 4.17 revealed according to finding that the sub catchment run off and node flooding remained unchanged throughout the hour considered. While the link velocity fluctuated from 10.01ft/sec to 0.78ft/sec at 3.30mins and later increased at 4.00mins for the remaining hour of the day.

The nature of water selected profiles/flood hydrograph of the study areas. In Port Harcourt metropolis were the water elevation profile included from node 36 to out 1 (figure 4.31) and that of node 38 to out 1 (figure 4.32). The one from node 36 to out 1 has increasing in elevation with increasing distance to the outfall while the one for node 38 to out 1 outlined to decrease. Analysis and findings for flood vulnerability in Port Harcourt metropolis revealed that the land use map vulnerability to flood according to each land use identified in the study area. It explained the types of land use discovered and the spatial extent of each of them. The analysis further showed that the spatial extent of the area for moderate flood vulnerability was 48.7% while high flood vulnerability was 51.3%.

The types of land use discovered and the spatial extent of each of them, built-up area (141783308.91m^2) vegetation patches (50813320.29m^2). The findings revealed farmland /space vegetation recorded 35785889.00m^2 while water bodies and vegetation patches 10.37% and 19.94% respectively. The findings also showed that spatial extent for moderate flood vulnerability was 33.98% while high flood vulnerability was 66.02%.

SUMMARY

The study compared the storm water generation and flood vulnerability between Port Harcourt Metropolis. Findings showed that Port Harcourt the total stream length, number of streams and the flow length was higher in Port Harcourt. However, the average stream length was higher in Port Harcourt Metropolis. Considering the number of sub basins in the study area, findings showed that Port Harcourt had more (654) sub-basins. Hence the total area of the basin was higher in Port Harcourt, although the average area of the basin was higher in Uyo than Port Harcourt. The digital elevation in Port Harcourt was lower in range. For Port Harcourt, it ranged between -6m to 39m. The total runoff in Port Harcourt Metropolis was higher in Port Harcourt Metropolis (0.74) inches, the maximum flow was 3.64 CFS and total volume of storm water was 0.394 x 10^6 gal. The analysis revealed that rate of change of catchment behavior. The catchment precipitation, node flooding and runoff in both study areas continued to increase with increasing time of the day, although the rate of change of the volume of runoff varied slightly between Port Harcourt. The width of the hydrograph in Port Harcourt was wider. The areas prone to moderate and high flood in Port Harcourt was higher (95.03%).

CONCLUSION

The study can be concluded that the runoff generated in Port Harcourt was higher. Also the flood vulnerability level of Port Harcourt is higher in Port Harcourt considering the land use, elevation, proximity to river and soil texture.

RECOMMENDATIONS

Based on the findings, the study suggested the following recommendations:

1. Government should be fully prepared against flood intensity because of the level of vulnerability to flood in Port Harcourt is found
2. The area liable to moderate and high flood vulnerability should be well guided and guarded to minimize the destruction of lives and properties
3. Better planning of the cities is required to regulate the effect of flooding in the study area

CONTRIBUTION TO KNOWLEDGE

The study has revealed the level of storm water and runoff gradient in Port Harcourt Metropolis. Also, it has helped in comparing the flood vulnerability levels experienced in Port Harcourt. This has helped in providing additional information on the existing volume of literature on flood vulnerability across the Niger Delta areas of Nigeria thereby contributing to knowledge.

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