International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Flood Mapping and Analysis in Anambra State, Nigeria, Using Synthetic Aperture Radar

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ABSTRACT-

Flooding has become a recurring and destructive natural hazard in Anambra State, Nigeria, exacerbated by climatic variability, inadequate urban planning, and the lack of up-to-date flood mapping resources. This study investigates the spatial-temporal dynamics of flooding from September to November 2022 using Sentinel-1 Synthetic Aperture Radar (SAR) data. The objectives were to determine flood extent, analyze expansion trends, and identify highly affected local government areas (LGAs). Sentinel-1 datasets were collected, preprocessed, and analyzed using thresholding and change detection techniques in a GIS environment. The findings revealed a significant increase in flooded areas, from 425.07 km² in September to 1379.72 km² in October, before receding to 845.56 km² in November. Grasslands and water bodies were the most affected land cover classes, while Anambra West, Ogbaru, and Ayamelum LGAs emerged as the most severely impacted. The study concludes by advocating for flood early warning systems and improved land use planning based on reliable SAR-derived flood maps.

Keywords: Flood Mapping, Sentinel-1, Synthetic Aperture Radar, Anambra State, GIS, Time Series, Disaster Risk Reduction

1. Introduction

Flooding is one of the most frequent and destructive natural hazards affecting human populations and the environment globally. It causes widespread displacement, disruption of livelihoods, infrastructure destruction, and significant economic losses, particularly in developing countries with limited disaster mitigation infrastructure (Ward et al., 2015; Jongman et al., 2014). Nigeria, and particularly its southeastern region, is highly susceptible to both riverine and flash flooding due to its climatic conditions, low-lying topography, unplanned urban development, and poor drainage systems (Aderogba, 2012; Nkwunonwo et al., 2020).

Anambra State, located in the southeastern part of Nigeria, is one of the worst-hit areas during annual flood events. The state's proximity to the Niger River and its numerous tributaries makes it particularly vulnerable to overbank flooding during the rainy season. The situation is exacerbated by anthropogenic factors such as deforestation, settlement expansion into floodplains, and improper waste disposal into drainage channels (Igbokwe et al., 2008; Okoye et al., 2020). The 2022 flood incident, which severely affected over 10 LGAs in Anambra State, led to the displacement of thousands and the destruction of farmland, schools, homes, and health facilities, further emphasizing the need for efficient flood monitoring systems (NEMA, 2022).

Effective flood mapping is essential for preparedness, mitigation, and response strategies. Traditional field-based mapping techniques are often time-consuming, costly, and difficult to execute during active flood events. Remote sensing, particularly using satellite imagery, offers a faster and more efficient alternative (Islam & Sado, 2000; Giustarini et al., 2015). However, optical imagery, commonly used in past flood studies, is limited by cloud cover, which often coincides with flood events, reducing its effectiveness (Brakenridge et al., 2003; Zhang et al., 2018).

Synthetic Aperture Radar (SAR) data, particularly from the Sentinel-1 platform, have proven highly valuable for flood mapping due to their all-weather, day-and-night imaging capabilities (Chini et al., 2017; Liu et al., 2019). SAR sensors detect differences in surface roughness and moisture, allowing the reliable delineation of inundated areas even under cloudy conditions (Martinis et al., 2015). The use of Sentinel-1's VV polarization in Interferometric Wide Swath (IW) mode provides a fine spatial resolution suitable for flood mapping over large areas (Cian et al., 2018).

Time series analysis of SAR imagery enhances the understanding of flood dynamics by enabling the detection of flood extent at different time intervals (Schlaffer et al., 2015; Thomas et al., 2017). This is especially important in Anambra State, where flooding evolves rapidly during the rainy season. Mapping the temporal evolution of floods supports early warning systems, post-disaster assessments, and long-term planning efforts.

Despite the increasing frequency of floods in Nigeria, few studies have employed multi-temporal SAR analysis to examine the spatial and temporal variations in flood extent across Anambra State. Most existing flood maps are either outdated or based on anecdotal or inconsistent data, thereby limiting their usefulness for risk planning and emergency response. This study addresses this gap by employing a time series analysis of Sentinel-1 SAR imagery to map flood extent and dynamics from September to November 2022.

The specific objectives of this study are to: (i) assess the spatial extent of flooding in Anambra State using multi-temporal Sentinel-1 SAR data; (ii) evaluate the rate and pattern of flood expansion and recession over the three-month period; and (iii) identify and quantify flood impact on landcover classes and across local government areas. The outcome of this study will support data-driven decision-making for flood disaster risk reduction and urban planning.

2.Materials and Methods

2.1 Description of the Study Area

The study was conducted in Anambra State, located in the southeastern region of Nigeria. Anambra lies within latitudes 5°42′N and 6°47′N and longitudes 6°37′E and 7°19′E, covering an approximate area of 4,844 km². The state is bordered by Delta, Imo, Enugu, Abia, and Kogi States. It is drained by the Niger River and its tributaries, which significantly influence the state's susceptibility to flooding. The topography of Anambra State is characterized by low-lying plains in the riverine areas and gentle undulating hills in the central and northern parts. The climate is tropical with distinct wet and dry seasons, and rainfall is often intense during the months of July to October, making these months particularly prone to flood events. High population density, rapid urbanization, and agricultural activities further complicate flood risk dynamics within the state.

2.2 Data Collection

This research employed multi-temporal Synthetic Aperture Radar (SAR) datasets acquired from the Sentinel-1 mission operated by the European Space Agency (ESA). The satellite imagery consisted of Level-1 Ground Range Detected (GRD) products captured in Interferometric Wide (IW) swath mode with vertical transmit and receive polarization (VV). The datasets covered three different time points corresponding to peak flood season—September, October, and November of the year 2022. These datasets were downloaded from the Copernicus Open Access Hub. Additionally, administrative boundary shapefiles for Anambra State were obtained from the Office of the Surveyor General of the Federation (OSGOF), while Shuttle Radar Topography Mission (SRTM) 30m Digital Elevation Model (DEM) was sourced from the USGS Earth Explorer for terrain correction and georeferencing.

2.3 Preprocessing of Sentinel-1 Data

All SAR datasets underwent extensive preprocessing using the Sentinel Application Platform (SNAP) software, developed by ESA. The preprocessing pipeline included precise orbit file correction to ensure accurate image geometry. Radiometric calibration was applied to convert raw image values to sigma naught backscatter coefficients, enabling comparison across time. Thermal noise removal was conducted to eliminate sensor-based anomalies. Speckle filtering was performed using the Refined Lee filter to reduce inherent SAR image noise while preserving important features such as flood boundaries. Finally, terrain correction was implemented using the Range-Doppler terrain correction algorithm in conjunction with the SRTM DEM to reproject the data to the Universal Transverse Mercator (UTM) coordinate system, Zone 32N (WGS84 datum), and to eliminate topographic distortions.

2.4 Flood Detection and Mapping

Flooded areas were extracted through a threshold-based classification method applied to the calibrated SAR backscatter data. Water surfaces generally exhibit lower backscatter values due to their smooth surface and specular reflection characteristics. A threshold of -15 dB was identified and used to delineate flood extents by separating low-backscatter (flooded) areas from high-backscatter (non-flooded) surfaces. The classification process was repeated for each of the three observation months. Change detection was conducted by comparing the extracted flood extents across the time series to assess flood progression, peak inundation, and subsequent recession. All outputs were validated visually using Google Earth Pro and field reports from local authorities.

2.5 Landcover Classification and Impact Analysis

To understand the impact of flooding on different landcover types, a landcover classification was performed using supervised classification on Sentinel-2 optical imagery acquired during the dry season when cloud-free images were available. Landcover types identified included water bodies, grasslands, dense vegetation, and bare surfaces. A maximum likelihood classification algorithm was applied in QGIS after training the model with representative training samples. Post-classification accuracy assessment was conducted using confusion matrices and ground control points derived from field data and high-resolution imagery. The flood extent layers were then overlaid on the landcover map to compute the areal extent of inundation per landcover category using zonal statistics tools in GIS.

2.6 Analysis of Flooded Area by Local Government Area (LGA)

The flood extent shapefiles for each month were spatially intersected with administrative boundaries of the 21 Local Government Areas (LGAs) of Anambra State. Using GIS overlay and area calculation tools, the total flooded area within each LGA was computed for September, October, and November. This process allowed for a comparative analysis of temporal changes in flood extent across different administrative regions. The results were tabulated and visualized through bar charts and thematic maps to identify flood hotspots and assess the severity of impact over time.

2.7 Time Series and Change Analysis

A multi-temporal flood progression analysis was carried out by comparing the extent of flooding in the three months under consideration. The rate of flood expansion was determined by calculating the difference in flood area between consecutive months. Areas experiencing new inundation or recession were mapped and quantified. This time series approach provided insights into the dynamics of the flood event—highlighting both its peak and post-peak characteristics. It also informed the understanding of persistent flood-prone zones across the landscape.

3. Results

3.1 Flood Extent in Anambra State Between September – November, 2022.

Based on the results obtained from Sentinel-1 data for Anambra State between September to November 2022, it is evident that the state experienced severe flooding during this period.

The results show that in September, the flood extent covered a total area of 425.07 km², which affected 12 Local Government areas in the state, including Anambra East, Anambra West, Awka North, Ayamelum, Ekwusigo, Idemili South, Ihiala, Nnewi North, Nnewi South, Ogbaru, Onitsha North, and Onitsha South.

In October, the flood extent increased significantly to 1379.72 km², which spread across 13 local government areas, including the ones affected in September, as well as Idemili North. This indicates that the flooding intensified during this period, covering a larger area and affecting more people.

In November, although the flood extent decreased slightly to 845.56 km², it still affected the same 13 local government areas as in October. This indicates that the flooding persisted in the state, causing significant damage and displacing people from their homes.

Overall, these results suggest that the flooding in Anambra State between September to November 2022 was severe and widespread, affecting a significant portion of the state and causing immense damage to people's homes and livelihoods. These findings are important for disaster management agencies and policymakers to plan for disaster response and recovery efforts, including providing relief to affected communities and implementing measures to prevent or mitigate future flooding in the state, these results are illustrated in figures 1 and 2.

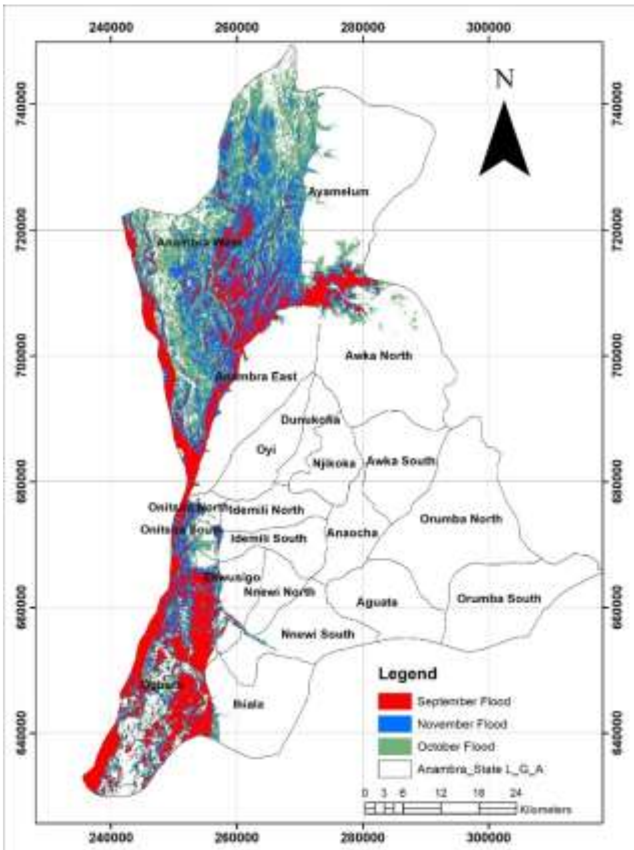

Figure 1: Flood Extents from September to November, 2022

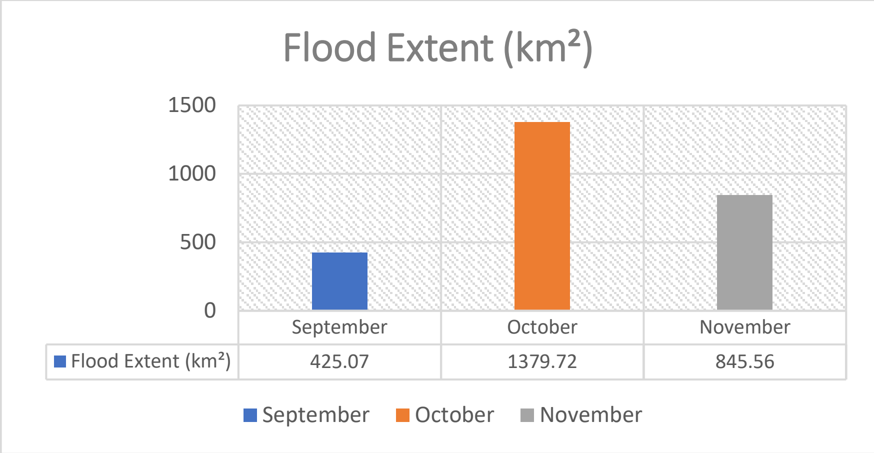

Figure 2: Flood Extent in Anambra State between September and November, 2022

3.2 Rate of flood expansion between September – November, 2022.

The rate of expansion of flood between September and November in Anambra State, was calculated by dividing the temporal period into two epochs of between September and October, and between October and November. To calculate the rate of expansion for the first epoch, the following formula was used:

Rate of expansion = ((Flood extent in October - Flood extent in September)/Flood extent in September) x 100%Substituting the values obtained from the results:

Rate of expansion = ((1379.72 km² - 425.07 km²)/425.07 km²) x 100%

Rate of expansion = 224.06%

Therefore, the rate of expansion of flood between September and October in Anambra State was approximately 224.06%. This indicates that the flood extent increased significantly between these two months, covering more than double the area affected in September.

On the other hand, the rate of expansion of flood between October and November also, using the formula:

Rate of expansion = ((Flood extent in November - Flood extent in October)/Flood extent in October) x 100%

Substituting the values obtained from the results:

Rate of expansion = ((845.56 km² - 1379.72 km²)/1379.72 km²) x 100%

Rate of expansion = -38.17%

Therefore, the rate of expansion of flood between October and November in Anambra State was approximately -38.17%. This indicates that the flood extent reduced between these two months. However, it is important to note that the flood still covered a vast area in November, and the rate of reduction was not significant enough to indicate a significant improvement in the situation, and there is still a need for urgent intervention to mitigate the impacts of flooding and improve the resilience of communities to future flooding events.

The significance of this lies in its ability to provide decision-makers and disaster management agencies with valuable insights into the temporal dynamics of flooding in Anambra State. The results highlight the need for proactive measures, such as improved drainage systems, flood-resistant building designs, and effective flood warning systems, to mitigate the impacts of flooding and improve the resilience of communities. The study also underscores the importance of leveraging satellite data and remote sensing technologies for timely and accurate monitoring of natural disasters such as flooding, which can aid in disaster management and decision-making processes.

3.3 Areas Affected by Flood across Anambra State between September – November.

3.3.1 Landcover/landuse Distribution

Image classification was carried out to determine the landcover/landuse classes affected by the flood between September and November in Anambra State. The results of the image classification, as shown in table 1 and figure 3, revealed that there are six categories of landcover/landuse in the study area: Water Body, Dense Vegetation, Agricultural Land, Built-up Area, Open Space, and Grassland.

The category with the highest area coverage is Grassland, which covers 1697.66 km² or 37.34% of the study area.

The second-largest category is Dense Vegetation, covering 1156.52 km² or 25.44% of the study area. Agricultural Land and Built-up Area follow as the third and fourth-largest categories, respectively. Agricultural Land covers 285.31 km² or 6.27% of the study area, while Built-up Area covers 1284.63 km² or 28.28% of the study area.

Water Body and Open Space are the smallest categories in the landcover/landuse distribution, covering 97.04 km² and 19.76 km², respectively. Water Body covers 2.14% of the study area, while Open Space covers 0.43% of the study area.

Table 1: Landcover/Landuse Class Area Coverage

Landcover/Landuse Class	**Area Coverage (km²)**	**Percentage (%)**
Water Body	97.04	2.14
Dense Vegetation	1156.52	25.47
Agricultural Land	285.31	6.28
Built up Area	1284.63	28.29
Open Space	19.76	0.43
Grassland	1697.66	37.38
Total	4540.93	100

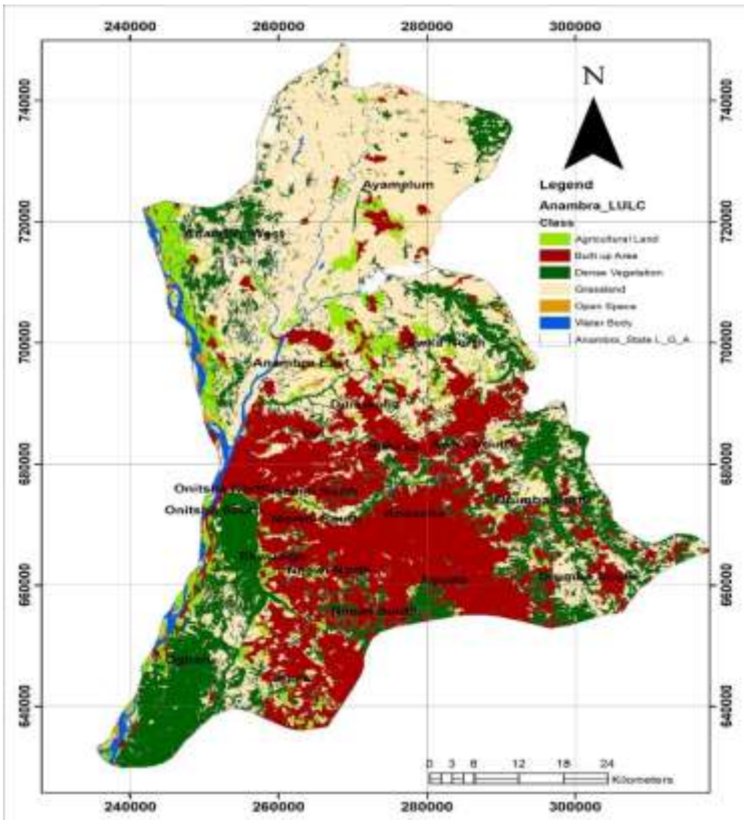

Figure 3: Landcover/Landuse Map of Anambra State

3.3.2 Landcover/Landuse Classes Affected by Flooding

The total area of landcover/landuse affected by flood in September is 400.20 km². This means that out of the total area covered by the landcover/landuse categories mentioned, 400.20 km² was submerged by flood during September, see table 2 and figure 4.

Table 2: Landcover/Landuse Class affected by flood in September

Landcover/Landuse Class	**Area Affected by Flood (km²)**	**Submerged Percentage (%)**
Water Body	77.60	79.98
Dense Vegetation	103.75	8.97
Agricultural Land	43.99	15.41
Built up Area	9.36	0.73
Open Space	15.22	77.02
Grassland	150.28	8.85
Total	400.20km²	

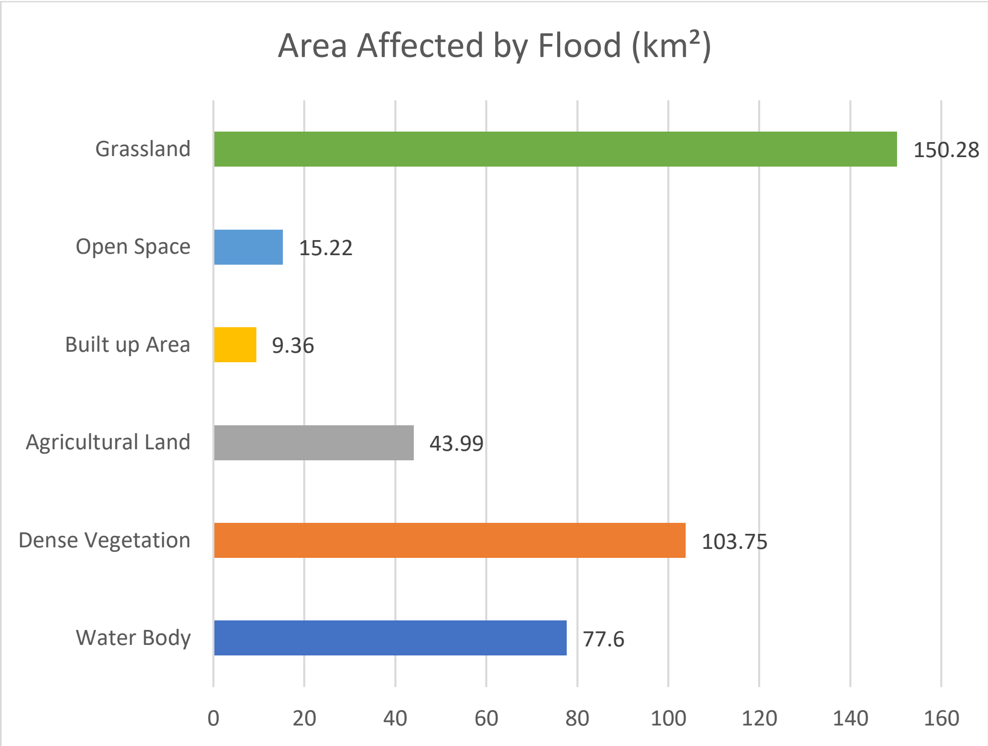

Figure 4: Distribution of Landcover/Landuse Class affected by flood in September

From table 2 and figure 4, water Body was the most affected landcover/landuse type, covering 77.60 km² of the flooded area with 79.96% of submergence. The second most affected landcover/landuse type was open Space, covering 15.22 km² with 77.02% submergence.

Agricultural Land covered 43.99 km² of the flooded area with 15.41% submergence, which implies that agricultural activities in the affected areas were disrupted, leading to potential food shortages and loss of income for farmers. Built-up Area, covering 9.36 km², was also affected by the 0.73% flood submergence, indicating that urban areas were not spared from the impact of the flooding.

Dense Vegetation, covering 103.75 km², was the least affected landcover/landuse type with 8.9% flood submergence. This could be due to the fact that dense vegetation can help reduce surface runoff and increase water infiltration into the soil, thus reducing the potential for flooding.

Grassland, covering 150.28 km² had 8.85% submergence. This is also expected, as grasslands tend to have low elevation and poor drainage, making them vulnerable to flooding.

In October, the total area of landcover/landuse affected by flood in Anambra State was estimated and table 3 and figure 5 show the different landcover/landuse classes and their corresponding areas affected by flood in October:

Table 3: Landcover/Landuse Class affected by flood in October

Landcover/Landuse Class	**Area Affected by Flood (km²)**	**Submerged Percentage (%)**
Water Body	93.21	96.05
Dense Vegetation	382.87	33.10
Agricultural Land	128.57	45.06
Built up Area	35.24	2.74
Open Space	17.36	87.85
Grassland	672.37	39.60
Total	1329.62	

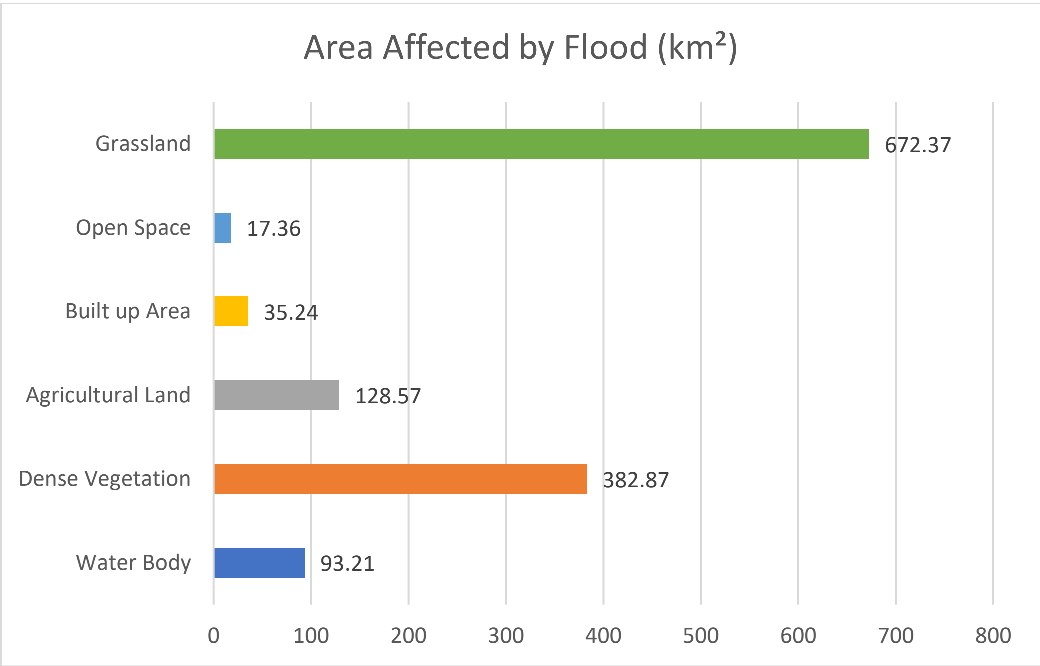

Figure 5: Distribution of Landcover/Landuse Class affected by flood in October

As can be seen from table 3 and figure 5, the total area of landcover/landuse affected by flood in October was 1,329.62 km², which is significantly higher than the total area affected in September. In October, the landcover/landuse classes most affected by flood were also waterbody and open space, with 93.21 km² and 17.36 km² respectively with submergence of 96.05% and 87.85% respectively. Agricultural land was also significantly affected, covering an area of 128.57 km² with a submergence of 45.06%, which could potentially lead to significant impacts on food security and agricultural production in the affected areas.

In addition, built-up areas were also affected by flood, covering an area of 35.24 km² with a submergence of 2.74%. Grassland and dense vegetation were also affected, covering an area of 672.37 km² and 382.87 km^2 with submergence of 39.60% and 33.10% respectively.

Overall, the significant increase in the total area of landcover/landuse affected by flood in October compared to September indicates the severity of the flood event in Anambra State. The high percentage of waterbody and open space affected by flood could also potentially have significant ecological and environmental impacts, such as habitat loss and soil erosion, which could affect the overall health of the ecosystem in the affected areas.

Lastly, in November, the flood extent in Anambra State affected a total area of 805.74 km², as shown by the landcover/landuse data in table 4 and figure 6.

Table 4: Landcover/Landuse Class affected by flood in November

Landcover/Landuse Class	**Area Affected by Flood (km²)**	**Submerged Percentage (%)**
Water Body	87.52	90.19
Dense Vegetation	214.49	18.55
Agricultural Land	81.89	28.70
Built up Area	21.01	1.64
Open Space	16.63	84.16
Grassland	384.20	22.63
Total	805.74	

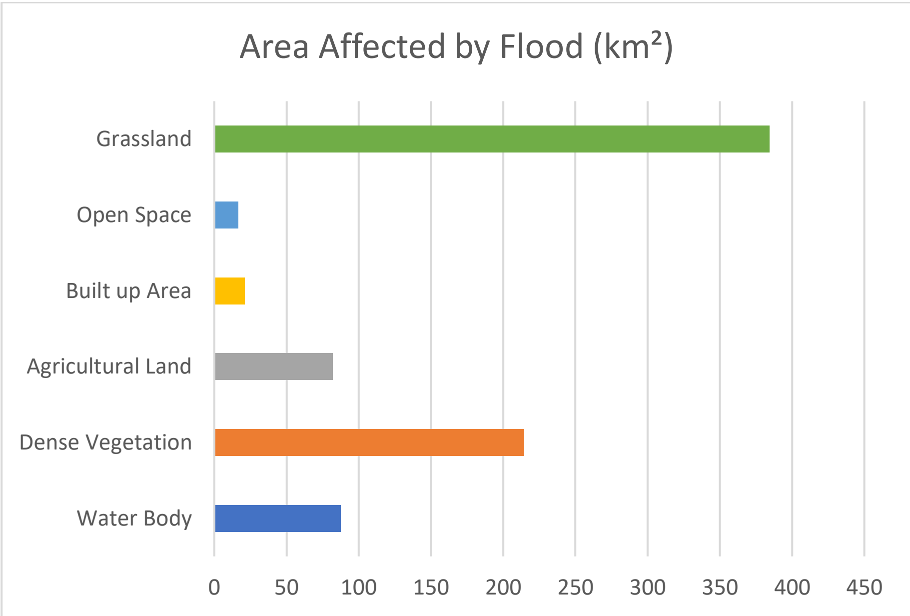

Figure 6: Distribution of Landcover/Landuse Class affected by flood in November

From table 4 and figure 6, of the total areas affected by flood, water bodies covered 805.74 km², indicating a decrease from October. In November, the landcover/landuse classes most affected by flood were also waterbody and open space, with 87.52 km² and 16.63 km² respectively with submergence of 90.195% and 84.16% respectively. Agricultural land was also significantly affected, covering an area of 81.89 km² with a submergence of 28.70%,

In addition, built-up areas were also affected by flood, covering an area of 16.63 km² with a submergence of 1.64%. Grassland and dense vegetation were also affected, covering an area of 384.20 km² and 214.49 km² with submergence of 22.63% and 18.55% respectively. Overall, the data shows that flood continued to affect a large area of landcover/landuse in November, with a significant reduction observed as observed in October. However, the decrease in flood coverage was not significant enough to indicate an improvement in the situation, and urgent intervention is still required to mitigate the impact of flooding and improve the resilience of communities to future flooding events.

3.3.3 Flood Area Coverage in Anambra State Local Government Areas

The result shows the total area of Local Government Areas (LGAs) in Anambra State affected by flood in September. Figure 7 and table 5 shows the affected areas for each LGA, with the corresponding area in km².

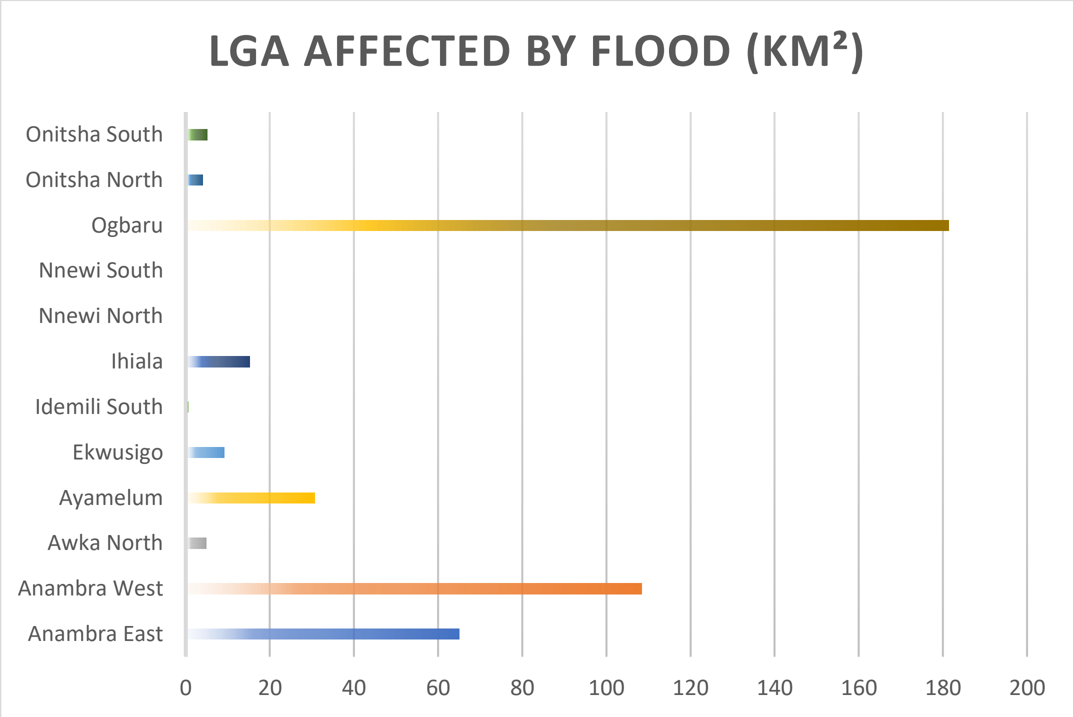

Figure 7: Distribution of LGA affected by flood in September

Table 5: LGA affected by flood in September

Local Govt. Area	**Area Affected by Flood (km²)**
Anambra East	64.98
Anambra West	108.46
Awka North	4.92
Ayamelum	30.67
Ekwusigo	9.21
Idemili South	0.58
Ihiala	15.26
Nnewi North	0.04
Nnewi South	0.08
Ogbaru	181.33
Onitsha North	4.01
Onitsha South	5.16

From figure 7 and table 5, the LGA with the highest area affected by flood is Ogbaru, with an area of 181.33 km². This is followed by Anambra West with 108.46 km² and Anambra East with 64.98 km². Ayamelum LGA is the fourth-largest affected area with 30.67 km², followed by Ihiala with 15.26 km². Onitsha North, Onitsha South, and Ekwusigo have the smallest affected areas, with 4.01 km², 5.16 km², and 9.21 km² respectively. Idemili South and Nnewi North and South have very small affected areas, with 0.58 km², 0.04 km², and 0.08 km² respectively.

In October, thirteen local government areas were affected by flooding, and the areas affected range from as low as 0.49 km² to as high as 625.04 km². Anambra West has the highest area coverage with 625.04 km², followed by Ogbaru with 322.60 km², and Ayamelum with 176.18 km². Anambra East also has a significant area affected with 135.59 km².

The local government areas with the lowest area coverage are Nnewi North, Idemili North, and Idemili South with 0.71 km², 0.49 km², and 9.94 km², respectively, see figure 8 and table 6.

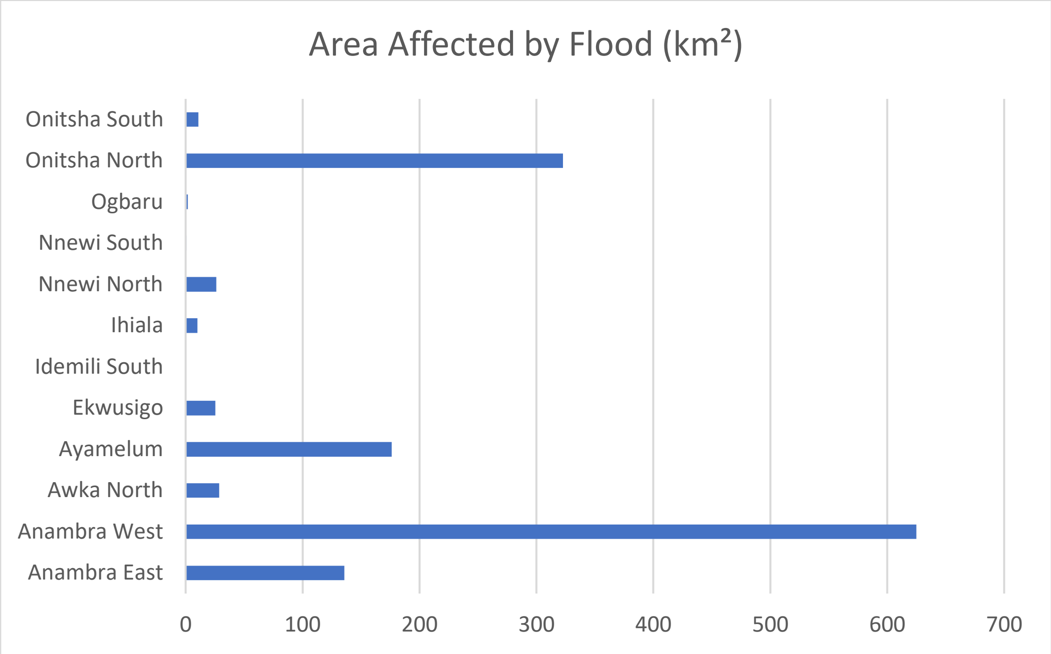

Figure 8: Distribution of LGA affected by flood in October

Table 6: LGA affected by flood in October

Local Govt. Area	**Area Affected by Flood (km²)**
Anambra East	135.59
Anambra West	625.04
Awka North	28.71
Ayamelum	176.18
Ekwusigo	25.36
Idemili South	0.49
Ihiala	9.94
Nnewi North	26.20
Nnewi South	0.71
Ogbaru	1.97
Onitsha North	322.60
Onitsha South	10.85

Lastly, in November, Anambra West has the highest area coverage of 321.15 km², followed by Ogbaru with 251.35 km². Anambra East is the third-largest affected area with 107.21 km². Ayamelum and Onitsha South also have significant areas affected by flood, with 93.01 km² and 11.74 km², respectively. The local government areas with the least affected areas by flood are Nnewi North, Nnewi South, and Idemili North, with 0.38 km², 0.63 km², and 0.11 km², respectively. See figure 9 and table 7 for details.

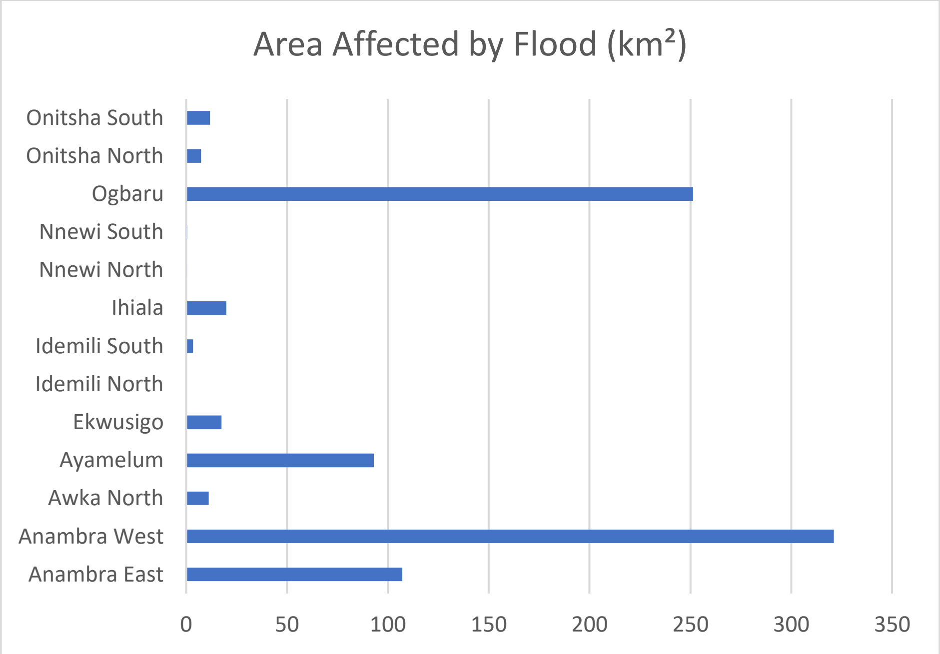

Figure 9: Distribution of LGA affected by flood in November

Table 7: LGA affected by flood in November

Local Govt. Area	**Area Affected by Flood (km²)**
Anambra East	107.21
Anambra West	321.15
Awka North	11.24
Ayamelum	93.01
Ekwusigo	17.46
Idemili North	0.11
Idemili South	3.48
Ihiala	19.96
Nnewi North	0.38
Nnewi South	0.63
Ogbaru	251.35
Onitsha North	7.42
Onitsha South	11.74

It is important to note that this information is crucial in identifying the areas that have been significantly affected by the flood in each LGA. This information can be used to prioritize aid and relief efforts to the affected areas, as well as to plan for mitigation measures in the future. Additionally, it can help to determine the potential impact of the flood on the communities and infrastructure in the affected areas.

4. Conclusion

The findings of the study make it evident that Anambra State suffered from severe flooding from September to November 2022, resulting in significant environmental damage. The study identified six categories of landcover/landuse affected by the flood, with grassland being the most affected. The study also identified the local government areas with the highest and lowest areas affected by the flood, which can aid disaster management agencies and policymakers in planning for disaster response and recovery efforts, including providing relief to affected communities and implementing measures to prevent or mitigate future flooding in the state. Overall, the findings of this study highlight the importance of effective disaster management and planning in vulnerable areas to mitigate the impact of future disasters.

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