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RESEARCH ARTICLE

ASSESSMENT OF FLOOD VULNERABILITY CHARACTERISTIC OF STREAMS AND URBANIZED RIVER BASINS IN SOUTHERN NIGERIA

Valentine Barinedum Kponi, Vremudia Onyeayana Wekpe*

Department of Geography and Environmental Management, Faculty of Social Sciences, University of Port Harcourt.
****Corresponding Author email: vremudia.wekpe@uniport.edu.ng***

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ABSTRACT

The catastrophic impact of the flood has led to the loss of both human life and valuable assets. The effect of flooding in urban centres is even more severe. The aim of this study is centred on identification of communities vulnerable to flooding in urbanized river basins in Obio/Akpor LGA. The result indicates that the stress placed on the various river basins in most part of the study area due to urbanization which has resulted to intermittent flooding. This study utilized GIS/Remote sensing techniques in producing the flood risk maps and identifying the various river basin in the study area while revealing the communities that are most vulnerable to flooding within the study area. The results of the flood risk map shows that areas around Rukpokwu, Eneka, Rumudumaya, Rumuola have very high risk of being flooded with a percentile of 24.60 % while areas around Iriebe, Atali, Rumuduru, and Eligmbu have high risk with a 21.36 %, other areas such as Choba, Ozuoba, Rumuologu, Rumuosi, Alakahia, Nkpolu, Rumudara, and Eliozu will be moderately flooded with percentile of 21.08%. However, areas around Rumueme, Rumueprikon, Mgbuogba, Iwofe, Egbelu and Rumuorolu have low susceptibility to flooding with 19.50% probability of flood risk and areas around Diobu, Rumomasi, Oginigba, Mgbuodiaha, Mgbuosimini, Rumuolumeni have lower risk of being flooded with a percentage value of 13.45% in the occurrence of one. Amongst the recommendations made, it is pertinent for development to be decentralized, this will help to reduce the stressed placed on the river basins and aid in flood management.

KEYWORDS

Urban Flooding, Flood Risk Management, Vulnerability Assessment.

1. INTRODUCTION

The natural environment is greatly impacted by rivers and streams, serving as the lifeblood of ecosystems, sustaining communities, and nurturing diverse flora and fauna (Chakraborty and Chakraborty, 2021). These watercourses are not only essential for the environment but also hold immense significance for human societies. However, as the world witnesses unprecedented urbanization, the dynamics of rivers and their surrounding basins are undergoing a transformation of profound consequence. Population increase, and rural-to-urban migration are the primary forces propelling urbanization and brings with it an array of challenges and opportunities that demand our understanding and intervention. Healthy watersheds offer a broad spectrum of ecosystem benefits, encompassing enhanced water efficiency, the natural filtration of pollutants, increased biodiversity, control of soil erosion, retention of sediments, climate regulation, and recreational opportunities (USEPA, 2021; Hou et al., 2016).

Nevertheless, human activities within a watershed have the potential to modify its characteristics, including alterations to land cover, geomorphology, and soil properties, thereby inducing shifts in the hydrological cycle within watersheds and the deterioration of stream quality (Baker, 2006; Price, 2011; Miserendino et al., 2011). In addition, the surface water quality and ecosystem integrity have been impacted by recent severe weather events including heatwaves, droughts, and floods, all of which are caused by global warming (Mosely, 2015; Chang et al., 2017). Hence, the reduction of detrimental human-induced impacts on watersheds and stream ecosystems, across different spatial and temporal scales, has assumed growing significance in safeguarding the health of stream ecosystems and bolstering their capacity to adapt (Park et al., 2020).

More so, urbanization, characterized by the replacement of naturally permeable vegetated surfaces with impervious areas, introduces substantial alterations to the hydrological processes within a drainage basin. These transformations have a pronounced impact on water storage in various reservoirs, including surface water, groundwater, and evapo-transpirated water. Urbanization increases the pace and amount of surface runoff by reducing the delay between the highest amount of rainfall and the highest flow of water. This has resulted to the flooding of some areas. Notably, it is being established that one of the contributing factor to flooding of an area is the terrain. Both the frequency and severity of floods are significantly impacted by topographical features, which in turn dictate the hydrological response behaviour of watershed systems. It is a complicated technique in hydrological research to evaluate floods in river basin systems. According to research on the impact of watershed characteristics on river basin flood susceptibility in Makanda, North-West India, the vulnerability assessment was classified as high, moderate, or low (Singh and Kumar, 2019). The most place that is more inhabited by humans is classified as being more vulnerable to flooding and this is due to stress placed on the river basin and mostly associated to impervious surfaces

A key priority in global hydrology is understanding the possible impacts of land-use changes on hydrological processes, since urbanization is

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increasingly a worldwide phenomenon (Greg et al., 2019). Around the globe, a lot of research has looked at how urbanization affects water systems, nonetheless, many methods for calculating the water impact of cities have been suggested (Jones, 2017). One method is to compare two watersheds side by side, a practice known as in-pair comparisons. Comparing and comparing the hydrological features of a less urbanized watershed with an urbanized one is the essence of this approach. The usual method for doing this kind of comparison is to look at two nearby watersheds that are geographically and climatically similar but have different levels of urbanization. Drawing from prior research, a multitude of attributes associated with watersheds, stemming from both human-driven and natural processes, exhibit strong associations with diverse characteristics of stream ecosystems. For instance, earlier studies have indicated that a significant correlation exists between various physiological and biological indicators of streams, including water quality, concentrations of nutrients and pollutants, and the biological state, and the characteristics of the watersheds, such as the proportions of different land use types, population density, areas covered by impermeable surfaces, the intensity of land use, and the composition and conFigureuration of land use and land cover (Alvarez-Cabria et al., 2016; Clement et al., 2017; Giri et al., 2019).

Furthermore, numerous investigations have underscored the pivotal role of watershed topography, soil properties, and local climate in determining the health of stream ecosystems (Varanka et al., 2015; Alnahit et al., 2020). These intricate relationships between watershed attributes and the well-being of stream ecosystems are highly contingent on site-specific factors, considering the unique characteristics of both the streams, such as their order, topography, depth, flow rate, and shape, and the watersheds, which includes their location, size, prevailing weather conditions, and geological factors. Consequently, it becomes apparent that the implementation of distinct management strategies tailored to specific watersheds and stream types is warranted (Alnahit et al., 2020). To examine the flood vulnerability characteristics of urbanized river basins in Obio/Akpor Local Government Area in Rivers State, Nigeria. The urban landscape in this region, like many others globally, is rapidly expanding, affecting the form and function of its river basins. It is against this background that this study is initiated to examine the flood vulnerability characteristic of streams and urbanized river basins in Obio/Akpor LGA of Rivers State, Nigeria.

2. MATERIALS AND METHODS

2.1 Study Area

The research region is situated in the Niger Delta Basin, specifically in the Obio-Akpor Local Government region, with coordinates ranging from 4° 33' to 4° 50' N latitude and 7° 20' to 7° 35' E longitude. Refer to Figure 1. It is distinguished by alternating periods of rainy and dry weather. In 1972, the yearly total rainfall ranged from 160mm to 294mm, the relative humidity was above 90%, and the mean temperature was 27°C. Most of researcher in their study extensively described the geology (Allen, 1965; Rayment, 1965; Short and Stauble, 1967). The climate is defined by alternating dry and rainy seasons (Hoje, 1972). The detailed geology of the area has been described (Allen, 1965; Rayment, 1965; Short and Stauble, 1967). The local geology of the area consists of the stratified sediments starting with Benin Formation underlain by the Miocene Agbada formation and under compacted Akata formation respectively (Short and Stauble, 1967). The Benin formation consists of massive highly porous sands and gravels of fluviatile origin. Agbata formation is also of Eocene-recent in age, and it consists of an admixture of inter-bedded sands, which are fluviatile coastal, fluvio-marine and shale in origin. Akata formation is also predominately shale or clay but is relatively under compacted (Ehirim et al., 2009). The mean maximum temperature all the year round in the study area is 30°CThe temperature within the Study area is 33°c.

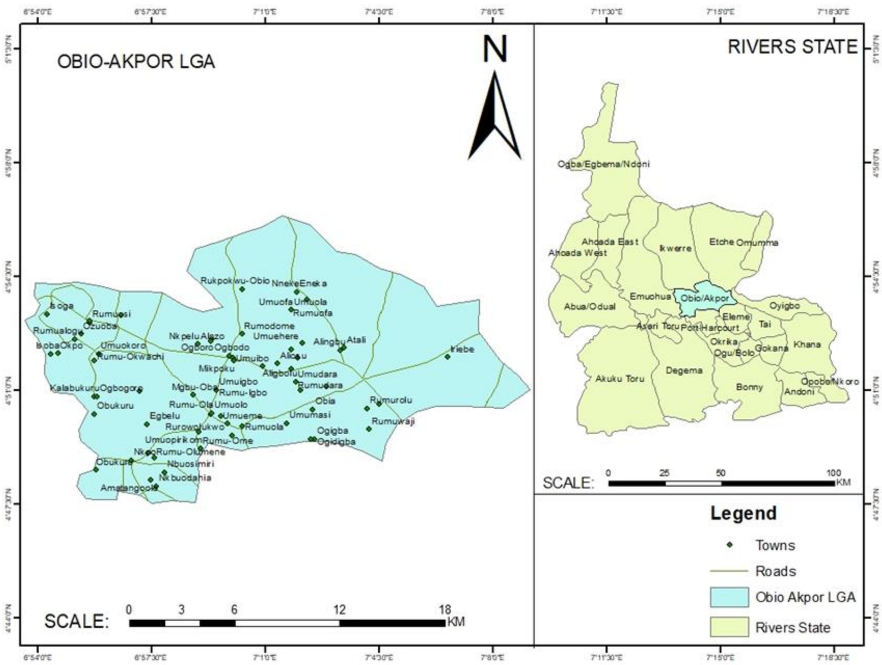

Figure 1: Study Area showing LGA boundary and communities

2.2 Type of data/Method of Data Collection

This study utilized the secondary data to achieve comprehensive analysis. This secondary data is remotely sensed LANDSAT imagery which provides valuable information on land use changes over time. The LANDSAT imagery was used to analyze the spatial and temporal variations in the landscape, offering insights into how human activities and natural processes have altered the study area's environment. Also, the study utilized the SRTM (Shuttle Rader Topographic Mapper) satellite imagery in carrying out the various hydrological analysis. This allows for a thorough investigation of the river systems.

Data for this study was collected from USGS (United States Geological Survey). The data includes both the SRTM satellite data used in the hydrological analysis and the landsat 9 satellite data downloaded. The STRM data was to generate the entire elevation of the study area vis-à-vis the river basin, stream ordering analysis. The satellite data downloaded is composed of (30m x 30m) spatial resolution.

2.3 Method of Data Analysis

GIS/Remote sensing is a computer program used to map and analysed geographical features, patterns and occurrences. Common database procedures, such as querying and statistical analysis can now be performed on maps with the use of GIS/Remote sensing technology. During this study, the need to incorporate the use of GIS/RS is highly necessary as this will aid to show the general mapping and the extent of the study. The various data for this study was analysed using the GIS/Remote sensing techniques. The DEM data was generated to show the general elevation of the entire study area. This is because the DEM is the primary input data in carrying out an elevation modelling. Also, to determine the flood vulnerability areas, several hydrological analyses was carried out, this process aids the researcher to identify areas that is very high, high, moderate, low and very low in relation to flooding. The hydrological analysis carried out aids in the identification of the various river basin present in any area. The analysis reveals the number of river basins present in any area of study.

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2.4 Presentation of Results

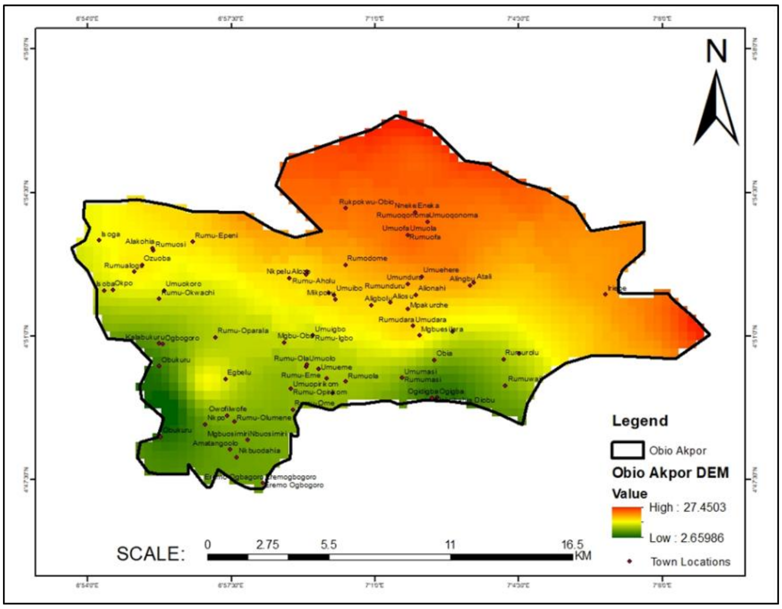

Figure 2: Digital Elevation Model of Obio/Akpor.

Figure 2 shows a high-resolution digital elevation model of Obio/Akpor LGA which represent places of low height and high elevation, respectively. From the result presented, it is notably visible that the high elevation point is (27.4503) which occupies 59. 63% of the study area with an area of 126.64 Sqm. while the low elevation points are (2.65986) metres which covers 40.36% of the area with an area coverage of 85.72 Sqm. This is a clear indication that communities that falls within the lowest point will be prone to flooding and the spatial extent of the flood will cover 85.72 Sqm of the entire study area. However, communities that falls in the high elevation points will be free from flooding and this only covers area that falls within 126.64 Sqm.

Table 1: Topographic Classification

S/N	Elevation	Elevation Index	Spatial Extent	Percentage (%) distribution	Vulnerability Index
1	Low	2.65988	85.72 Sqm.	40.36	Very low
2	High	27.4503	126.64 Sqm.	59.63	Very High
Total			212.36 Sqm.	100%	

Source: Researchers Compilation (2024)

Table 1 presents the topographic classification of elevation index of the study area and the associated spatial extent of the different vulnerability classes.

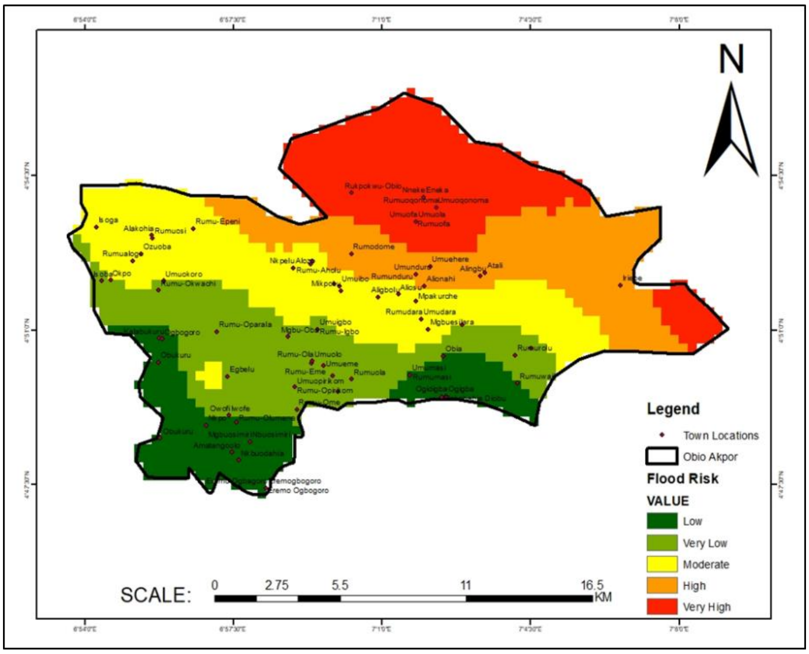

Figure 3: Flood Risk Vulnerability Assessment of Obio/Akpor LGA.

The flood risk assessment in Obio/Akpor LGA is shown on the map in Figure. (3). Throughout the whole local government region, the map shows places that are at risk of flooding. Five categories were used to categorise the vulnerability assessment: low, extremely low, moderate, high, and very high. Communities within the research region that are most at risk of flooding may be identified using this categorisation. From the result of the analysis carried out, it is being revealed that Rukpokwu, Eneka, Rumudumaya, Rumuola, and Eneka is classified as very high in the vulnerability to flooding, whereas Iriebe, Atali, Rumuduru, and Eligmbu is classified as highly vulnerable to flooding. Also, areas such as Choba, Ozuoba, Rumuologu, Rumuosi, Alakahia, Nkpolu, Rumudara, and Eliozu is moderately vulnerable to flooding. Furthermore, areas such as Rumueme, Rumueprikon, Mgbuogba, Iwofe, Egbelu and Rumuorolu is low in the vulnerability exposure to flooding. Finally, it is observed from the vulnerability assessment that areas such as Diobu, Rumomasi, Oginigba, Mgbuodiaha, Mgbuosimini, Rumuolumeni as very low in the vulnerability to flooding.

Table 2: Flood Vulnerability Assessment Analysis

Flood Hazard Class Number	Flood Risk Classes	Flood Class Risk Value	Percentage (%) Distribution	Spatial Extent
1	Very High	435	24.60	89.49 Sqm.
2	High	378	21.36	50.89 Sqm.
3	Moderate	373	21.08	30.99 Sqm.
4	Low	345	19.50	24.66 Sqm.
5	Very Low	238	13.45	16.33 Sqm.
TOTAL		**1,769**	**100%**	

Source: Researchers Compilation (2024)

Table 2 shows five categories of flood risk identified within the study area: very high, high, moderate, very low, and low. The corresponding numbers represent the relative importance of each risk category. You can see the different percentiles of flood danger in the percentage distribution. If a flood were to occur, the regions indicated by the flood risk analysis's geographic extent would be submerged. The high-risk flood zones include 50.89Sqm, whereas the very high-risk sections span 89.49Sqm. The intermediate danger zone, which is rather similar, extends over 30.99 square meters. A total of 24.66 square meters constitutes the low-risk zone, whereas 16.33 square meters constitute the very low-risk zone. By the percentage distribution, the very-high vulnerable areas covers about 24.60 %. This implies that in the occurrence of flood event, 24.60% of the total land area in Obio/Akpor will be flooded. However, the high zone occupies 21.36 %. In the same vein, the implication is 21.36% of the area under investigation will be flooded as it is not completely free from flooding. Furthermore, the moderate risk zone occupies 21.08% of the surface area, this goes to expose that about 21.08% of the area is likely to be flooded, while the low-risk zone is 19.50 %. Similarly, the total area that is classified as a low-risk zone is just 19.50% of the total land in Obio/Akpor. Of worthy to note, it is clear from the analysis carried out that the very low risk zone in the study area is just 13.45% of the entire area. This implies that out of the total land area in Obio/Akpor, it is only 13.45% that is completely free from flooding in the occurrence of any flood related event.

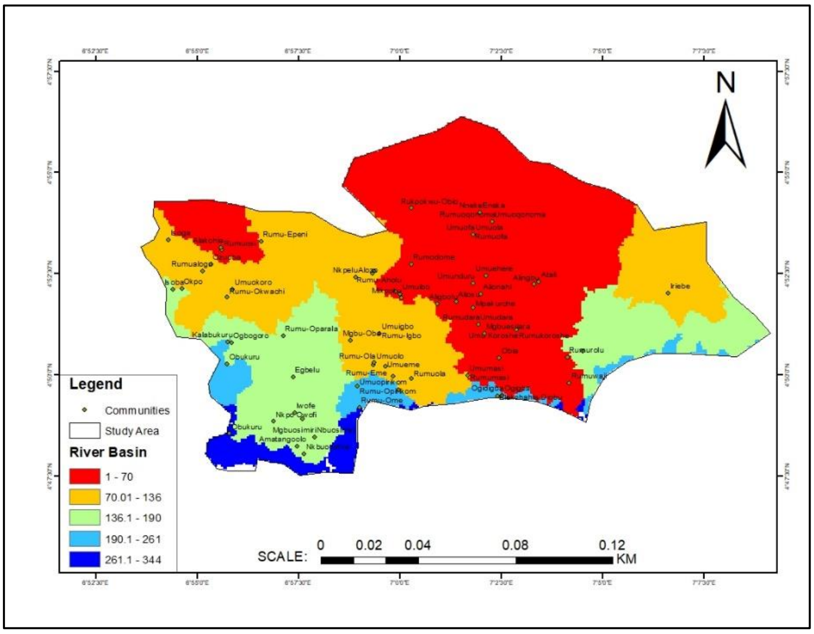

Figure 4: Delineated River Basins in within the Study Area

Figure 4 shows the river basin analysis for the study area. The presented result suggests that there exist five river basins in Obio/Akpor LGA. The five basins have their various capacity. Interestingly, the smallest river basin occupies the most area with an area size of (1-70) hectares. Quite notably, communities within this area comprises Rukpokwu, Eneka, Rumuola, Atali, Ogbum.Nu-Abali, Rumuomasi, Eliozu. However, the low river basin is composed of an area size of (70.01-136) hectares with the following communities such as Iriebe, Rumuokoro, Rumuologu, Choba, Rumukwachi, Owipa, Rumuosi, Alakahia etc. In the same vein, the medium river basin has an area size of (136.1-190) hectares of the land area. Also, the following communities are situated within this river basin, they are Egbelu, Ogogoro, Mini Olu, Mini-Opara, Mgbuosimini, Rumuorolu. While the area with a considerable big river basin has an area of (191.1-261) hectares with the associated communities, Rumuolumeni, Rumuwaji, Obukuru, Nkpor, Finally, the area with the bigger river basin is has an area size of (261.1-344) hectares. The communities within these areas are Elekahia, Woji, Diobu, Elechi, Oginigba etc.

3. Discussion of Results

Flooding and its associated risks have been shown to have devastating consequences for societies and communities when they occur. The development of topographic maps is highly necessary for a proper understanding of the general terrain of an area. A proper understanding of the general terrain of the area is necessary as it will further aids in the general planning. This underscores the essence of developing a high-resolution DEM for Obio/Akpor LGA. Hydrologic and hydraulic models rely heavily on elevation models. The reliability of digital elevation models (DEMs) is crucial for flood inundation mapping.

Results shown in Figures 2, 3 and 4 helps to identify areas within the study area that are susceptible to possible flooding issues at differing scales. If a flood were to occur, the regions indicated by the flood risk analysis's geographic extent would be submerged. The high-risk flood zones include 50.89Sqm, whereas the very high-risk sections span 89.49Sqm. The intermediate danger zone, which is rather similar, extends over 30.99 square meters. A total of 24.66 square meters constitutes the low-risk zone, whereas 16.33 square meters constitute the very low-risk zone. By the percentage distribution, the very-highly vulnerable areas covers about 24.60 %. This implies that in the occurrence of flood event, 24.60% of the total land area in Obio/Akpor will be flooded. However, the high zone occupies 21.36 %.

In the same vein, the implication is 21.36% of the area under investigation will be flooded as it is not completely free from flooding. Furthermore, the moderate risk zone occupies 21.08% of the surface area, this goes to expose that about 21.08% of the area is likely to be flooded, while the low-risk zone is 19.50 %. This agrees with results obtained (Williams et al., 2000; Gallant and Dowling, 2003). A group researcher made it crystal obvious in a similar research how important DEM is for identifying flood-prone locations by comparing river stage with the surrounding terrain's elevation (Nardi et al., 2006). The results of this research agree with those of the study of which found that the topographic index and other data included in the DEM may be used to identify flood-prone locations with little effort (Manfreda et al., 2007).

The flood risk assessment in Obio/Akpor LGA is shown in Figure 3. Throughout the whole local government region, the map shows places that are at risk of flooding. Five categories were used to categorise the vulnerability assessment: low, extremely low, moderate, high, and very high. Communities within the research region that are most at risk of flooding may be identified using this categorisation. From the result of the analysis carried out, it is being revealed that Rukpokwu, Eneka, Rumudumaya, Rumuola, and Eneka is classified as very high in the vulnerability to flooding, whereas Iriebe, Atali, Rumuduru, and Eligmbu is classified as highly vulnerable to flooding. Also, areas such as Choba, Ozuoba, Rumuologu, Rumuosi, Alakahia, Nkpolu, Rumudara, and Eliozu is moderately vulnerable to flooding. Furthermore, areas such as Rumueme, Rumueprikon, Mgbuogba, Iwofe, Egbelu and Rumuorolu is low in the vulnerability exposure to flooding. Finally, it is observed from the vulnerability assessment that areas such as Diobu, Rumomasi, Oginigba, Mgbuodiaha, Mgbuosimini, Rumuolumeni as very low in the vulnerability to flooding.

By implication, the river basin explains how one basin exists in relation to another basin. It also helps to establish the number of basins that is in existence within a particular area. However, it aids in the general understanding of the movement of water within an area. The analysis presented in Figure 4 can be arguably relevant in the identification of the various river basins within the study area, as well as aid in revealing the various communities that exist in each of the river basin as they exist in the study area. The vulnerability risk assessment to flood in Obio/Akpor LGA revealed that Rukpokwu, Eneka, Rumudumaya, Rumuola, is highly vulnerable to flooding. However, Iriebe, Atali, Rumuduru, and Eligmbu is vulnerable to flood. Also, areas such as Choba, Ozuoba, Rumuologu, Rumuosi, Alakahia, Nkpolu, Rumudara, and Eliozu is moderately vulnerable to flooding. This finding agrees with the results of who identified sections of the Niger Delta as flood prone (Ochege et al., 2016). Furthermore, areas such as Rumueme, Rumueprikon, Mgbuogba, Iwofe, Egbelu and Rumuorolu is low in the vulnerability exposure to flooding. Finally, it is observed from the vulnerability assessment that areas such as Diobu, Rumomasi, Oginigba, Mgbuodiaha, Mgbuosimini, Rumuolumeni as very low in the vulnerability to flooding.

4. Conclusion

In conclusion, the study provides a comprehensive analysis of the communities vulnerable to flooding in Obio/Akpor LGA. The result of the flood risk map alongside the river basin map indicates that there is a synchronization between the impact created by urbanization as it relates to flooding. From the analysis, the various flood prone areas are revealed, and the study highly recommends that development in Rivers State should be decentralized, this will help to reduce the stressed placed on the river basins and aid in flood management. It is also recommended that no structural measures to towards flood risk management be given significant priority.

Data Availability Statement

The data sources that support the findings of this study have been provided in the body of the study.

Conflict of Interest Statement

The authors declare that they do not have any conflict of interest.

Ethics Statement

There are no ethical considerations for this research.

Declaration of Generative AI in Scientific Writing

The authors declare that AI was not used in the writing of this article

References

AghaKouchak, A., Chiang, F., Huning, L.S., Love, C.A., Mallakpour, I., Mazdiyasni, O., and Sadegh, M., 2020. Climate extremes and compound hazards in a warming world. Annual Review of Earth and Planetary Sciences, 48, Pp. 519-548.

Almousawi, D., Almedeij, J., and Alsumaiei, A.A., 2020. Impact of urbanization on desert flash flood generation. Arabian Journal of Geosciences, 13, Pp. 1-11.

Alnahit, A.O., Mishra, A.K., Khan, A.A., 2020. Quantifying Climate, Streamflow, and Watershed Control on Water Quality across Southeastern US Watersheds. Sci. Total Environ., 739, Pp. 139945.

Álvarez-Cabria, M., Barquín, J., Peñas, F.J., 2016. Modelling the Spatial and Seasonal Variability of Water Quality for Entire River Networks: Relationships with Natural and Anthropogenic Factors. Sci. Total Environ., 545, Pp. 152–162.

Anim, D.O., and Banahene, P., 2021. Urbanization and stream ecosystems: the role of flow hydraulics towards an improved understanding in addressing urban stream degradation. Environmental Reviews, 29 (3), Pp. 401-414.

Baker, A., 2006. Land use and Water Quality. In Encyclopedia of Hydrological Sciences; John Wiley & Sons, Ltd.: Chichester, UK; Volume 17.

Bell, C.D., Tague, C.L., and McMillan, S.K., 2019. Modeling runoff and nitrogen loads from a watershed at different levels of impervious surface coverage and connectivity to storm water control measures. Water Resources Research, 55 (4), Pp. 2690-2707.

Berdegué, J.A., Proctor, F.J., and Cazzuffi, C., 2014. Cities in the rural transformation. Journal Environment and Urbanization, 22 (2).

Bilgiç, E., and Baba, A., 2023. Effect of Urbanization on Water Resources: Challenges and Prospects. Groundwater in Arid and Semi-Arid Areas: Monitoring, Assessment, Modelling, and Management, Pp. 81-108.

Bolick, M.M., Post, C.J., Naser, M.Z., Forghanparast, F., and Mikhailova, E.A., 2023. Evaluating Urban Stream Flooding with Machine Learning, LiDAR, and 3D Modeling. Water, 15 (14), Pp. 2581.

Carey, R.O., Migliaccio, K.W., Li, Y., Schaffer, B., Kiker, G.A., Brown, M.T., 2011. Land use Disturbance Indicators and Water Quality Variability in the Biscayne Bay Watershed, Florida. Ecol. Ind., 11, Pp. 1093–1104.

Chakraborty, S.K., and Chakraborty, S.K., 2021. Ecology of Fishes of Rivers: Functional Roles. Riverine Ecology Volume 2: Biodiversity Conservation, Conflicts and Resolution, Pp. 187-286.

Chang, H., Bonnette, M.R., Stoker, P., Crow-Miller, B., Wentz, E., 2017. Determinants of Single-Family Residential Water use Across Scales in Four Western US Cities. Sci. Total Environ., 596, Pp. 451–464.

Cheng, Z., Wang, F., Sun, J., Wang, H., Wang, Y., Guan, X., and Yu, C., 2022. Recession and hysteresis effects of hyporheic zone permeability changes on baseflow in seasonal freeze-thaw mountainous areas. Journal of Hydrology, 610, Pp. 127925.

Clément, F., Ruiz, J., Rodríguez, M.A., Blais, D., Campeau, S., 2017. Landscape Diversity and Forest Edge Density Regulate Stream Water Quality in Agricultural Catchments. Ecol. Ind., 72, Pp. 627–639.

Debbage, N., and Shepherd, J.M., 2018. The influence of urban development patterns on streamflow characteristics in the Charlanta Megaregion. Water Resources Research, 54 (5), Pp. 3728-3747.

Freeman, L.A., Corbett, D.R., Fitzgerald, A.M., Lemley, D.A., Quigg, A., and Steppe, C.N., 2019. Impacts of urbanization and development on estuarine ecosystems and water quality. Estuaries and Coasts, 42, Pp. 1821-1838.

Garg, V., Nikam, B.R., Thakur, P.K., Aggarwal, S.P., Gupta, P.K., and Srivastav, S.K., 2019. Human-induced land use land cover change and its impact on hydrology. Hydro Research, 1, Pp. 48-56.

Giri, S., Zhang, Z., Krasnuk, D., Lathrop, R.G., 2019. Evaluating the Impact of Land Uses on Stream Integrity using Machine Learning Algorithms. Sci. Total Environ., 696, Pp. 133858.

Gold, A.C., Thompson, S.P., and Piehler, M.F., 2019. The effects of urbanization and retention-based stormwater management on coastal plain stream nutrient export. Water Resources Research, 55 (8), Pp. 7027-7046.

Greg, J.M., Griffies, S.M., Hughes, C.W., Lowe, J.A., Church, J.A., Fukimori, I., and van de Wal, R.S., 2019. Concepts and terminology for sea level: Mean, variability and change, both local and global. Surveys in Geophysics, 40, Pp. 1251-1289.

Hou, Y., Li, B., Müller, F., Chen, W., 2016. Ecosystem Services of Human-Dominated Watersheds and Land use Influences: A Case Study from the Dianchi Lake Watershed in China. Environ. Monit. Assess., 188, Pp. 1–19.

Hussain, M., and Imitiyaz, I., 2018. Urbanization concepts, dimensions and factors. International Journal of Recent Scientific Research, 9 (1), Pp. 23513-23523.

Islam, A., and Deb Barman, S., 2020. Drainage basin morphometry and evaluating its role on flood-inducing capacity of tributary basins of Mayurakshi River, India. SN Applied Sciences, 2 (6), Pp. 1087.

John, E.J., 1997. Introduction to Hydraulics and Hydrology with Applications for Stormwater Management Delmar Thompson Learning.

Joo, H., Kim, H.S., Kim, S., and Sivakumar, B., 2021. Complex networks and integrated centrality measure to assess the importance of streamflow stations in a River basin. Journal of Hydrology, 598, Pp. 126280.

Kaur, L., Rishi, M.S., Sharma, S., and Khosla, A., 2019. Impervious Surfaces an Indicator of Hydrological Changes in Urban Watershed: A Review. Open Access J. Environ. Soil Sci., 4 (1), Pp. 469-473.

Kaymaz, I., 2013. Urban landscapes and identity. In Advances in landscape architecture. IntechOpen.

Keen, K.A., Beltran, R.S., Pirotta, E., and Costa, D.P., 2021. Emerging themes in population consequences of disturbance models. Proceedings of the Royal Society B, 288 (1957), Pp. 20210325.

Komolafe, A.A., Awe, B.S., Olorunfemi, I.E., and Oguntunde, P.G., 2020. Modelling flood-prone area and vulnerability using integration of multi-criteria analysis and HAND model in the Ogun River Basin, Nigeria. Hydrological Sciences Journal, 65 (10), Pp. 1766-1783.

Lee, S., Hwang, S., Lee, S., Hwang, H., Sung, H., 2009. Landscape Ecological Approach to the Relationships of Land use Patterns in Watersheds to Water Quality Characteristics. Landsc. Urban Plann., 92, Pp. 80–89.

Li, X., Cheng, G., Fu, B., Xia, J., Zhang, L., Yang, D., and Ran, Y., 2022. Linking critical zone with watershed science: The example of the Heihe River basin. Earth's Future, 10 (11)

Luo, Z., Shao, Q., Zuo, Q., and Cui, Y., 2020. Impact of land use and urbanization on river water quality and ecology in a dam dominated basin. Journal of Hydrology, 584, Pp. 124655.

MacKenzie, K.M., Singh, K., Binns, A.D., Whiteley, H.R., and Gharabaghi, B., 2022. Effects of urbanization on stream flow, sediment, and phosphorous regime. Journal of Hydrology,

Mautner, M.R., Foglia, L., Herrera, G.S., Galán, R., and Herman, J.D., 2020. Urban growth and groundwater sustainability: Evaluating spatially distributed recharge alternatives in the Mexico City Metropolitan Area. Journal of Hydrology, 586, Pp. 124909.

McPhillips, L.E., Earl, S.R., Hale, R.L., and Grimm, N.B., 2019. Urbanization in arid central Arizona watersheds results in decreased stream flashiness. Water Resources Research, 55 (11), Pp. 9436-9453.

McVey, I., Michalek, A., Mahoney, T., and Husic, A., 2023. Urbanization as a limiter and catalyst of watershed-scale sediment transport: Insights from probabilistic connectivity modeling. Science of The Total Environment, Pp. 165093.

Miller, O.L., Miller, M.P., Longley, P.C., Alder, J.R., Bearup, L.A., Pruitt, T., and McKinney, T., 2021. How will baseflow respond to climate change in the upper Colorado River Basin?. Geophysical Research Letters, 48 (22),

Miserendino, M.L., Casaux, R., Archangelsky, M., Di Prinzio, C.Y., Brand, C., Kutschker, A.M., 2011. Assessing Land-use Effects on Water Quality, in-Stream Habitat, Riparian Ecosystems and Biodiversity in Patagonian Northwest Streams. Sci. Total Environ., 409, Pp. 612–624.

Mohanty, R., and Kumar, B.P., 2021. Urbanization and smart cities. In Solving urban infrastructure problems using smart city technologies (pp. 143-158). Elsevier

Mosley, L.M., 2015. Drought Impacts on the Water Quality of Freshwater Systems; Review and Integration. Earth Sci. Rev., 140, Pp. 203–214.

Müller, A., Österlund, H., Marsalek, J., and Viklander, M., 2020. The pollution conveyed by urban runoff: A review of sources. Science of the Total Environment, Pp. 709.

Nafi'Shehab, Z., Jamil, N.R., Aris, A.Z., and Shafie, N.S., 2021. Spatial variation impact of landscape patterns and land use on water quality across an urbanized watershed in Bentong, Malaysia. Ecological indicators, Pp. 122.

Niemczynowicz, J., 1999. Urban hydrology and water management–present and future challenges. Urban water, 1 (1), Pp. 1-14.

O'Driscoll, M., Clinton, S., Jefferson, A., Manda, A., and McMillan, S., 2010. Urbanization effects on watershed hydrology and in-stream processes in the southern United States. Water, 2 (3), Pp. 605-648.

Ochege, F.U., Wekpe, V.O., and Obafemi, A.A., 2016. An Overview of Flood vulnerability mapping: strategy for disaster risk reduction in the Niger Delta Region, Nigeria. Nigerian Journal of Hydrological Sciences, 4 (1), Pp.13-26.