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Flood Assesment and Monitoring of River Benue Channel

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Abstract: This paper presents the findings of a comprehensive assessment and monitoring study of floods in the River Benue channel from 2015 to 2022. Floods are significant natural disasters with global impacts, and Nigeria, particularly the River Benue channel, is susceptible to recurring and severe flood events. The study employed advanced geospatial technology, including satellite imagery and remote sensing, to generate flood extent maps for each year. These maps were analyzed to determine the spatial distribution and intensity of flood events, and inundation frequency was calculated to assess the recurrence of floods. The results reveal significant variations in flood patterns and impacts across different years and states along the River Benue. In 2015, widespread inundation was recorded in all states, signifying the severity of flooding during that year. Subsequent years exhibited fluctuations in flood intensity and spatial distribution, with some states experiencing higher intensity than others. The most severely affected locations varied from year to year, with notable occurrences in Adamawa, Taraba, Kogi, Nasarawa, and Benue states. The study's implications underscore the localized nature of flood events and the need for context-specific flood management strategies.

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I. INTRODUCTION

➢ *Background*

Floods are natural occurrences that frequently impact river systems, resulting from factors such as heavy rainfall, seasonal rains, or snow-melt that exceed the river channel's capacity to contain the water flow. These events have global significance, affecting economic development, livelihoods, agriculture, and human life, making them a significant concern (Wood, 2005). According to Abam (2006), flood is the rapid influx of a substantial volume of water that inundates the stream channel and its floodplain within a short period, leading to severe economic and residential impacts. Emodi (2012) characterizes floods as the temporary submersion of areas not typically submerged, caused by an abrupt rise in water levels in streams, rivers, lakes, or seas.

The prevalence of flood disasters worldwide is well-documented, with floods being the most common natural disasters globally, occurring across regions (DMSG, 2001). In recent years, the frequency of flood occurrences has reached unprecedented levels, with approximately 70 million people exposed to flooding annually and over 800 million individuals residing in flood-prone areas globally. Rentschler and Salhad (2020) estimate that approximately 1.47 billion people, constituting about 19% of the world population, face substantial risks during 1in100 year flood events.

Nigeria, with its complex river systems, is particularly vulnerable to floods, which are the most frequent and recurring natural hazards in the country (World Bank, 2022). The compounding effects of climate change, inter-decade cycles influenced by sea-surface temperatures in oceans, and the reduction of aerosol concentrations over the North Atlantic have intensified the recurrence, intensity, and spatial extent of floods across Nigeria (World Bank, 2022). Rapid urbanization, coupled with inadequate waste management and insufficient drainage systems, has amplified the vulnerability to flood incidents in urban areas. Notable flood events in 2012 and recent years have had detrimental impacts on various sectors, including agriculture, infrastructure, health, education, and the economy (World Bank, 2022). This has prompted global attention, leading to explicit mention of floods in Sustainable Development Goal (SDG) 11 (sustainable cities and communities) and SDG 13 (climate action).

Among the various types of floods experienced in Nigeria, river flooding stands out as the most extensive and damaging (Ologunorisa, 2004). The River Benue channel, one of Nigeria's major rivers, has witnessed severe flooding,

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resulting in the loss of numerous lives and significant economic damage. Communities along the river basin have faced repeated displacement, often resettling in other flood-prone zones, perpetuating a cycle of losses. Notable instances of flooding have occurred in various parts of the River Benue channel in recent years in 2008, 2012, 2014, 2018, 2020, and 2022 most recent (Nimet Annual Flood Outlook 2022).

To optimally address and manage flood disaster before, during and after the event, a collaborative approach needs to be adopted. Collaborative efforts between the National Emergency Management Agency (NEMA) and other relevant stakeholders in disaster management are crucial for effective flood disaster management in flood-prone areas. This collaboration should focus on developing robust forecasting and prediction systems to enable proactive measures that will help to mitigate the impact of disaster. Adopting a competent model with advanced Geo-visualization capabilities becomes crucial for accurate and effective decision-making. Geo-spatial technology including Geographic Information Systems (GIS) and Remote Sensing, offers a valuable framework for comprehensive flood assessment, facilitating the implementation of proactive measures to mitigate flood impacts and enhance flood management strategies. Leveraging Geo-spatial technology can enable accurate and detailed flood monitoring and assessment of the River Benue channel from 2015 to 2022, providing valuable insights for future mitigation efforts.

➢ *Statement of Problem*

Recent devastating flood events that affected several states bordering the Benue River in Nigeria has highlighted the urgent need for effective flood management strategies. The fundamental cause of river flooding is excess runoff induced by heavy rainfall, which is exacerbated by anthropogenic factors such as concentrated development activities along the river's natural flow path. The flood incident resulted in significant loss of life, displacement of people, damage to infrastructure, and destruction of farmland. Despite the predictions by the Nigeria Hydrological Services Agency (NIHSA) about the impending flood disaster and the recommendation to relocate activities and residences from the floodplain to the upland, there was a lack of spatially synthesized information to support decision-making. Specifically, there was a need for comprehensive and accurate information regarding the extent of the area at risk or vulnerable to flooding along the Niger and Benue Rivers. The absence of such crucial information hindered proactive measures and effective response to flood disasters. Therefore, the problem at hand is the lack of spatially synthesized information that can accurately detect and delineate the areas along the Niger and Benue Rivers that are at risk or vulnerable to flooding. The absence of this critical information limits the ability of authorities and stakeholders to implement proactive measures, adequately plan for relocation, and effectively manage future flood events. Addressing this problem requires the development of a comprehensive and accurate flood risk assessment and mapping system that can provide timely and spatially precise information to support decision-making. Such a system would enable the identification of vulnerable areas, facilitate proactive measures for relocation and mitigation, and enhance overall flood management strategies in the affected regions.

➢ *Aim and Objectives*

The aim is to monitor and assess floods in the river Benue Channel with the following objectives;

- To map the inundation extent in the River Benue channel from 2015 -2022.
- To estimate the extent of damage to the population and croplands.
- To determine the inundation frequency in settlements across the river Benue channel.
- To identify vulnerable settlements across the river Benue channel.

➢ *Study Area*

The Benue River is located between latitude 6°29′N to 11°46′N and longitude 8°55′E to 13°30′E. It extends 532 km from north to south and 480 km from west to east and covers an area of 154,328.9 km^2. Lake Chad Watershed bounds the upper Benue River to the north, to the east and south by the Republic of Cameroon, and to the west by Lower Benue and Upper Niger. The major river is the River Benue which has its origins in the Adamawa Plateau of Northern Cameroon and flows southwest to meet with River Niger in Lokoja. The River Benue is joined by its major tributaries; the Gongola River, the Mayo Kébbi, the Taraba River, and River Katsina-Ala. The altitude ranges from 80 to 2034 m with a mean elevation of 400 m. According to the Koppen climate classification, the upper Benue River is characterized by a tropical Savannah climate in the south and a middle and warm semi-arid climate in the north. The river is marked by these aggro-ecological zones; mid-latitude zone, derived Savannah, northern guinea Savannah, southern guinea Savannah, and Sahel Savannah. The mean annual rainfall ranges between 700 and 1200 mm and the average annual temperature ranges from 24 to 27 °C (Ishaku et al. 2015).

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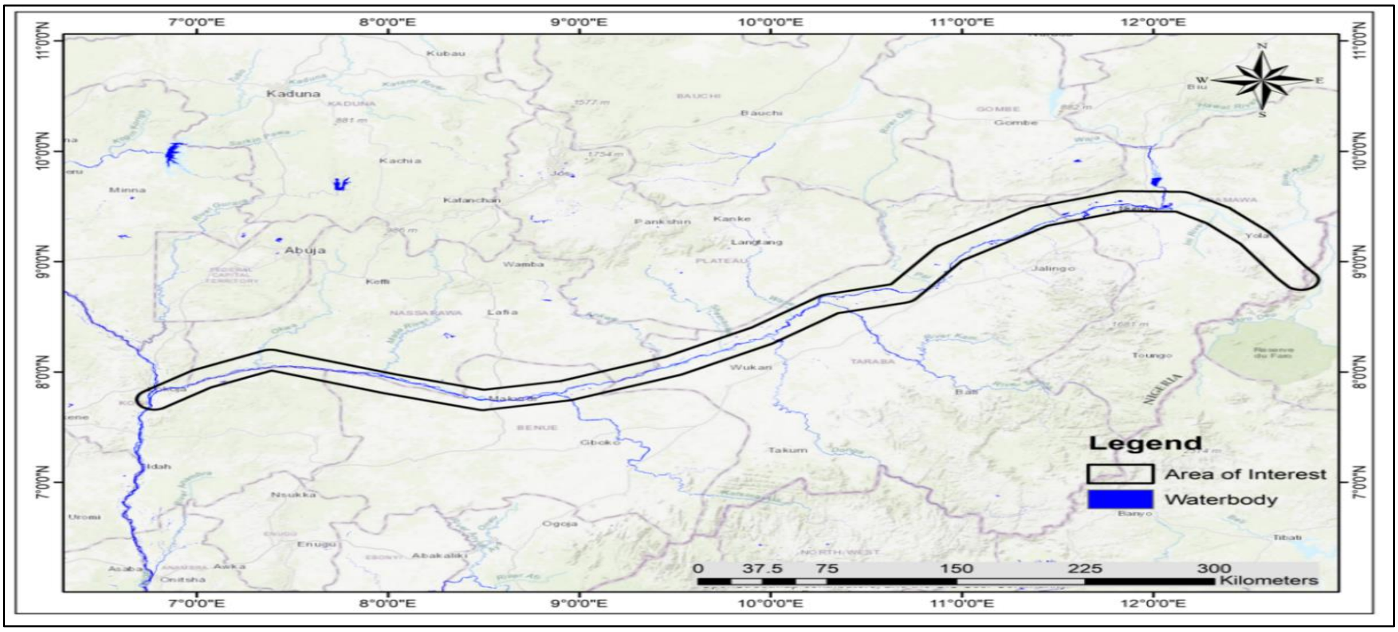

Fig 1 Map Showing Study Area of Interest.

II. LITERATURE REVIEW

Flooding is a recurring natural hazard that endangers human lives, infrastructure, and the environment. Settlements along the River Benue are prone to flooding due to natural topography and proximity, causing devastating effects on the surrounding communities. As a result, monitoring and assessing flood events in the River Benue channel is critical for effective disaster prevention and mitigation strategies.

➢ *River Benue*

The River Benue, as the major tributary of the River Niger, plays a vital role in Nigeria's water resources and economy (Andersen and Golitzen, 2005). However, its geographical characteristics and seasonal rainfall patterns make it susceptible to severe flooding events. To address the challenges posed by these floods, researchers have focused on developing methods for flood assessment and monitoring along the River Benue channel.

Abubakar et al. (2020) conducted a study on the socioeconomic impact of flooding on the riverine communities of the River Benue. Their research highlighted the extensive destruction of farmlands and properties caused by floods over the years. It emphasized the need for accurate flood assessment and monitoring to enable proactive measures and timely responses. The study also highlighted the severe impact of flooding on transportation, limiting agricultural productivity in the area due to the lack of effective mobility during flood events.

➢ *Flood*

Floods are the most common environmental hazard in Nigeria (Etuonovbe, 2011). The country has experienced numerous devastating flood disasters, including those in Ibadan, Osogbo, Yobe, and coastal cities such as Lagos, Port Harcourt, Calabar, and Uyo (Olajuyigbe, Rotowa, and Durojaye, 2012). These flood events have resulted in the loss of lives and significant damage to properties.

Benedict et al. (2016) conducted a flood risk assessment of residential neighborhoods in Calabar. Their study revealed higher vulnerability in low-lying residential areas. The researchers recommended the enforcement of stringent flood control legislation and development control measures to discourage construction in flood-prone areas of Calabar.

In the field of coastal flood hazard analysis, Kriebel and Geiman (2014) proposed the use of a generic flood stage (FS) based on extreme high-water events. This statistical FS can be compared with moderate and major FS values established by the National Weather Service (NWS), providing a consistent reference for assessing the flooding potential of future storm events and sea level rise.

➢ *Factors Influencing Flood in the Area*

Ologunorisa, Ogbuokiri, and Eludoyin (2021) identified rainfall, soil type, slope, and geology as prominent factors influencing flooding in the River Benue area. Additionally, Shabu and Musa (2015) attributed the flood disaster along the River Benue to the absence of buffer dams to regulate water releases from the Lagdo Dam in Cameroon and an inefficient warning system that failed to alert communities within flood-prone areas.

Akoteyon (2022) conducted a study on factors influencing flooding in Lagos, Nigeria. Through questionnaire surveys, the study identified anthropogenic, natural, and institutional factors contributing to flooding in the area.

Overall, the literature review highlights the significance of the River Benue in Nigeria, the impact of floods on communities along the river, and the factors influencing flood occurrences in the area. Understanding these factors is crucial for developing effective flood management strategies, including flood control measures, warning systems, and land-use planning regulations.

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III. METHODOLOGY

The methodology employed in this research aimed to provide accurate and up-to-date flood extent maps, inundation frequency tables, flood impact charts and tables for effective flood monitoring and assessments across the River Benue channel. The methods facilitated the efficient processing of satellite imagery and the generation of valuable insights of the study area for flood management and mitigation strategies.

- Data Access**:** The research utilized the Google Earth Engine platform for accessing and processing satellite imagery. The Sentinel-1 Synthetic Aperture Radar (SAR) data was used for flood extent mapping, and additional data-sets such as population density, cropland extent, and settlement points were intersected with the flood extent to assess the impact of floods on various aspects.
- Data Selection**:** Suitable satellite imagery was selected based on availability, spatial resolution, and temporal coverage. High-resolution satellite imagery, such as MODIS, Global Human Settlement Layer (GHSL), Sentinel-1 and 2 were preferred for their detailed information and frequent revisit times.
- Data Source**:** The primary data source for this study was the Google Earth Engine platform repository, which provided a vast collection of Geo-spatial data. Additionally, satellite imagery from the National Space Research Agency (NASRDA) Nigeria Sat-X was used for validation purposes. Other ancillary data sets, such as settlement layers and administrative boundary shape-files, were obtained from Geo-Referenced Infrastructure and Demographic Data for Development (GRID^3) Nigeria.
- Data Collection and Analysis: Sentinel-1 and 2 SAR data was collected from 2015 to 2022 to assess the flood extent and monitor changes over time. Population data, cropland extent, and building footprints were intersected with the flood extent maps to analyze the impact of floods on these aspects. Validation of the flood extent maps was performed using Nigeria Sat-X satellite imagery.
- Data Pre-Processing**:** The selected satellite data underwent pre-processing steps to enhance their quality and suitability for flood extent mapping. Radiometric calibration, atmospheric correction, and geometric correction were performed to remove distortions and align the imagery spatially.
- Flood Mapping Techniques**:** Google Earth Engine serves as a Cloud Processing platform employed for generating Flood extent maps through the application of image differencing methods. The procedure involves the comparison of satellite images captured before and after the flood event. Water indices, such as the Normalized Difference Water Index (NDWI), were computed to enhance the visibility of water bodies within the images. Subsequently, a combination of thresholding and classification techniques was implemented to distinguish regions affected by the flood from those unaffected.

Table 1 Table Showing the Utilized Datasets

Data	**Acquisition Date**	**Characteristics**	**Sources**
Sentinel-1 SAR	20-09-2015 26-09-2016 21-09-2017 28-09-2018 23-09-2019 29-09-2020 24-09-2021 09-10-2022	Spatial Resolution: 10m Swath: 250 Km Revisit Period: 12 days Polarization: VV Pass Direction: Descending	Google Earth Engine: https://earthengine.goog le.com/
GHSL- Global Human Settlement Layer	21-09-2022	Cell Size: 100 x 100m	Google Earth Engine: https://earthengine.goog le.com/
Building footprints, roads, and boundary shape file	14-09-2022	Vector layers	HCMGIS plugins on QGIS
Pre-classified LULC (Sentinel-2)	2020	Resolution: 10m	Global land cover https://cds.climate.coper Nicus
Nigeria Settlement point	2023	Vector Layer	http://grid3.gov.ng
Nigeria River Shape file	2023	Vector Layer	www.esri.com
Nigeria-Sat-X satellite Images	2023	Raster Layer	National Space Research and Development Agency (NASRDA)

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➢ *Flow-Chart*:

United Nations Office for Outer Space Affairs through the United Nations Platform for Space-Based Information for Disaster-management and Emergency Response (UN-SPIDER) Knowledge Portal recommended flood monitoring and assessment script employed the following processes: Figure 2 below.

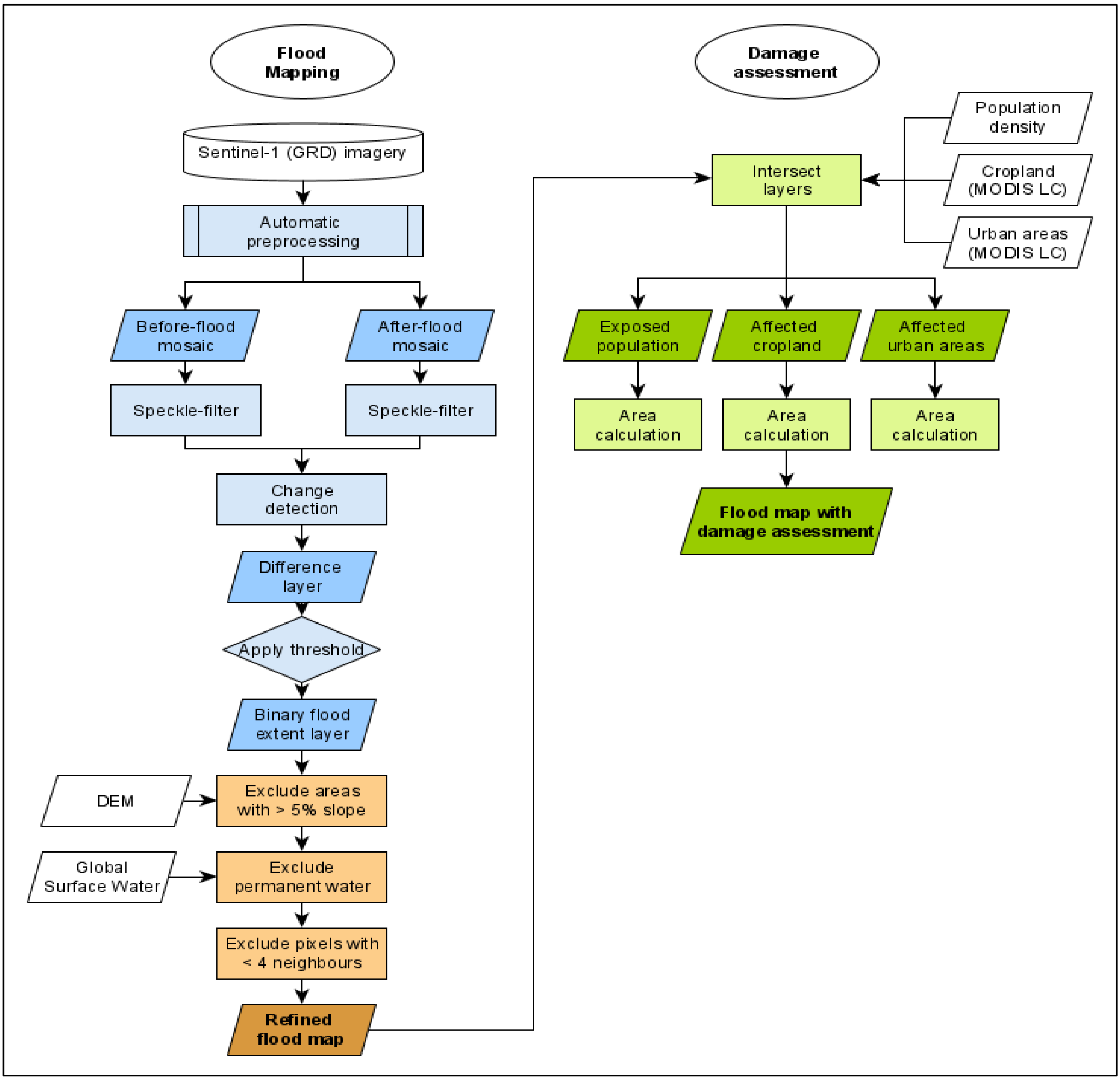

Fig 2 Flowchart Showing Employed Methodology.

* Data Analysis and Visualization: The flood extent maps generated using Google Earth Engine were analyzed and visualized to understand the spatiotemporal patterns of flooding in the River Benue channel. The maps were imported into Q-GIS for further analysis and visualization enhancements.
* Inundation Frequency**:** The frequency of inundation was calculated by analyzing the maximum yearly inundation extent over an eight-year period (2015-2022). The annual inundation maps were stacked and summed to create a single-layer result that depicted the frequency distribution of flooding over time.
* Field Validation**:** A field survey took place from April 26th to 30th, 2023, across several locations in Nigeria: Lokoja in Kogi state, Ogba in Nasarawa state, Ntchouo in Benue state, Kurmi in Taraba state, and Goluma in Adamawa state. These areas were identified as flood-prone settlements along the Benue River channel through satellite-based flood monitoring within a 5km buffer channel along the river.

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The objective of the field validation was twofold: to evaluate flood impacts and validate the accuracy of space-based flood analysis. Findings indicated that the settlements, including government institutions, schools, residential zones, and farmlands, were all situated within flood-vulnerable regions, rendering them highly susceptible to flooding. The 2022 flood event significantly affected key road infrastructure, leading to logistical disruptions.

In the survey, specific areas in Lokoja, such as Kpata market, Marine police station, and Methodist Church, were identified as impacted. Ground measurements were gathered and compared with satellite data for spatial analysis and impact assessment. Notably, the extent of the 2022 flood surpassed that of previous years.

The validation exercise underscored the importance of field measurements in confirming flood patterns and damage, and recommended producing detailed annual flood vulnerability maps for the identified settlements along the Benue River channel. These settlements share proximity and topography, amplifying their susceptibility to recurrent flood events. To mitigate human losses in flood-prone areas, the report urged sufficient funding for early warning systems and resettlement plans, along with strict enforcement of construction regulations. Effective communication and implementation planning among emergency management stakeholders were also advised.

In conclusion, the field validation emphasized the national significance of employing space-based analysis to model precise geographical attributes for addressing flood-related concerns. See figures 3 to 6.

Fig 3 The Field Officers Observing the Normal River extent

Fig 4 The Marine Police Station Damaged by the 2022 Flood Disaster

Fig 5 An Agricultural Field/Crop-Land Submerged During the Flood Occurrence Around the Confluence Area.

Fig 6 Residential Buildings that Were Submerged During the Flood Event

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IV. RESULTS AND DISCUSSIONS

In this section, we present the results and discuss the findings of our research on assessing and monitoring floods in the river Benue channel. The outcomes of the study include maps showing the flooded extent in the channel, charts illustrating the flood impact on population and farmland as well as a table summarizing the inundation frequency over an eight-year period (2015-2022).

➢ *Results*

- Flood extent in the channel**:** Flood extent maps were generated for the different years, depicting the areas/communities affected by flood within the 5km buffer along the River Benue channel. These maps provide spatially explicit information on the extent of flooding, enabling the identification of flood-prone areas and supporting flood management strategies.

The flood extent maps clearly illustrate the varying extent of flooding in the different years. They show the areas that experienced inundation, including riverbanks, floodplains, and adjacent regions. By visually analyzing these maps, it is evident that the River Benue channel is highly susceptible to flooding, with significant portions of the surrounding land being affected during flood events.

The maps also highlight the spatial variability of flood extent over the study period (2015-2022). Some years exhibit more extensive flooding than others, indicating variations in rainfall patterns, hydrological conditions, and other influencing factors. These maps serve as valuable tools for understanding the dynamics of flood in the River Benue channel and can aid in the development of targeted mitigation measures and flood management plans.

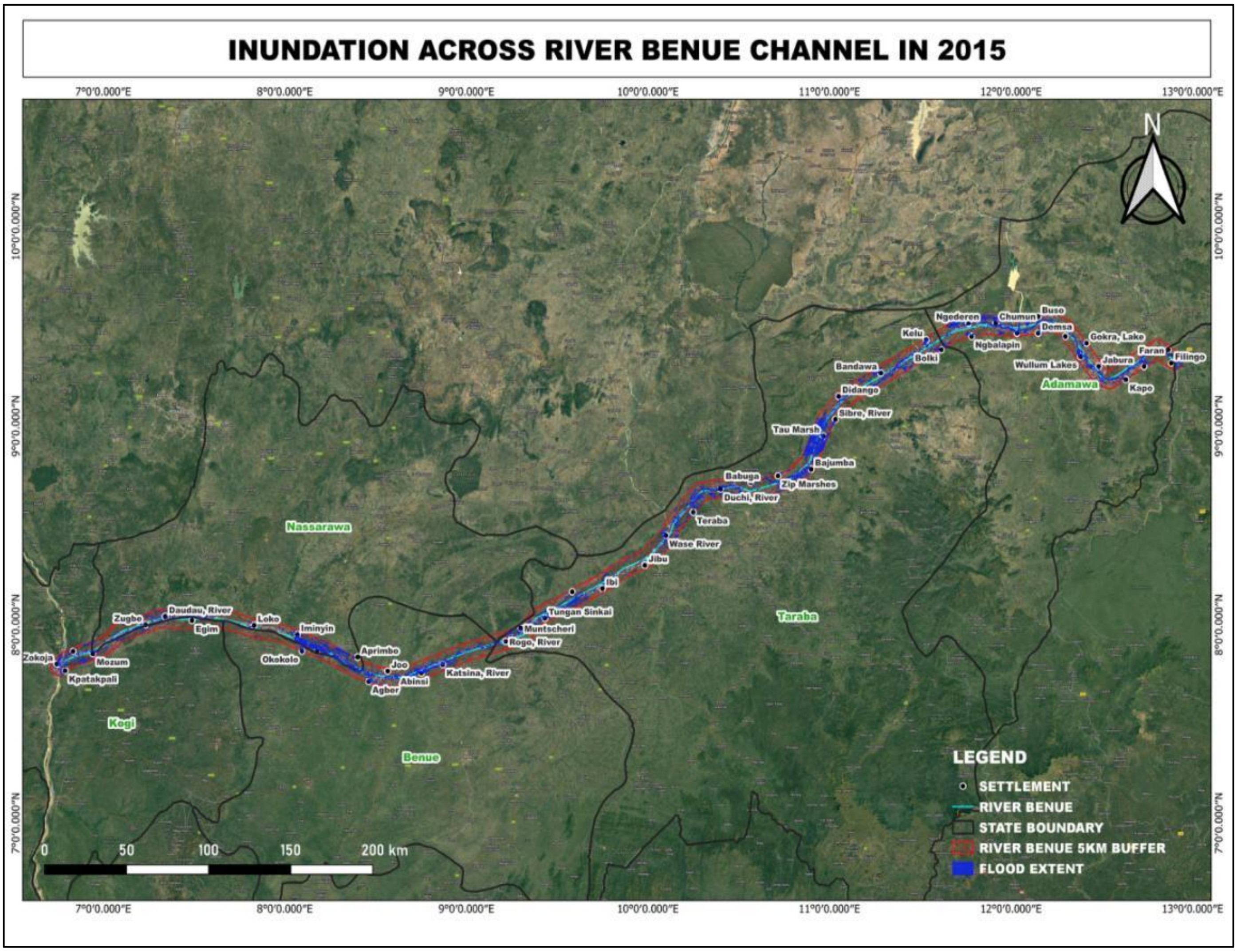

Fig 7 Map Showing Inundation Across River Benue Channel in 2015

The analysis of the flood extent map for the year 2015 (Figure 7) reveals that the states traversed by the river Benue encountered widespread inundation at varying intensity levels. This indicates that the entire region experienced flooding to different degrees during that specific period. The inundation was not limited to specific sections but affected the entirety of the states through which the River Benue traverses.

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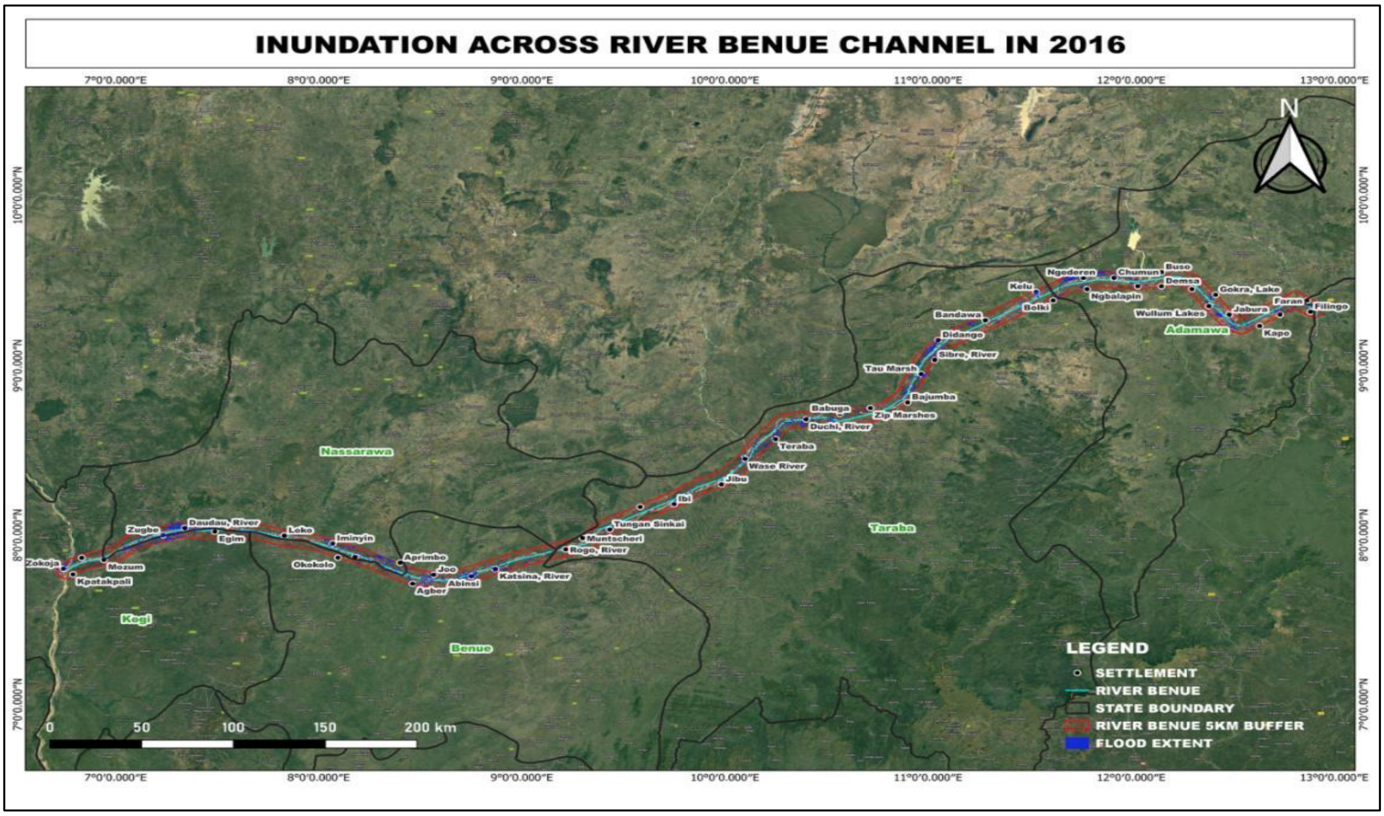

Fig 8 Map Showing Inundation Across River Benue Channel in 2016

The analysis of the flood extent map for the year 2016 (Figure 8) reveals that flood events were observed in all the states traversed by the River Benue. However, the intensity of the floods in 2016 was comparatively lower than that of the previous year (2015). While the entire region experienced flooding, the severity of the inundation was reduced. This indicates that the floodwaters in 2016 did not reach the same levels as in 2015. The lower intensity of the floods in 2016 suggests a relatively milder impact on the states along the river Ben.

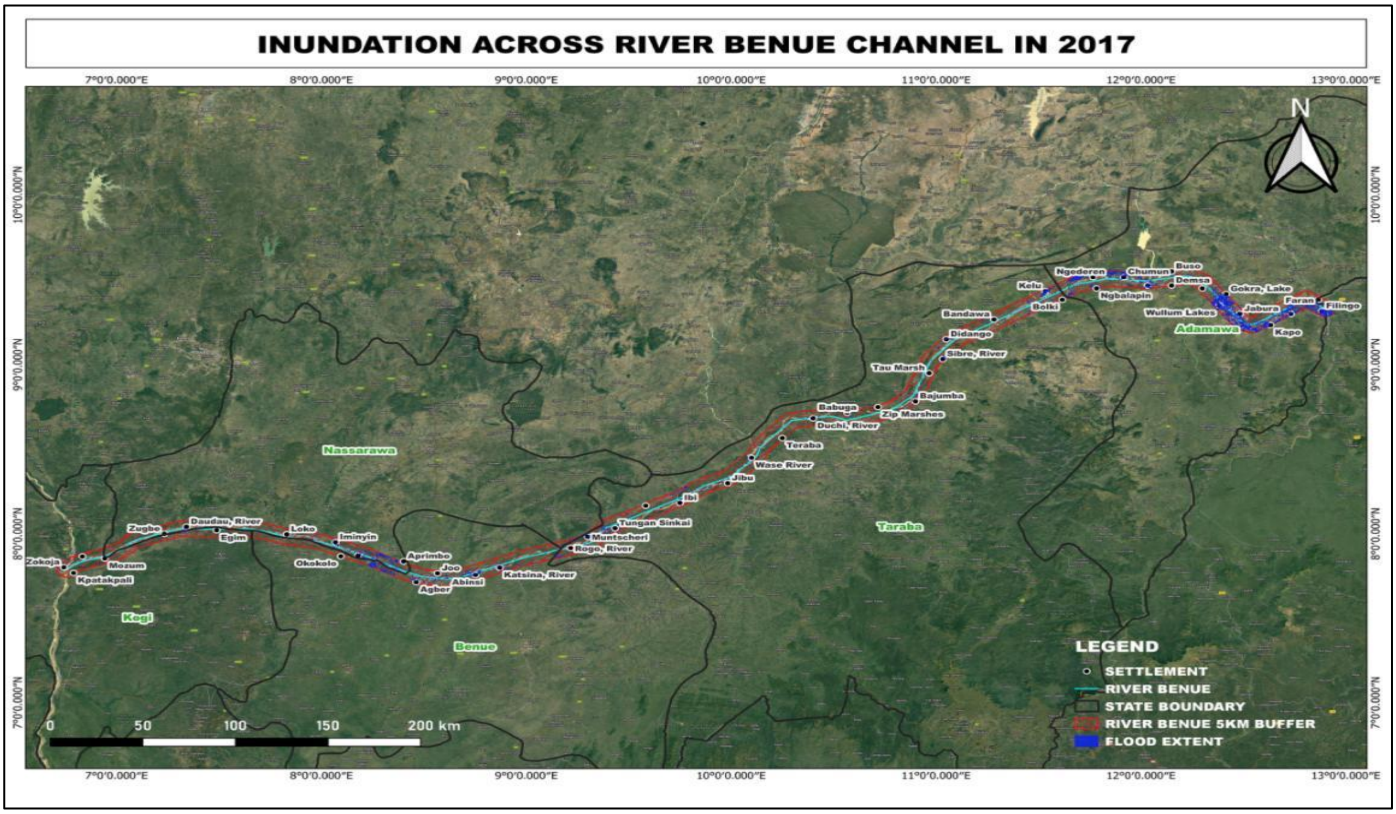

Fig 9 Map Showing Inundation Across River Benue Channel in 2017

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The flood extent map for the year 2017 (Figure 9) reveals that flooding occurred in Nasarawa, Benue, and Adamawa states, with varying intensity levels. In Nasarawa and Benue states, the flood events were recorded at a relatively low intensity. However, in Adamawa state, the floods were observed to have occurred at a significantly greater intensity. This indicates that while all three states experienced flooding during that year, the impact and severity of the floods were more pronounced in Adamawa state

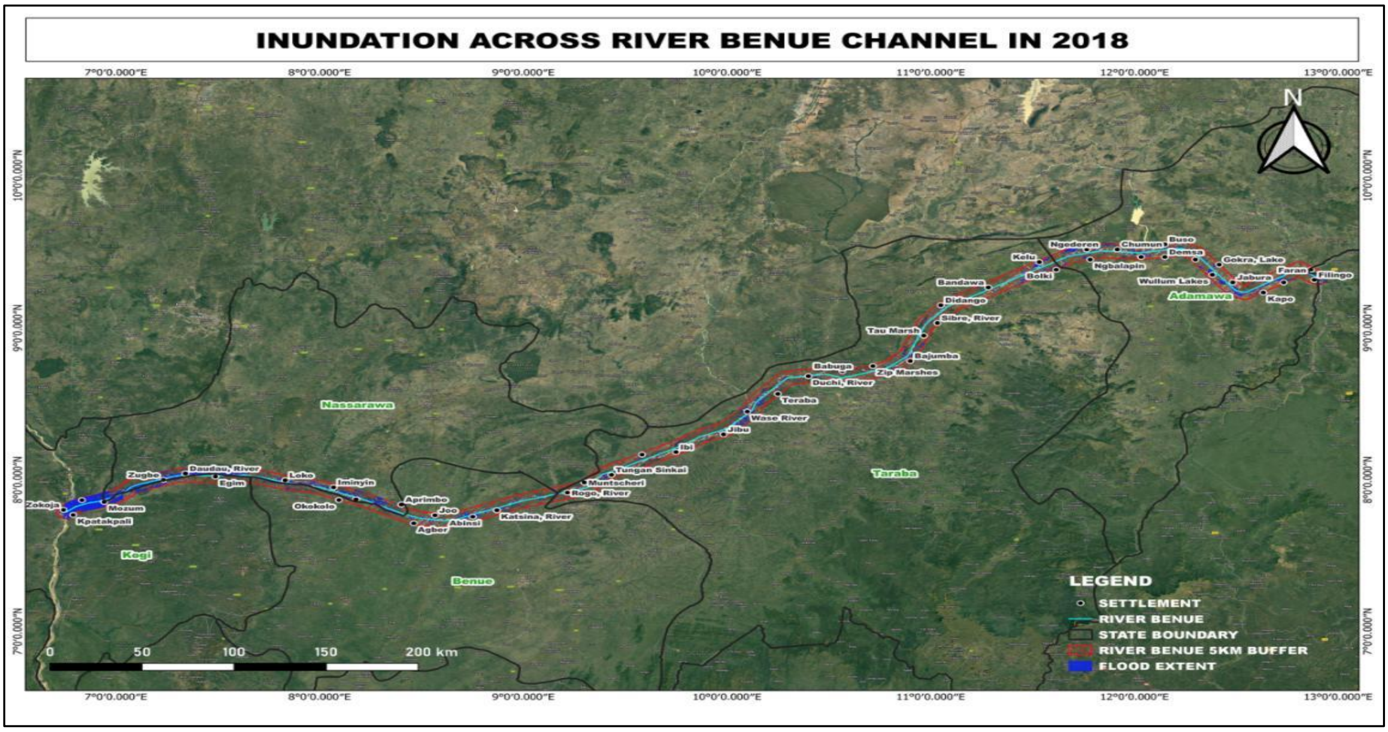

Fig 10 Map Showing Inundation Across River Benue Channel in 2018

The flood extent map for the year 2018 (Figure 10) indicates that flood events were observed in communities across all the states traversed by the river Benue. However, the intensity of the floods in 2018 was notably higher in Kogi State compared to other states. This suggests that while flooding affected communities in all the states along the River Benue, the impact and severity of the floods were particularly significant in Kogi State.

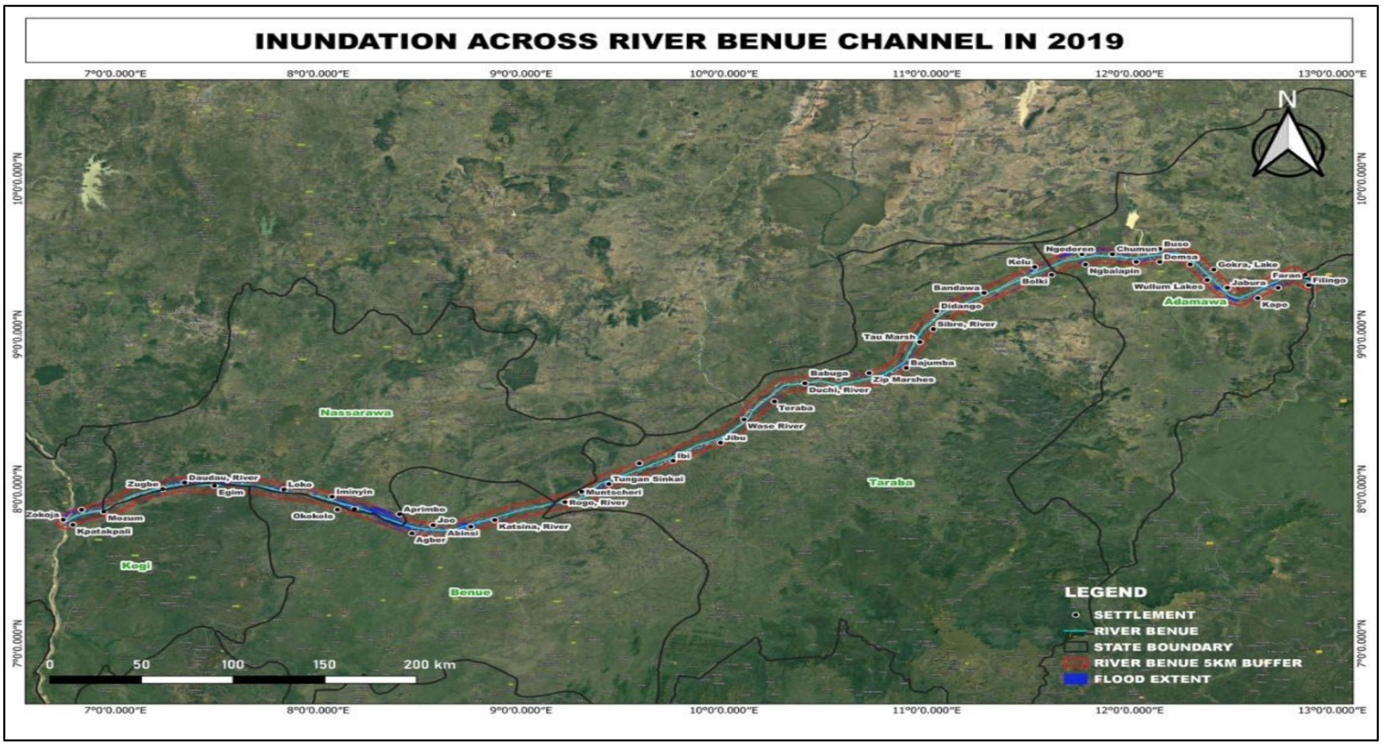

Fig 11 Map Showing Inundation Across River Benue Channel in 2019

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The flood extent map for the year 2019 (Figure 11) reveals that flood events were more prominently recorded in Nasarawa and Benue states. However, the proportion of flooding observed in Adamawa and Kogi states was considerably lower. This indicates that while Nasarawa and Benue experienced a higher occurrence of floods during that year, Adamawa and Kogi states were relatively less affected

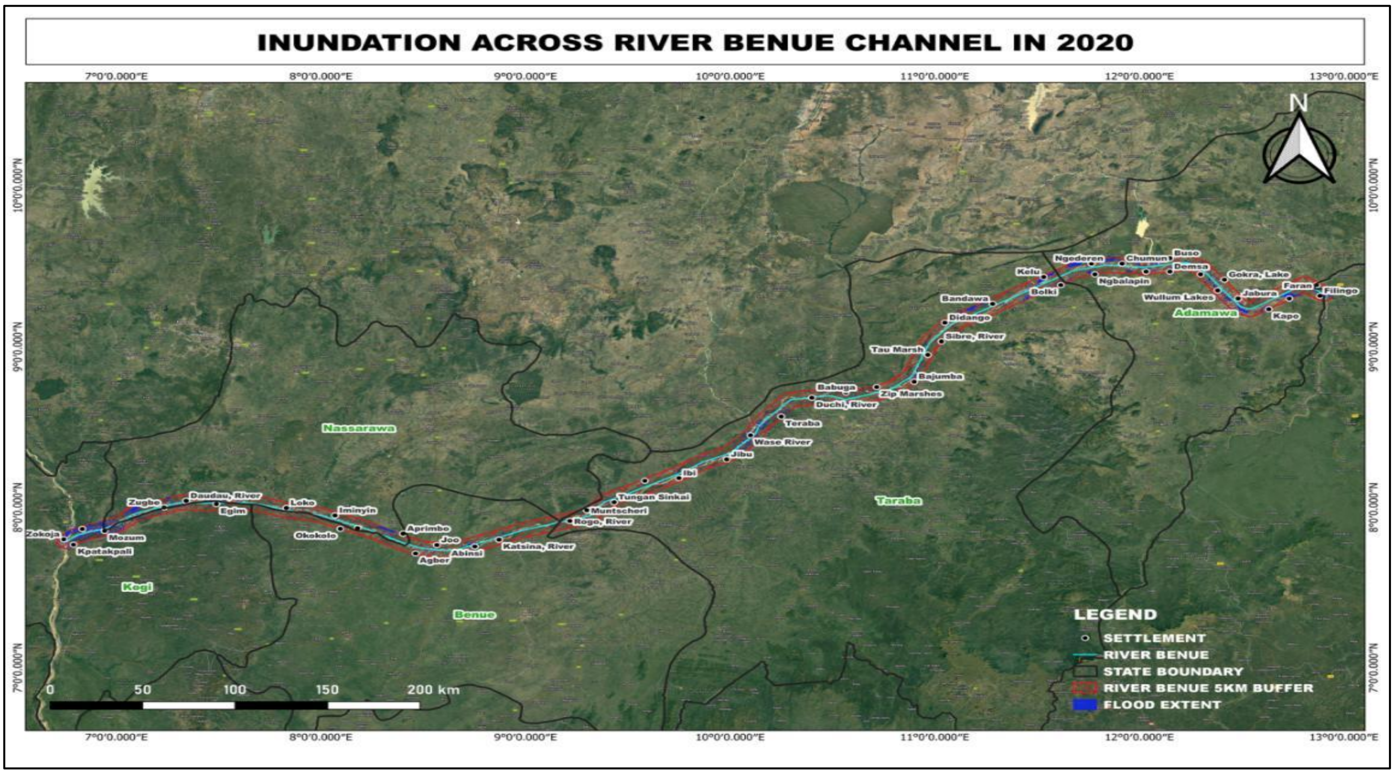

Fig 12 Map Showing Inundation Across River Benue Channel in 2020

The flood extent map for the year 2020 (Figure 12) highlights that flood events were more prominently recorded in Kogi and Adamawa states compared to all the other states traversed by the River Benue. The analysis indicates that Kogi and Adamawa experienced a higher occurrence and intensity of floods during that particular year, surpassing the flood impacts observed in other states along the River Benue.

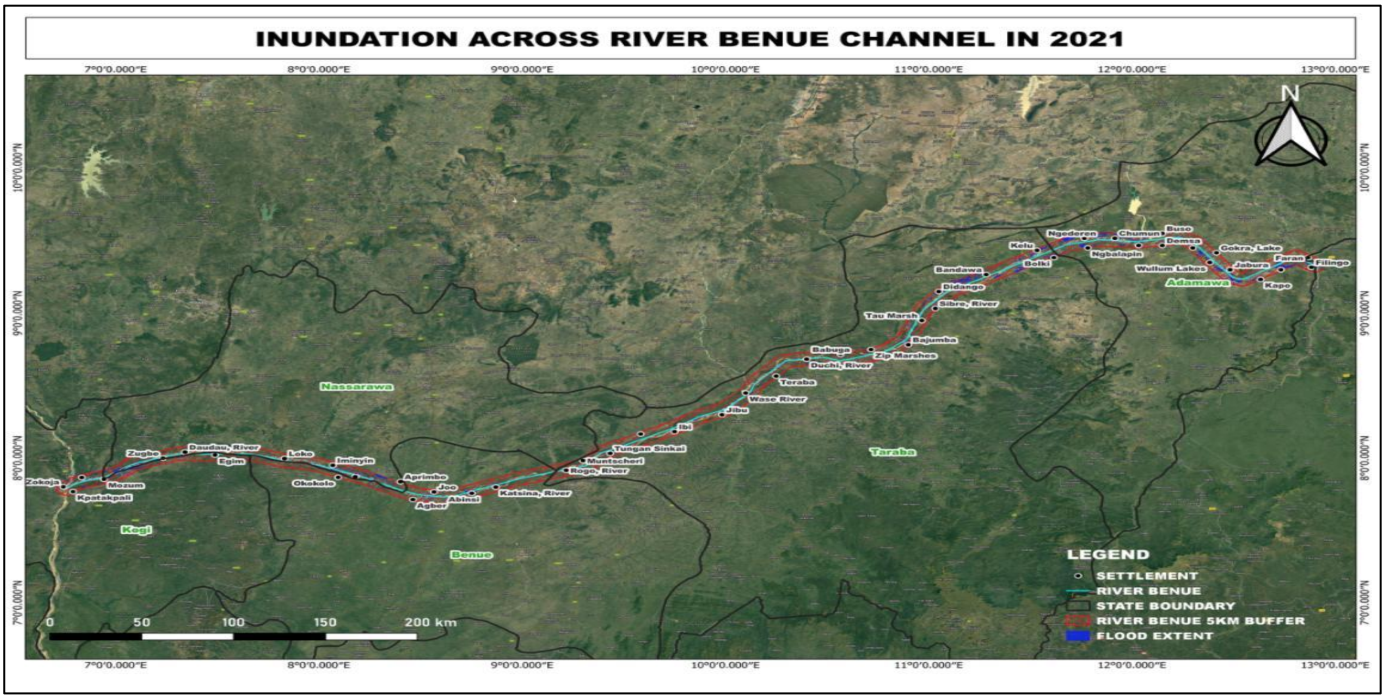

Fig 13 Map Showing Inundation Across River Benue Channel in 2021

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The flood extent map for the year 2021 indicates that the overall incidence of floods across the river Benue channel was relatively low. However, the most severely affected locations were identified in Adamawa and Taraba states. While the flood intensity was comparatively lower in other areas, Adamawa and Taraba states experienced a higher concentration and severity of flooding during that year. This emphasizes the localized nature of the flood events, with specific regions being more susceptible to inundation.

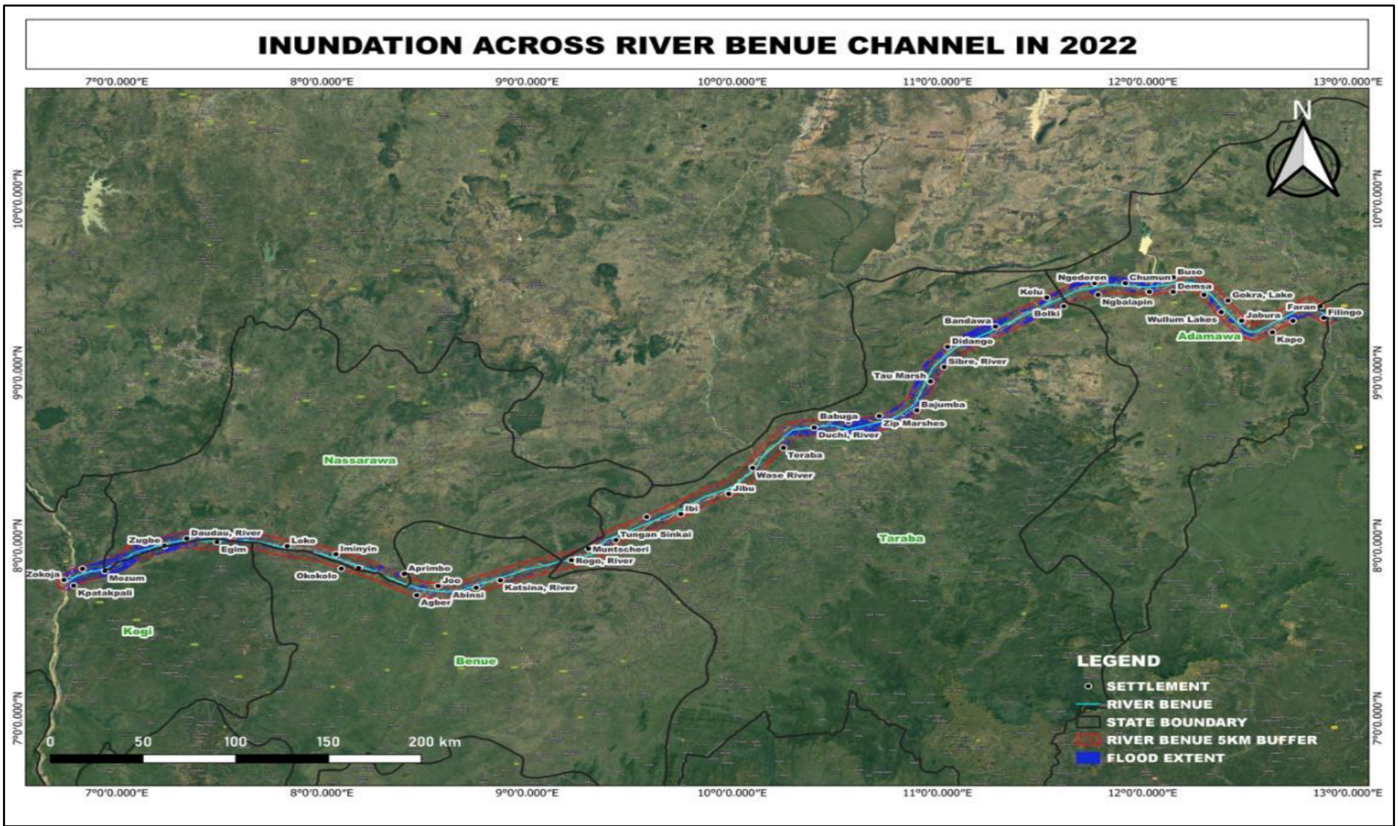
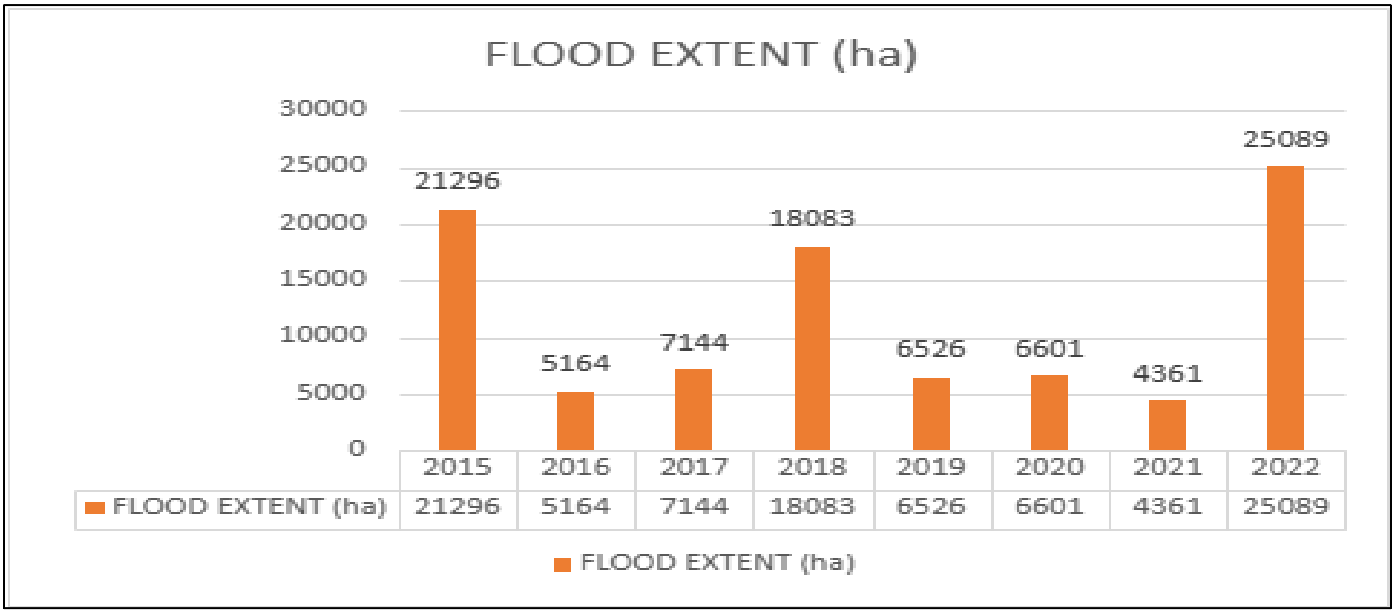


Fig 14 Map Showing Inundation Across River Benue Channel in 2022

The flood extent map for the year 2022 reveals a significant increase in the severity of flood incidents across all the states traversed by the river Benue. The analysis shows that flood occurrences were recorded in all the states, indicating a widespread impact. However, the severity of the floods in Adamawa, Taraba, and Kogi states was notably higher compared to other regions. This suggests that these states experienced more intense and devastating flood events during that year.



	2015	2016	2017	2018	2019	2020	2021	2022
FLOOD EXTENT (ha)	21296	5164	7144	18083	6526	6601	4361	25089

Fig 15 Chart Showing Flood Extent (2015 – 2022)

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- Flood impact on population and farmland**:** To assess the impact of flood on population and farmland, the flood extent maps were intersected with relevant data layers; population density and cropland extent. This analysis allowed for the quantification and visualization of the flood impact on these aspects.

The charts generated based on the intersection analysis provide valuable insights into the flood impact in the study area. They depict the estimated population and farmland exposed to flooding in the different years. By examining these charts, it becomes apparent that flood events have significant consequences for the population residing in flood-prone areas, resulting in potential displacement, damage to infrastructure, and disruption of livelihoods.

Furthermore, the charts reveal the extent of agricultural land affected by floods. This information is crucial for understanding the potential impacts on food security and the agricultural sector. The analysis also identifies areas with a high concentration of communities exposed to flooding, indicating the vulnerability of people and the need for targeted flood risk reduction measures.

The visual representation of the flood impact through charts enhances the understanding of the consequences of flooding on population, farmland, and communities. This knowledge can guide decision-making processes related to mitigation strategies, disaster response planning, and development in flood-prone areas.

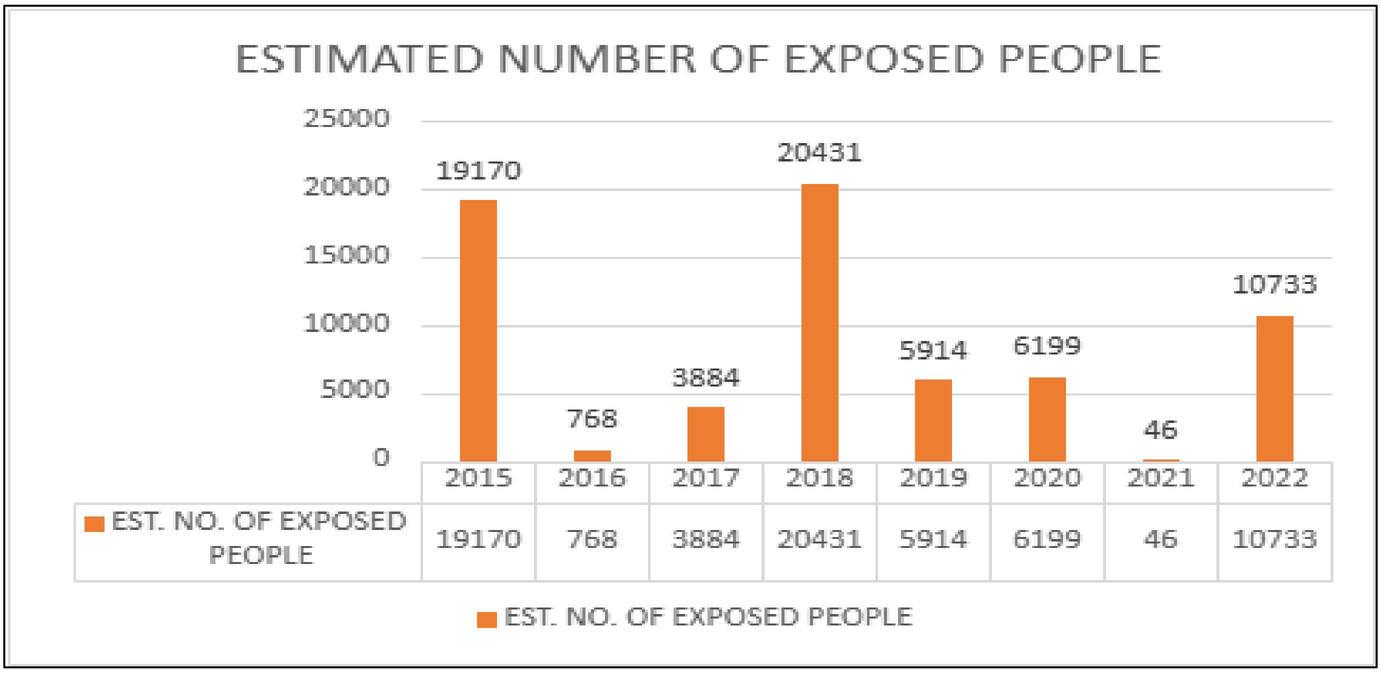

Fig 16 Chart Showing Estimated Number of Exposed People (2015 – 2022)

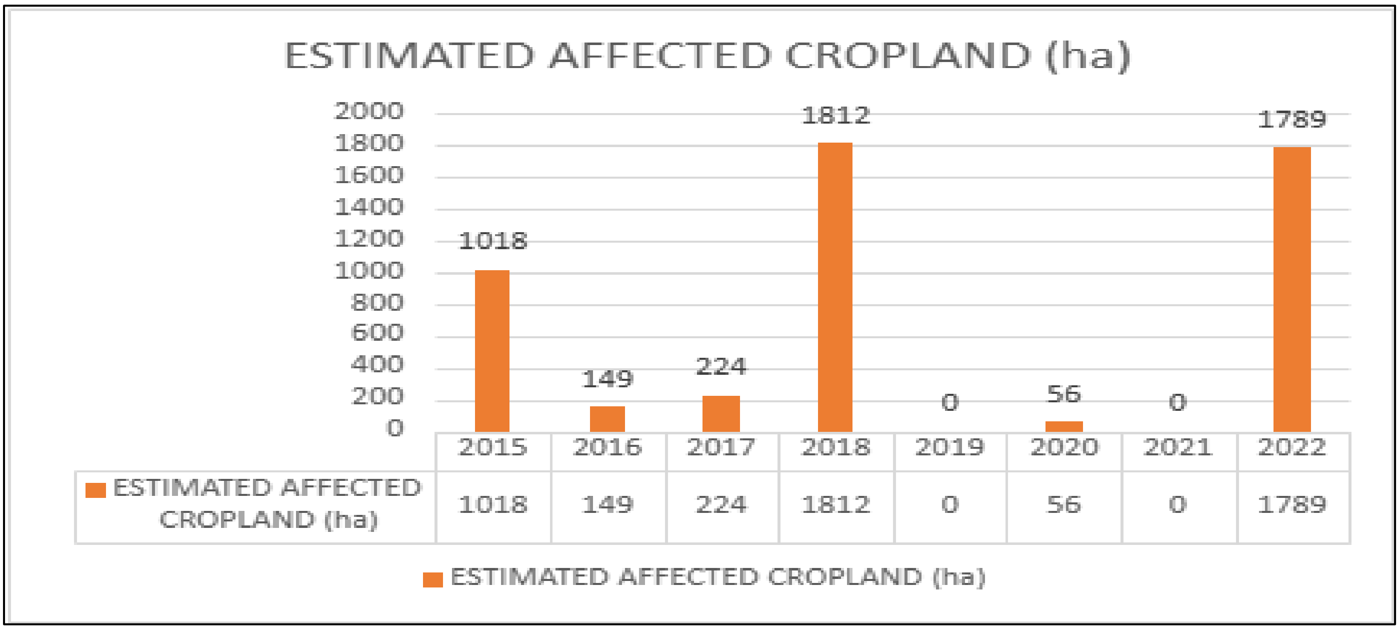

Fig 17 Chart Showing Estimated Affected Cropland (2015 – 2022)

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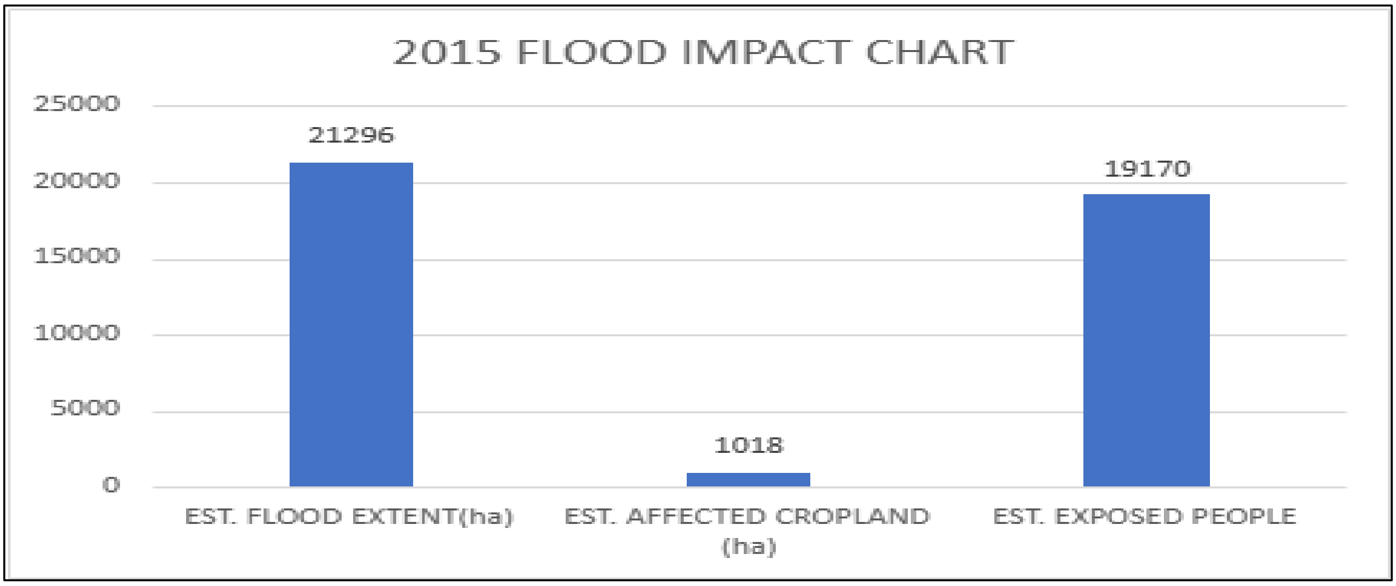

Fig 18 Chart Showing the Impact of the Flood in 2015

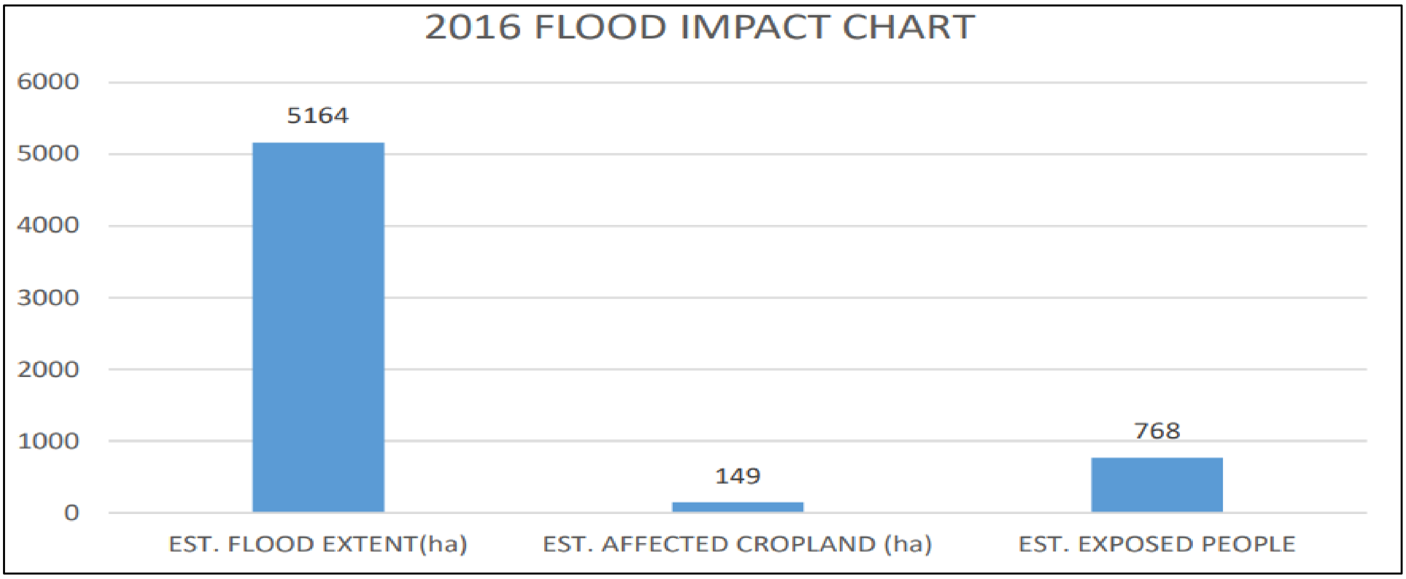

Fig 19 Chart Showing the Impact of the Flood in 2016

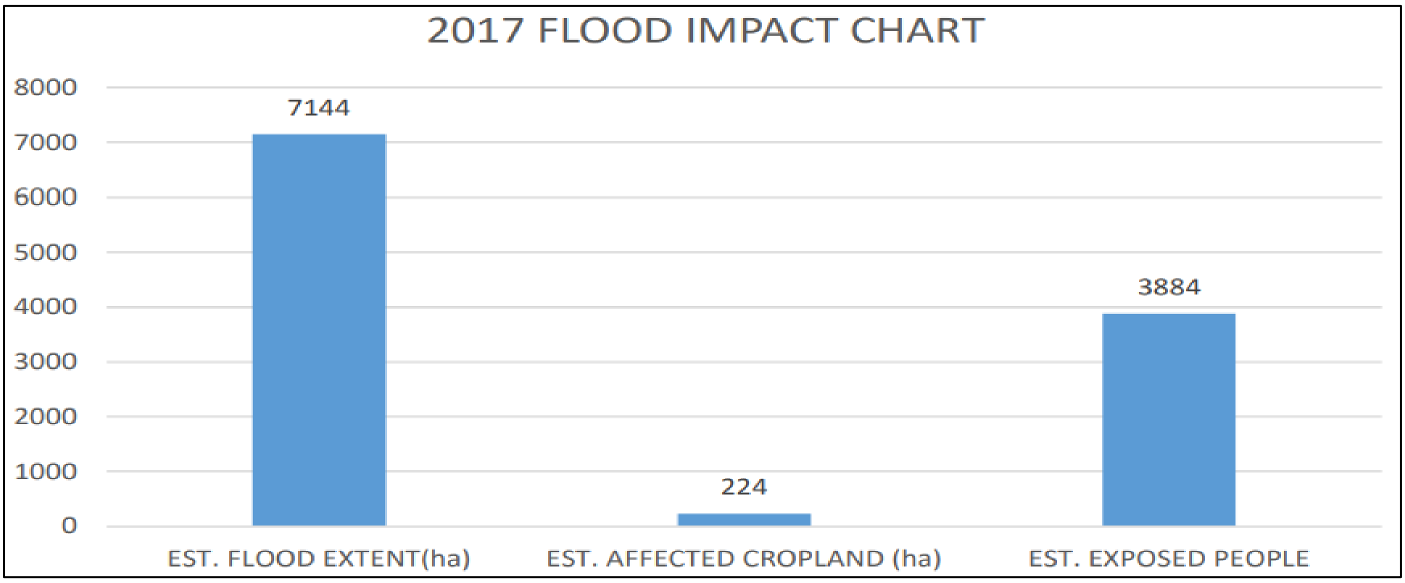

Fig 20 Chart Showing the Impact of the Flood in 2017

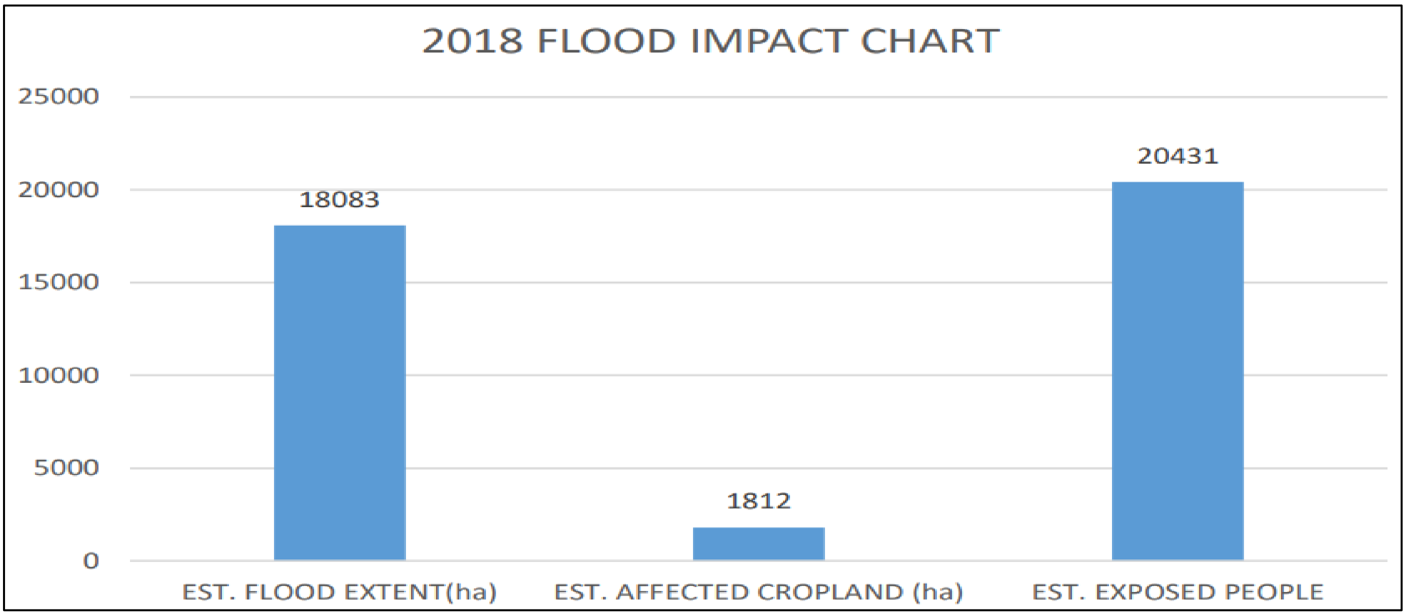

Fig 21 Chart Showing the Impact of the Flood in 2018

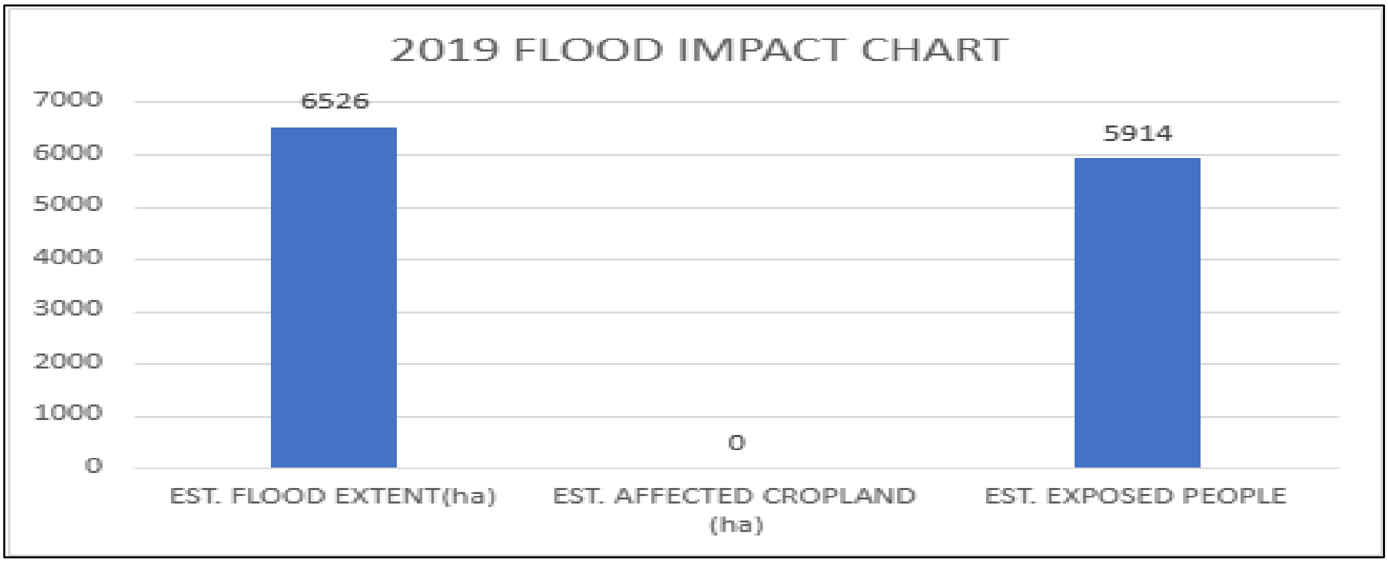

Fig 22 Chart Showing the Impact of the Flood in 2019

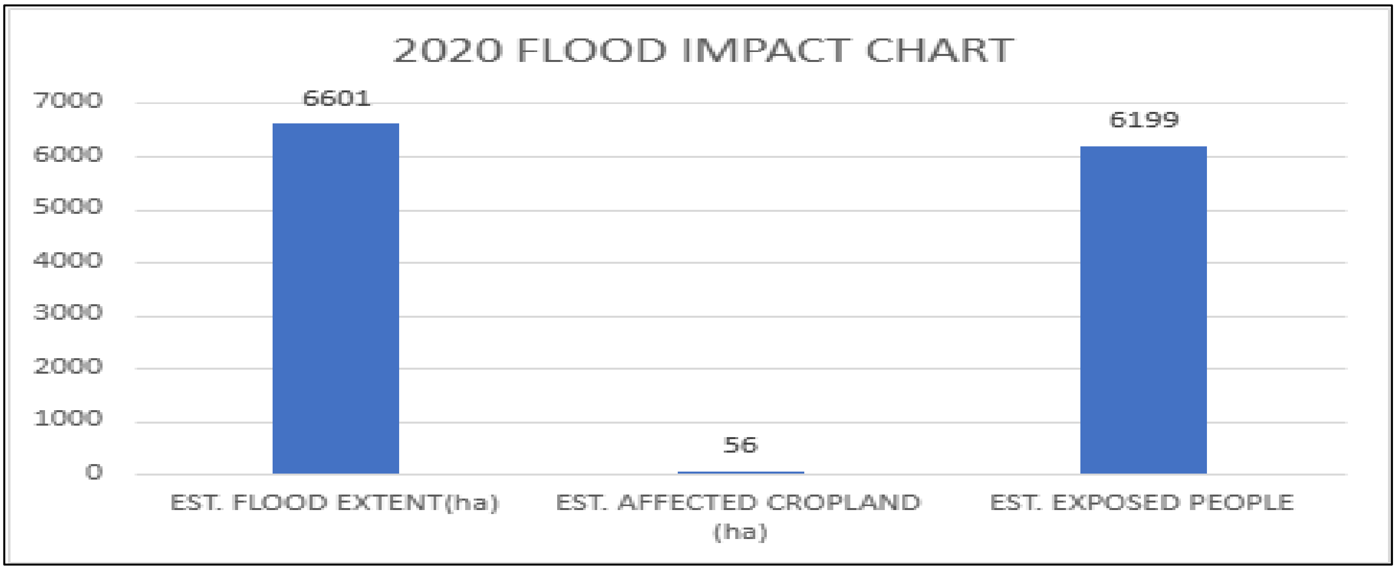

Fig 23 Chart Showing the Impact of the Flood in 2020

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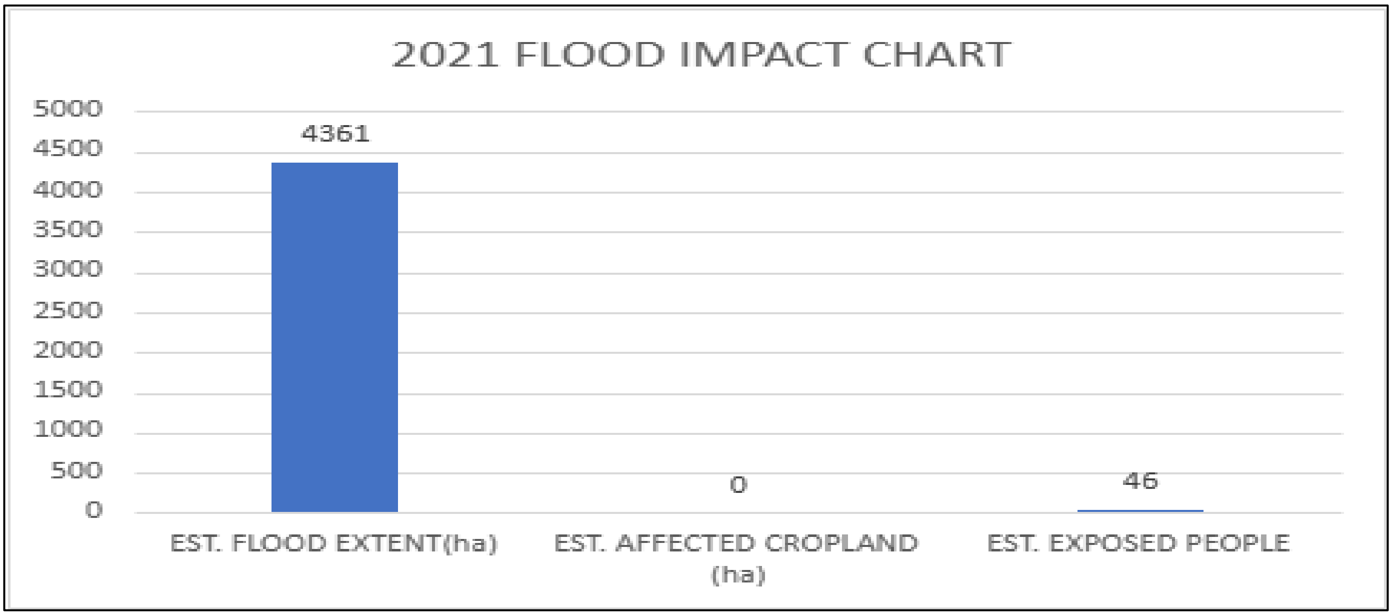

Fig 24 Chart Showing the Impact of the Flood in 2021

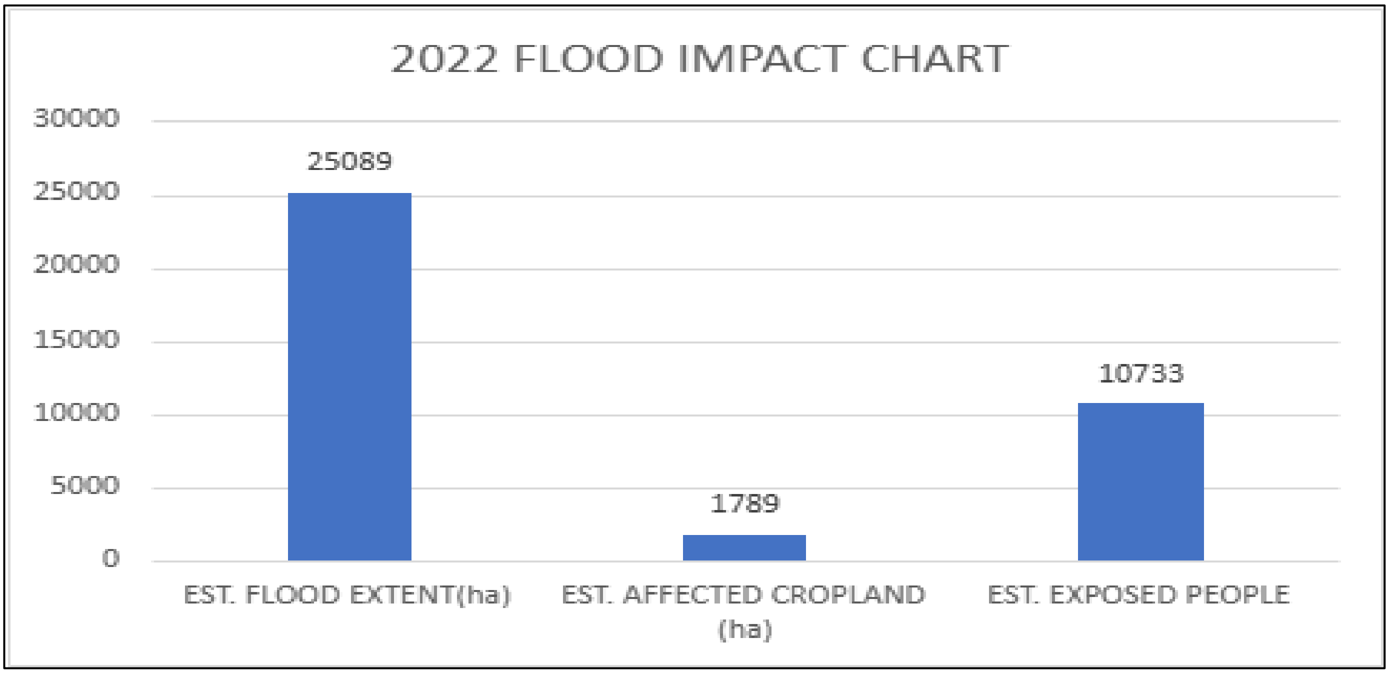

Fig 25 Chart Showing the Impact of the Flood in 2022

- Inundation Frequency**:** The inundation frequency was calculated over an eight-year period (2015-2022) and summarized in table. This information provides insights into the recurrence of floods and aids in the formulation of proactive measures and flood management strategies.

The table presents a comprehensive overview of inundation frequency for each year within the study period. It shows the number of times a particular region experienced flooding during this period, indicating the relative frequency of flood events. By analyzing the table, it becomes evident which areas are more prone to recurrent flooding and which may require more focused attention in terms of mitigation efforts.

Understanding the inundation frequency is vital for effective flood management and preparedness. It allows authorities and stakeholders to prioritize resources and allocate efforts to areas that experience frequent flooding. By implementing proactive measures such as early warning systems, improved infrastructure, and land-use planning regulations, the impacts of recurrent floods can be mitigated, reducing the potential loss of lives and damage to property.

The inundation frequency table serves as a valuable reference for flood risk assessment and the development of flood management strategies. It provides a quantitative basis for decision-making and supports the implementation of measures to enhance resilience and reduce vulnerability to future flood events.

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Table 2 Communities Inundated for 2 Years and Above Across the River Benue Channel from 2015 To 2022

S/N	STATES	SETTLEMENT	2015	2016	2017	2018	2019	2020	2021	2022
1	ADAMAWA	Kangali	YES	NO	YES	NO	NO	YES	YES	NO
2	ADAMAWA	Golumba	YES	YES	YES	YES	YES	NO	YES	YES
3	ADAMAWA	Gugu	YES	YES	YES	YES	YES	NO	YES	YES
4	ADAMAWA	Bajabure	YES	YES	YES	NO	YES	YES	NO	YES
5	ADAMAWA	Rugange	NO	NO	YES	NO	YES	YES	YES	NO
6	ADAMAWA	Opalo	YES	NO	YES	NO	NO	YES	NO	YES
7	ADAMAWA	Dwam	YES	NO	YES	NO	YES	NO	YES	YES
8	ADAMAWA	Linga Tasala	YES	NO	YES	YES	YES	NO	NO	NO
9	ADAMAWA	Wuro Bokki	YES	YES	YES	YES	YES	YES	NO	YES
10	ADAMAWA	Jiberu	YES	YES	YES	NO	NO	NO	NO	NO
11	ADAMAWA	Bogalere	YES	YES	YES	NO	NO	NO	NO	NO
12	ADAMAWA	Kabawa	YES	NO	NO	NO	YES	NO	YES	NO
13	ADAMAWA	Zeken	YES	NO	YES	NO	NO	NO	NO	YES
14	ADAMAWA	Koh	YES	YES	NO	YES	NO	NO	NO	NO
15	ADAMAWA	Wumu	NO	NO	NO	NO	YES	NO	NO	YES
16	ADAMAWA	Alhamsar	YES	NO	YES	NO	NO	NO	NO	NO
17	ADAMAWA	Damare	YES	NO	YES	NO	NO	NO	NO	NO
18	ADAMAWA	Bagale	YES	NO	YES	NO	NO	NO	NO	NO
19	ADAMAWA	Gongola	YES	NO	NO	NO	YES	NO	NO	NO
20	ADAMAWA	Bungudu	NO	NO	NO	NO	NO	NO	YES	YES
21	ADAMAWA	Tsakata	NO	NO	YES	NO	NO	NO	NO	YES
22	BENUE	Agome	YES	YES	YES	YES	YES	NO	NO	YES
23	BENUE	Guma	NO	YES	YES	YES	YES	NO	YES	YES
24	BENUE	Ntchouo	YES	NO	YES	YES	YES	YES	YES	YES
25	BENUE	Kocciel	YES	NO	NO	YES	YES	NO	NO	NO
26	BENUE	Makurdi North	NO	YES	NO	YES	YES	NO	NO	NO
27	BENUE	Mu	YES	YES	NO	NO	NO	NO	NO	YES
28	BENUE	Iga	YES	NO	NO	YES	NO	NO	NO	NO
29	BENUE	Ajoraku	YES	NO	NO	NO	YES	NO	NO	NO
30	BENUE	Ute	YES	NO	NO	NO	YES	NO	NO	NO
31	BENUE	Alabusa	YES	YES	NO	NO	NO	NO	NO	NO
32	KOGI	Amagede	YES	NO	NO	YES	YES	NO	NO	YES
33	KOGI	Atakpa	YES	NO	NO	YES	NO	NO	NO	YES
34	KOGI	Mozum	NO	NO	NO	YES	NO	YES	NO	YES
35	KOGI	Shikaku	YES	NO	NO	YES	YES	NO	NO	NO
36	KOGI	Lokoja	NO	NO	NO	YES	NO	NO	YES	NO
37	KOGI	Dangerri	NO	NO	NO	YES	NO	YES	NO	NO
38	KOGI	Benoue	YES	NO	NO	YES	NO	NO	NO	NO
39	KOGI	Kukuri	YES	NO	NO	YES	NO	NO	NO	NO
40	KOGI	Akpaku	NO	YES	NO	NO	No	NO	NO	YES
41	KOGI	Gwer u Kiriki	NO	NO	YES	NO	YES	NO	NO	NO
42	NASARAWA	Ogba	YES	YES	NO	YES	YES	YES	YES	YES
43	NASARAWA	Langayi	YES	NO	NO	YES	NO	NO	YES	YES
44	NASARAWA	Daudau	YES	YES	NO	YES	YES	NO	NO	YES
45	NASARAWA	Nyereku	YES	YES	NO	YES	YES	NO	YES	YES
46	NASARAWA	Agima	YES	YES	YES	NO	YES	NO	YES	NO
47	NASARAWA	Epe	YES	YES	NO	NO	YES	YES	YES	YES
48	NASARAWA	Egud	YES	YES	NO	YES	YES	YES	NO	YES
49	NASARAWA	Ogusu	NO	YES	NO	NO	NO	YES	NO	YES
50	NASARAWA	Zugbe	NO	YES	NO	YES	NO	NO	NO	YES
51	NASARAWA	Aburu	NO	NO	NO	NO	YES	YES	NO	YES
52	NASARAWA	Iminyin	YES	YES	YES	NO	NO	NO	NO	NO
53	NASARAWA	Udeni Magaji	YES	YES	YES	NO	NO	NO	NO	NO
54	NASARAWA	Gidan Musa	YES	NO	NO	YES	NO	NO	NO	NO
55	TARABA	Baba	YES	YES	NO	NO	NO	NO	NO	NO
56	TARABA	Mayo Renewo	YES	NO	YES	YES	YES	NO	YES	YES
57	TARABA	Garin Gada	YES	YES	NO	YES	NO	YES	YES	YES

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58	TARABA	Jen Kaigama	NO	NO	YES	NO	YES	YES	YES	YES
59	TARABA	Kelu	YES	NO	NO	NO	YES	NO	YES	YES
60	TARABA	Gwahir Marsh	YES	NO	NO	NO	YES	NO	YES	NO
61	TARABA	Hilmayi	YES	NO	YES	NO	NO	NO	YES	NO
62	TARABA	Lamurde	YES	NO	NO	NO	YES	NO	YES	NO
63	TARABA	Donga	YES	NO	NO	NO	NO	YES	NO	NO
64	TARABA	Wase	YES	NO	NO	YES	NO	NO	NO	NO
65	TARABA	Temba	YES	NO	NO	YES	NO	NO	NO	NO
66	TARABA	Kete	YES	NO	NO	NO	NO	NO	NO	YES
67	TARABA	Duchi	YES	NO	NO	NO	NO	NO	NO	YES
68	TARABA	Baranda	YES	NO	NO	NO	NO	NO	NO	YES
69	TARABA	Baka	YES	NO	NO	NO	YES	NO	NO	NO
70	TARABA	Wuro Karai	YES	NO	NO	NO	NO	NO	NO	YES
71	TARABA	Nubin	YES	NO	NO	NO	YES	NO		NO
72	TARABA	Ngaruwa	YES	NO	NO	YES	NO	NO	NO	NO
73	TARABA	Waduku	YES	NO	NO	NO	YES	NO	NO	NO

- Note: The table below shows communities that experienced flooding for at least two years along the river Benue channel from 2015 to 2022. Communities highlighted in green and labelled "YES" experienced flooding in the corresponding years. Communities in white fields labelled "NO," on the other hand, were unaffected. This table identifies the most vulnerable settlements as well as the frequency and patterns of inundation in the Benue River channel during the time period studied.

Table 3 Communities Inundated for 3 Years and Above Across the River Benue Channel from 2015 To 2022

S/N	STATE	SETTLEMENT	2015	2016	2017	2018	2019	2020	2021	2022
1	ADAMAWA	Kangali	YES	NO	YES	NO	NO	YES	YES	NO
2	ADAMAWA	Golumba	YES	YES	YES	YES	YES	NO	YES	YES
3	ADAMAWA	Gugu	YES	YES	YES	YES	YES	NO	YES	YES
4	ADAMAWA	Bajabure	YES	YES	YES	NO	YES	YES	NO	YES
5	ADAMAWA	Rugange	NO	NO	YES	NO	YES	YES	YES	NO
6	ADAMAWA	Opalo	YES	NO	YES	NO	NO	YES	NO	YES
7	ADAMAWA	Dwam	YES	NO	YES	NO	YES	NO	YES	YES
8	ADAMAWA	Linga Tasala	YES	NO	YES	YES	YES	NO	NO	NO
9	ADAMAWA	Wuro Bokki	YES	YES	YES	YES	YES	YES	NO	YES
10	ADAMAWA	Jiberu	YES	YES	YES	NO	NO	NO	NO	NO
11	ADAMAWA	Bogalere	YES	YES	YES	NO	NO	NO	NO	NO
12	ADAMAWA	Kabawa	YES	NO	NO	NO	YES	NO	YES	NO
13	ADAMAWA	Zeken	YES	NO	YES	NO	NO	NO	NO	YES
14	ADAMAWA	Koh	YES	YES	NO	YES	NO	NO	NO	NO
15	BENUE	Agome	YES	YES	YES	YES	YES	NO	NO	YES
16	BENUE	Guma	NO	YES	YES	YES	YES	NO	YES	YES
17	BENUE	Ntchouo	YES	NO	YES	YES	YES	YES	YES	YES
18	BENUE	Kocciel	YES	NO	NO	YES	YES	NO	NO	NO
19	BENUE	Makurdi North	NO	YES	NO	YES	YES	NO	NO	NO
20	BENUE	Mu	YES	YES	NO	NO	NO	NO	NO	YES
21	KOGI	Amagede	YES	NO	NO	YES	YES	NO	NO	YES
22	KOGI	Atakpa	YES	NO	NO	YES	NO	NO	NO	YES
23	KOGI	Mozum	NO	NO	NO	YES	NO	YES	NO	YES
24	KOGI	Shikaku	YES	NO	NO	YES	YES	NO	NO	NO
25	NASARAWA	Ogba	YES	YES	NO	YES	YES	YES	YES	YES
26	NASARAWA	Langayi	YES	NO	NO	YES	NO	NO	YES	YES
27	NASARAWA	Daudau	YES	YES	NO	YES	YES	NO	NO	YES
28	NASARAWA	Nyereku	YES	YES	NO	YES	YES	NO	YES	YES
29	NASARAWA	Agima	YES	YES	YES	NO	YES	NO	YES	NO
30	NASARAWA	Epe	YES	YES	NO	NO	YES	YES	YES	YES
31	NASARAWA	Egud	YES	YES	NO	YES	YES	YES	NO	YES
32	NASARAWA	Ogusu	NO	YES	NO	NO	NO	YES	NO	YES
33	NASARAWA	Zugbe	NO	YES	NO	YES	NO	NO	NO	YES
34	NASARAWA	Aburu	NO	NO	NO	NO	YES	YES	NO	YES

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35	NASARAWA	Iminyin	YES	YES	YES	NO	NO	NO	NO	NO
36	NASARAWA	Udeni Magaji	YES	YES	YES	NO	NO	NO	NO	NO
37	TARABA	Mayo Renewo	YES	NO	YES	YES	YES	NO	YES	YES
38	TARABA	Garin Gada	YES	YES	NO	YES	NO	YES	YES	YES
39	TARABA	Jen Kaigama	NO	NO	YES	NO	YES	YES	YES	YES
40	TARABA	Kelu	YES	NO	NO	NO	YES	NO	YES	YES
41	TARABA	Gwahir Marsh	YES	NO	NO	NO	YES	NO	YES	NO
42	TARABA	Hilmayi	YES	NO	YES	NO	NO	NO	YES	NO
43	TARABA	Lamurde	YES	NO	NO	NO	YES	NO	YES	NO

* Note: The table below shows communities that experienced flooding for at least three years along the river Benue channel from 2015 to 2022. Communities highlighted in green and labelled "YES" experienced flooding in the corresponding years. Communities in white fields labelled "NO," on the other hand, were unaffected. This table identifies the most vulnerable settlements as well as the frequency and patterns of inundation in the Benue River channel during the time period studied.

Table 4 Communities Inundated for 4 Years & Above Across the River Benue Channel from 2015 To 2022.

S/N	STATE	SETTLEMENT	2015	2016	2017	2018	2019	2020	2021	2022
1	ADAMAWA	Kangali	YES	NO	YES	NO	NO	YES	YES	NO
2	ADAMAWA	Golumba	YES	YES	YES	YES	YES	NO	YES	YES
3	ADAMAWA	Gugu	YES	YES	YES	YES	YES	NO	YES	YES
4	ADAMAWA	Bajabure	YES	YES	YES	NO	YES	YES	NO	YES
5	ADAMAWA	Rugange	NO	NO	YES	NO	YES	YES	YES	NO
6	ADAMAWA	Opalo	YES	NO	YES	NO	NO	YES	NO	YES
7	ADAMAWA	Dwam	YES	NO	YES	NO	YES	NO	YES	YES
8	ADAMAWA	Linga Tasala	YES	NO	YES	YES	YES	NO	NO	NO
9	ADAMAWA	Wuro Bokki	YES	YES	YES	YES	YES	YES	NO	YES
10	BENUE	Agome	YES	YES	YES	YES	YES	NO	NO	YES
11	BENUE	Guma	NO	YES	YES	YES	YES	NO	YES	YES
12	BENUE	Ntchouo	YES	NO	YES	YES	YES	YES	YES	YES
13	KOGI	Amagede	YES	NO	NO	YES	YES	NO	NO	YES
14	NASARAWA	Ogba	YES	YES	NO	YES	YES	YES	YES	YES
15	NASARAWA	Langayi	YES	NO	NO	YES	NO	NO	YES	YES
16	NASARAWA	Daudau	YES	YES	NO	YES	YES	NO	NO	YES
17	NASARAWA	Nyereku	YES	YES	NO	YES	YES	NO	YES	YES
18	NASARAWA	Agima	YES	YES	YES	NO	YES	NO	YES	NO
19	NASARAWA	Epe	YES	YES	NO	NO	YES	YES	YES	YES
20	NASARAWA	Egud	YES	YES	NO	YES	YES	YES	NO	YES
21	TARABA	Mayo Renewo	YES	NO	YES	YES	YES	NO	YES	YES
22	TARABA	Garin Gada	YES	YES	NO	YES	NO	YES	YES	YES
23	TARABA	Jen Kaigama	NO	NO	YES	NO	YES	YES	YES	YES
24	TARABA	Kelu	YES	NO	NO	NO	YES	NO	YES	YES

* Note: The table below shows communities that experienced flooding for at least four years along the river Benue channel from 2015 to 2022. Communities highlighted in green and labelled "YES" experienced flooding in the corresponding years. Communities in white fields labelled "NO," on the other hand, were unaffected. This table identifies the most vulnerable settlements as well as the frequency and patterns of inundation in the Benue River channel during the time period studied.

➢ *Discussion*

The findings of this assessment and monitoring of floods in the River Benue channel are consistent with previous research studies conducted in the region. Wood (2005) emphasized the significance of flood events in river systems, highlighting their global impact on economic development, livelihoods, agriculture, and human life. The recurrent nature of floods in Nigeria, particularly in the River Benue channel, has been well-documented (Ologunorisa, 2004).

The variations in flood intensity and spatial distribution observed in this study align with previous findings by Abam (2006) and Emodi (2012), who described floods as rapid influxes of water that inundate stream channels and floodplains, resulting in severe economic and residential impacts. The compounding effects of climate change and inadequate infrastructure were also highlighted by Rentschler and Salhad (2020) as factors intensifying the recurrence, intensity, and spatial extent of floods.

The analysis of flood extent maps from 2015 to 2022 reveals changing trends in flood patterns and impacts across

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different states. The significant increase in flood severity in 2022, particularly in Adamawa, Taraba, and Kogi states, indicates a heightened risk and underscores the need for enhanced flood management measures. These findings are consistent with previous studies that identified vulnerability hotspots in the River Benue basin, such as Kogi state (World Bank, 2022).

The assessment of inundation frequency also provides valuable insights into the changing dynamics of floods over time. The increase in flood occurrences in certain states, such as Adamawa and Taraba, compared to others in specific years, highlights the importance of localized factors in flood risk assessment. These findings align with the studies conducted by Akoteyon (2022) and Ologunorisa, Ogbuokiri, and Eludoyin (2021), which identified factors such as rainfall, soil type, slope, and geology as influential in flood occurrences. The NEMA Disaster record of 2006-2021 also reveals relative information to the findings on the inundation table

The results of this study underscore the need for context-specific flood management strategies and targeted interventions. The localization of flood impacts in certain states, such as Adamawa, Taraba, and Kogi, necessitates tailored approaches to enhance resilience and mitigate the severe impacts of floods. The findings also emphasize the importance of continuous monitoring, early warning systems, infrastructure resilience, land use planning, and community empowerment in effective flood management, which is consistent with the recommendations made by previous authors (Abubakar et al., 2020; Benedict et al., 2016; Kriebel and Geiman, 2014).

In conclusion, the findings from this study contribute to the existing body of knowledge on floods in the river Benue channel. The variations in flood patterns, intensity, and spatial distribution observed over the years highlight the dynamic nature of floods and the need for adaptive and context-specific flood management strategies. Implementing the recommended measures, such as strengthening early warning systems, improving infrastructure resilience, promoting land use planning, and empowering communities, will be crucial in enhancing flood preparedness, response, and long-term resilience in the river Benue channel.

V. CONCLUSION AND RECOMMENDATION

➢ *Conclusion*

The outcomes of the research demonstrate the effectiveness of the systematic approach employed for assessing and monitoring floods in the River Benue channel. By utilizing satellite imagery and geospatial data, the study successfully generated flood extent maps, analyzed the flood impact on population, farmland, and determined the inundation frequency over an eight-year period.

These outcomes contribute valuable insights for effective flood management and mitigation efforts. The flood extent maps provide spatially explicit information on the areas prone to flooding, aiding in the identification of vulnerable regions and supporting targeted flood mitigation measures. The charts depicting the flood impact on population and farmland, enhance the understanding of the consequences of floods, facilitating informed decision-making for infrastructure development, disaster response planning, and land-use regulations.

Furthermore, the inundation frequency table enables a comprehensive understanding of the recurrence of floods in the river Benue channel. This information is instrumental in prioritizing resources and implementing proactive measures to reduce vulnerability and enhance resilience to future flood events.

Overall, the research outcomes highlight the significance of utilizing satellite imagery and geospatial data for flood assessment and monitoring. The systematic approach outlined in the methodology provides a framework for effective flood management and supports the development of strategies to mitigate the impacts of floods in the river Benue channel.

➢ *Recommendations*

Based on the findings and implications of our research on assessing and monitoring floods in the river Benue channel, we propose the following recommendations for effective flood management and mitigation strategies:

- Enhance Early Warning Systems**:** Implement and strengthen early warning systems that provide timely and accurate information about flood events. This includes investing in real-time monitoring systems, weather forecasting technologies, and communication networks to ensure that communities at risk receive timely warnings and can take appropriate actions to protect lives and property.
- Improve Infrastructure Resilience**:** Develop and upgrade infrastructure to enhance resilience against floods. This includes constructing flood-resistant buildings, improving drainage systems, and implementing measures to mitigate flood impacts on critical infrastructure such as roads, bridges, and utilities. Incorporate flood risk considerations into urban planning and development regulations to avoid construction in high-risk flood zones.
- Promote Land Use Planning**:** Implement land use planning regulations that discourage development in flood-prone areas and promote sustainable land use practices. This can include zoning restrictions, land preservation measures, and incentives for relocating vulnerable communities to safer areas. Ensure that land use planning is supported by accurate flood extent maps and data to inform decision-making processes.
- Strengthen Community Resilience**:** Enhance community resilience through capacity building, awareness campaigns, and community-based flood management initiatives. Engage local communities in flood risk assessment, preparedness, and response activities. Foster partnerships between community members, local authorities, and relevant stakeholders to collectively address flood risks and improve community resilience.

- Invest in Flood Control Measures**:** Explore the implementation of flood control measures, such as the construction of buffer dams and reservoirs, to regulate water releases and manage river flow during flood events. Conduct feasibility studies and cost-benefit analyses to identify the most effective and sustainable flood control measures for the river Benue channel.
- Promote Climate Change Adaptation**:** Recognize the influence of climate change on flood occurrences and incorporate climate change adaptation strategies into flood management plans. This includes considering future climate projections, adopting nature-based solutions, and integrating climate resilience measures into flood risk reduction efforts.
- Enhance Data Sharing and Collaboration**:** Foster collaboration among relevant stakeholders, including government agencies, research institutions, and international organizations, to facilitate data sharing, knowledge exchange, and capacity development. Promote the use of standardized data formats, interoperable systems, and open-access platforms to enhance the accessibility and usability of flood-related data and information.
- Continued Monitoring and Research**:** Maintain a robust and continuous monitoring system to track changes in flood patterns, assess the effectiveness of flood management strategies, and identify emerging challenges. Invest in ongoing research to improve flood modeling, prediction, and mapping techniques, leveraging advancements in remote sensing, GIS, and geospatial technologies.

By implementing these recommendations, stakeholders can enhance their preparedness and response capabilities, reduce vulnerability to floods, and improve the resilience of communities and infrastructure along the river Benue channel. The collaborative efforts of government agencies, local communities, and international organizations are essential for effective flood management and the implementation of sustainable solutions.

It is important to acknowledge that the implementation of these recommendations may require financial resources, institutional support, and political will. Therefore, a multi-stakeholder approach, involving partnerships between government entities, civil society organizations, academia, and communities, is crucial to ensure the successful implementation of these recommendations.

Continued monitoring, evaluation, and adaptive management are also necessary to assess the effectiveness of implemented strategies, identify areas for improvement, and adjust flood management approaches based on evolving challenges and knowledge.

The recommendations provided here aim to enhance flood resilience, protect lives and property, and promote sustainable development in the face of recurring flood events in the river Benue channel. By adopting a comprehensive and proactive approach to flood management, stakeholders can reduce the impacts of floods, improve disaster preparedness, and foster long-term resilience in the region.

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VI. APPENDIX

SDG	Sustainable Development Goal
GIS	Geographic Information System
NiMET	Nigeria meteorological agency
NEMA	National Emergency Management Agency
NIHSA	Nigeria Hydrological Services Agency
FS	Flood Stage
NWS	National Weather Service
GEE	Google Earth Engine
SAR	Synthetic Aperture Radar
MODIS	Moderate Resolution Imaging Spectroradiometer
GHSL	Global Human Settlement Layer
NASRDA	National Space Research and Development
GRID3	Geo-Referenced Infrastructure and Demographic Data for Development
NDWI	Normalized Difference Water Index
UN-SPIDER	United Nations Platform for Disaster Management and Emergency Response
QGIS	Quantum Geographic Information System
DMSG	Disaster Management Support Group
LULC	Land Use Land Cover
Sat	Satellite