Floods to Food Crisis: A Satellite Image-based Numerical Extraction for Impact Analysis of Climate Change

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ABSTRACT
Flood is a natural disaster that has affected many parts of the world with devastating consequences to properties, farmlands, humans and animals. Climate change - a global phenomenon could be seen as the major driving force with one of its negative effects being unusual heavy rainfall. Hardly can one find any country without a past or current history of a significant flooding. Even nations with robust flood risk management are not left out with hundreds of lives and many properties worth billions of dollars lost. Flood analysis was performed on Lagos State as region of interest because of many water bodies that surround the city and its constant flooding history. The flooding analysis was extended to its neighbouring States in the southwest and states in other regions making a total of 8 states investigated Google Earth Engine (GEE) cloud platform was used for coding, visualization and data source. Satellite imageries such as global surface water, hydroSHEDS DEM, Global human settlement population density layer and MODIS – cropland were sourced from the GEE. Maps showing the flooded areas were generated. Numerical data were extracted as CSV from the satellite images, showing the number of population, hectares of exposed flooded areas and affected farmland. For all the 8 States investigated a total of 529,061 persons were exposed, 468,823 hectares of land were flooded out of which 53,020 hectares were farmland. It was concluded that aside insecurity ravaging the country, the impact of the 2022 flooding on land and the people has surely added to the sudden high cost of crop produce since 2023 which has become even worse in 2024.

Keywords
Climate change, flood, satellite image, Google Earth Engine, food crisis, farmland, Nigeria

1. INTRODUCTION
Floods are among the many natural disasters that get more frequent and severe due to rising temperature, leading to atmospheric warming and eventual heavy rainfall. In addition, the global rising in sea levels because of melting ice caps and glaciers is yet another contributor to the increasing extent of flooding in coastal areas, causing destructions to houses, infrastructures, agriculture and hazardous to human and animal lives. For instance, at the minimal level, flooding entails some of its impacts such as water pollution, spread of water-borne diseases, population displacement and food scarcity. Countries with low standard of living, which are found majorly in Africa and Asia, often suffer the consequences of flooding more than those in the developed nations because of lack of adequate technology or lack of will power to provide the necessary control measures. Another reason might be linked to corruption, where government agents and contractors embezzled money meant for construction of standard drainage. [7] observed that Asian and African countries have poor flood mitigation, control and human settlement characteristics unlike most European countries, where preparedness, warning systems and rescue procedures are more advanced. According to [10] flood accounts for nearly more than half of all the natural disasters in both developed and developing nations of the world. [3] report that the incidences of flooding are changing at a considerable rate due to increase rainfall events and storm surges.

Hardly can one find any country without a past or current history of a significant flooding in five years. Even countries with robust flood risk management are not left out. It was reported that a catastrophic floods affected countries like United Kingdom, Austria, Belgium, Germany and others in July 2021 leaving about 243 mortalities and more than €10 billion (US$11.8 billion) damage to properties [11]. Similarly, Henan province, China, had its own fair share in the same month of 2021, killing 69 people with over 1.31 million evacuated while damaging about 972,000 hectares of farmland. The report further stated that the 2021 flood affected 12.9 million people in 150 counties [12] including Nigeria.

In Nigeria, flood is one of the most common environmental hazards that occur almost every year. Globally, Nigeria is ranked among the top 20 countries exposed to coastal flooding based on present population and future scenarios in the 2070s [6]. Many states at the southern part of the country, which includes Lagos, Ogun, Ondo, Anambra, Rivers, Delta, Cross River, Akwa-Ibom, Bayelsa among others do experience coastal floods on yearly basis with hundreds of thousands of persons exposed and farmlands adversely affected. However, other regions of the country are not left out with flooding affecting states like Borno, Kano, Adamawa, Benue, Niger, Abuja, Kogi among others. In a study by [7], there is a lack of information in less developed countries that are strongly and frequently affected by fatal floods, unlike in the developed countries where data and research are widely available. The majority of studies center on Europe and Australia, while studies concerning other continents and countries, such as Asia and South America, were not identified. Same goes for African countries. Hence, this work focuses on Lagos State for flood analysis because of frequent occurrences of flood in the state. Furthermore, the analysis was extended to other states that are often hit by flooding.

2. FLOOD IN NIGERIA
Flood disaster in Nigeria is mainly attributed to anthropogenic

cause that is being aggravated by poor urban planning and inadequate environmental infrastructure. [7], [6] and [2]. affirmed that rapid urbanization with a minimal basic infrastructure, unplanned growth and in addition with the effects of climate change means heavy rainfall and flooding. In the works of [8] the Nigerian government through the National Emergency Management Agency (NEMA) recorded one of the worst cases across some states between July and October 2012 with 363 mortalities, 18,282 injured persons and 2.1 million displaced. It stated further that by September, 2012, socio-economic activities like farming were severely devastated in Edo State with 100,000 persons affected. NEMA also reported that the 2012 flood disaster ravaged 32 out of 37 States in the country, which calls for a serious concern by governments at all levels. The cause of the flood was blamed on the release of water from Lagdo dam in the neighbouring Cameroon, sometime in August 2012 because of heavy downpour. This event also coincided with the release of the water from both Kainji and Jebba dams into the River Niger [6]. Similar situation reoccurred at about the same time in 2022, but this time, it was devastating.

2.1 The worst flood in Nigeria in 40 Years

The 2022 flood in Nigeria began in early July and did not end until late October of same year and because of its severalty the floods were termed the worst in 40 years. It was caused by a combination of heavy rainfall, climate change, and the release of water from the Lagdo dam in the neighbouring Cameroon. According to the International Federation of Red Cross and Red Crescent Societies (IFRC), the floods affected over 4.4 million people across the country, displaced over 2.4 million people with over 660 deaths. The nine (9) most affected states include Lagos, Anambra, Kogi, Borno, Ebonyi, River State, Bauchi, Delta and Benue.

3. REDUCING FLOOD MORTALITY

[4] affirmed that between 1975–2001, flash floods and river floods accounted for 9 % of all deaths from natural disasters, claiming about 175,000 fatalities worldwide. [7] opined that rapid flash floods do surprise people within a very short time to decide what to do, resulting in less time for both warning and emergency

procedure activation like road closures and evacuations. Furthermore, the paper observed that high rate of male vulnerability and death due to flood can be related to their stronger exposure because of higher proportion of males that drive vehicles, wider mobility or because they work more outdoor. However, female fatalities become more noticeable in low-income countries like Africa and Asian countries. That one of the possible strategies to reduce flood mortality is to act on environmental factors with the implementation of more accurate forecasts and warning systems, based on advanced predicted rainfall totals and their effects on small watersheds, thus expanding the available time to issue warnings and perform protective actions. A frequent and long-term proposal, by many researchers, is through customized educational strategies by communicating the risk of floodwaters to children prior to their teenage years and highlighting the dangers of driving through floodwaters [9] A view shared by [1] educational campaigns should involve local councils, schools, emergency service agencies, police, vehicle manufacturers and insurance companies to reinforce messages about the potential dangers of entering floodwaters.

4. FROM FLOOD TO FOOD CRISIS: 2022-2024 SCENARIO

A report by the Nigerian National Bureau of Statistics [5] in its *Selected Food Price Watch for August 2024* shows that the average price of 1kg beans stood at N2,574.63 ($1.72), which indicates a rise of 271.55% in price on a year-on-year basis from N692.95 ($0.46) recorded in August 2023 while 12 piece of medium size eggs experienced significant price increase by 121.92% from N1,031.55 ($0.69) in August 2023 to N2,289.19 ($1.53) in August 2024. Also, there was 113.16% increase in price of bread from N684.85 ($0.46) in August 2023 to N1,459.85 ($0.97) in August 2024. Furthermore, the average price of 1kg locally produced rice went up by 148.41% from N 737.11 ($0.49) in August 2023 to N1,831.05 ($1.22) in August 2024. The average price of 1kg of Yam tuber increased by 188.31% from N576.39 ($0.38) in August 2023 to N1,661.80 ($1.11) in July 2024.

To this end, this work aimed at extracting numerical data from satellite imagery and analyzes the socio-economic impact of the 2022 flood in Nigeria by considering total hectares of land affected, percentage of hectares of land affected, hectares of farmlands affected and total exposed persons. Aside insecurity that is ravaging the country, this is to help determine the root cause of flood to food crisis that is currently being experienced at every nook and cranny.

5. IMPLEMENTATION SPECIFICATION

Implementation processes was carried out in Google Earth Engine (GEE), a cloud-based platform for analyzing and processing geospatial data (Landsat, Sentinel, and MODIS), offering powerful computational capabilities for advanced analysis such as integrated development environment (IDE) code editor that enables users to create, execute, debug and generate interactive maps for visualization and many more, for the understanding of satellite captured Earth's surface patterns. Figure 1 shows the architectural design and the flow of the implementation.

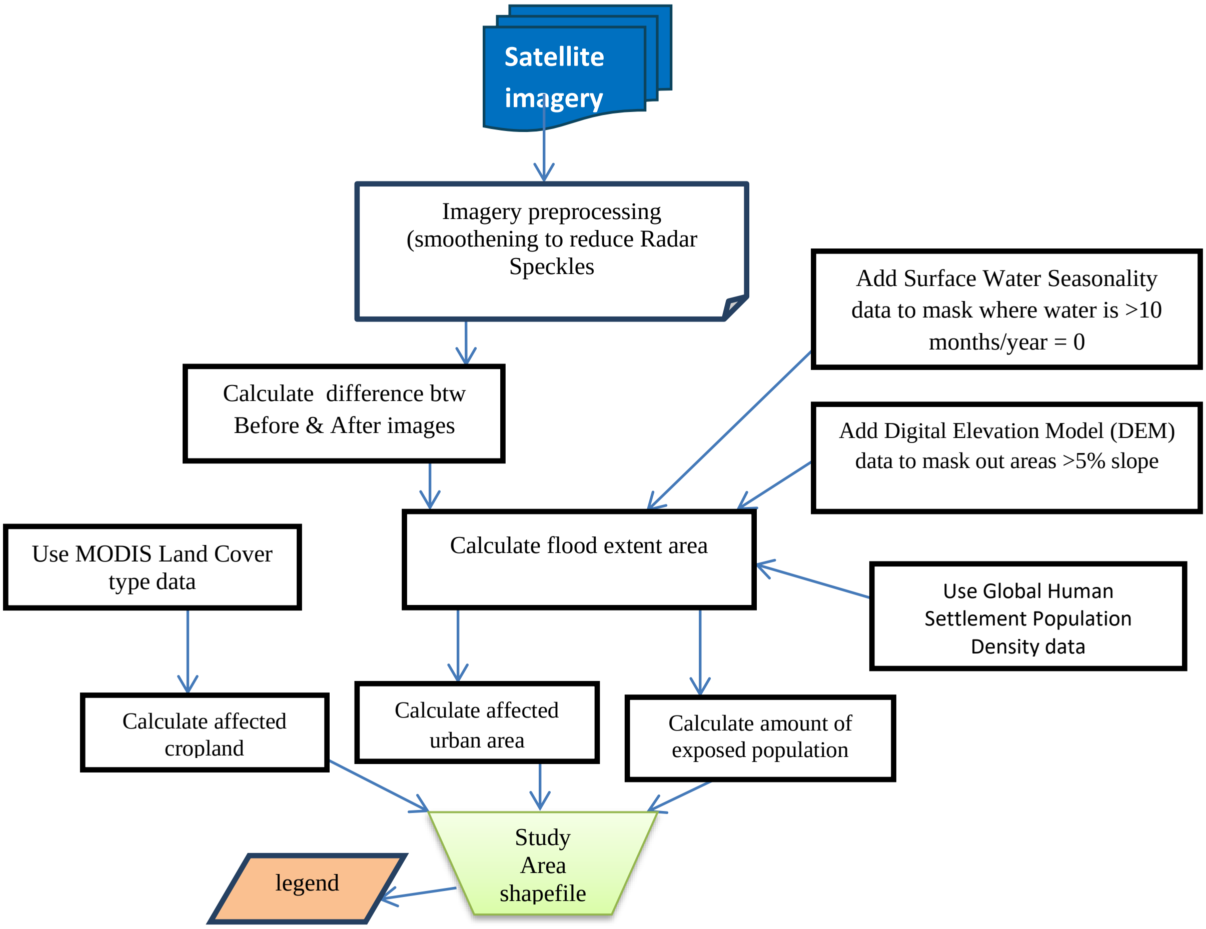

Fig 1: Design Architecture

6. DATASET DESCRIPTION

6.1 Satellite Image Collection

Lagos State, Nigeria was selected as the region of interest because of various water bodies, including rivers, lagoons and ocean that surround the state, making it prone to yearly flooding. Flood satellite data were obtained from global surface water, hydroSHEDS provides the Digital Elevation Model (DEM) dataset for masking out areas more than 5% slope. Global human settlement population density layer was used for estimating the exposed persons while cropland pixels (using classes cropland greater than 60% and cropland/natural vegetation mosaics of small-scale cultivation between 40 to 60%) were source from MODIS images.

6.1.1 Extending the Analysis

The scope of the study was broadened by extending the flood analysis to other neighbouring states in the southwestern region that includes Oyo, Ogun, Ondo, Osun and Ekiti States. However, due to the limited availability of adequate flood imagery covered by the Sentinel-1 satellite, because it did not provide enough image collection containing all of the GRD scenes (VV or HH, and dual band VV+VH and HH+HV) during the period of investigation, for states like Ekiti, Osun, and Oyo, the analysis was limited to Ondo and Ogun States in the region. Furthermore, since it was recognized that the flooding also impacted states beyond the southwestern region during the same temporal context, the analysis was extended to include six (6) other states outside the region, including Anambra and Ebonyi (southeast), Delta and Rivers (southsouth), Kogi (middle belt) and Borno (northeast).

7. DATA PRE-PROCESSING AND IMPLEMENTATION

7.1. Estimating the Flood Time Frame

Before clipping the image data to the study area it was filtered based on specific properties such as instrument mode, polarization, orbit properties, resolution and date range. Additionally, temporal filtering was applied to include images captured both before and after the occurrence of the flooding. This is to help ascertain the extent to which the flood affected the areas investigated, and to allow for computing the percentage of areas affected

The following time frames were taken into consideration:

i. *Before start:* This is the period before the flood started, which is around May, 2022
ii. *Before end:* The period almost before the flood started, which is around July, 2022
iii. *After start:* Period almost when the flood began, around July, 2022
iv. *After end:* Period when the flood stopped, around ending of October, 2022

Images were mosaicked and clipped to the boundaries of the selected administrative areas. Additional preprocessing steps include applying filters to reduce noise such as cloud spackles to improve the quality of SAR images. Also, processing steps to remove isolated pixels or small disconnected areas were applied to ensure a clean dataset. Furthermore, A threshold was set to determine significant changes, identifying potential flooded areas. Permanent water bodies were masked out while areas with high slopes were also excluded.

7.2. Flood Detection

To determine the exact area where the flooding took place, the following steps were taken: Image differencing was computed to identify changes between before and after the flooding.

Image difference from mean = im_i – Rim_n (1)

Note: The reference image is typically an average of multiple images of the same scene. It can be calculated using the following equation:

$$\text{R}im_n = \frac{(Im1 + Im2 + Im3 \ldots + Imn)}{\text{N}} \quad (2)$$

which can be re-written as:

$$\text{R}im_n = \frac{1}{N}\sum_{i=1}^{N} Imi \quad (3)$$

Combining equations (1) and (3) and obtain equation (4)

$$\text{D}im_n = Imi - \frac{1}{N}\sum_{i=1}^{N} Imi \quad (4)$$

where:
i represents the i^th^ image
Im_i = input image
Rim_n = reference image
N = number of images in the reference set.

Dim_n =*Image difference from mean*

7.3. Flooded Area Calculation

Total area and flooded area within each selected administrative area were calculated. Pixel areas (in /m^2) are multiplied by the binary flooded area mask to estimate flooded areas. These computed areas were then converted from square meters to hectares.

Let $A_{flooded}$ represents the total area of flooded regions within the study area, and $P_{flooded}$ denotes the number of pixels classified as flooded. Assuming each pixel area in Sentinel-1 imagery covers pixelArea per square meters (e.g., pixelArea = 10 m^2). The equation for calculating the flooded area in hectares is:

$$A_{flooded} = \frac{(P_{flooded} \text{ x pixelArea})}{10000} \text{ha} \quad (5)$$

7.4. Calculating the Percentage of Flooded Area

The percentage of flooded area compared to the total area of each state is computed as shown in equation (6). Let A_{state}represents the total area of the selected administrative state, and $A_{flooded}$ denotes the calculated flooded area within the state.The percentage of flooded area compared to the total area of the state is calculated using the equation 6:

$$\text{Percentage\_flooded} = \frac{A_{flooded}}{A_{state}} \text{x } 100 \quad (6)$$

Where:
- *$A_{flooded}$ is the flooded area within the administrative state.*
- *A_{state} is the total area of the administrative state.*

The results provide insights about the impact of the flood across different States in Nigeria.

8. NUMERICAL DATA EXTRACTION

8.1. Extracting Numerical Values from the Flood Satellite Imagery

Using functions available on Google Earth Engine, computation was performed, that extracted numerical data from the flood image as comma separate values (CSV) and presented as shown in Table 1, by computing the total flooded areas and the percentage of area affected by the flood across each of the six affected states where the analysis was extended.

9. RESULT ANALYSIS

The graphical representations of the results were presented in figures 2 through figure 9 for the respective states with the following colour depictions:

i). Blue represents permanent water bodies.
ii). Cyan represents steep areas that is 5% above sea level.
iii). Red represents flooded areas.

Lagos State Flood: Figure 2 revealed that even with the large volume of water bodies that surround the State the flood only affected areas closer to the water bodies, without any impact on the State capital, Ikeja,. This could be as a result of yearly proactive measures put in place by the government to contain flood.

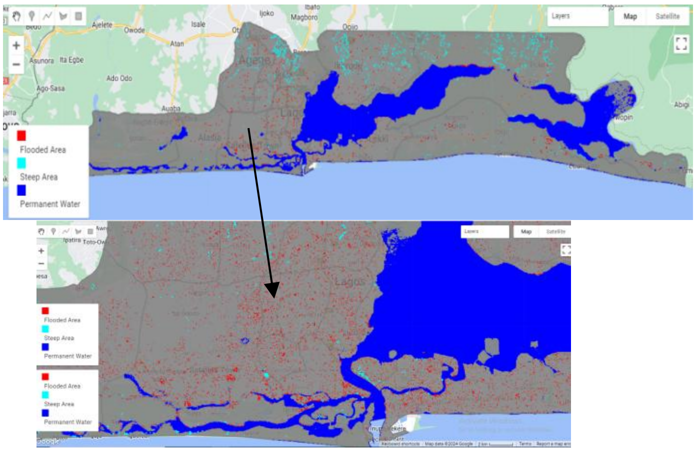

Figure 2: showing flooded areas in Lagos State

Delta State: Figure 3 revealed that the flood affected the entire State. This could be due to the fact that the State serves as flood channel to the sea from other parts of the country.

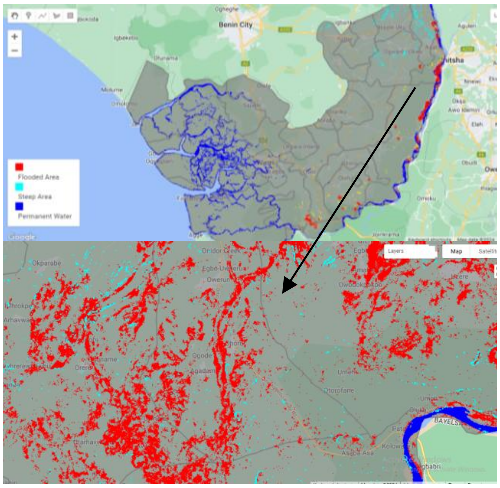

Figure 3: Flooded areas in Delta State

Anambra State: It could be seen from figure 4 the severity of the flood in the State with areas closer to the tributary of the Niger River that flows through the state, severely affected with significant on cropland.

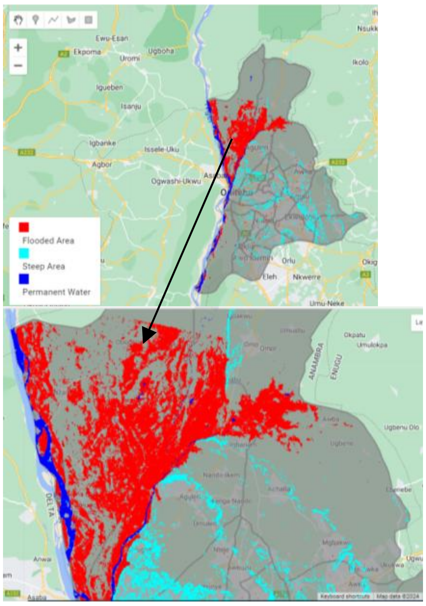

Figure 4: Flooded areas in Anambra State

Borno State: Figure 5 showed the severity of the flood in areas closer to the lake chad being severely affected with rebound effect on agricultural produce and livestock, which the state is known for.

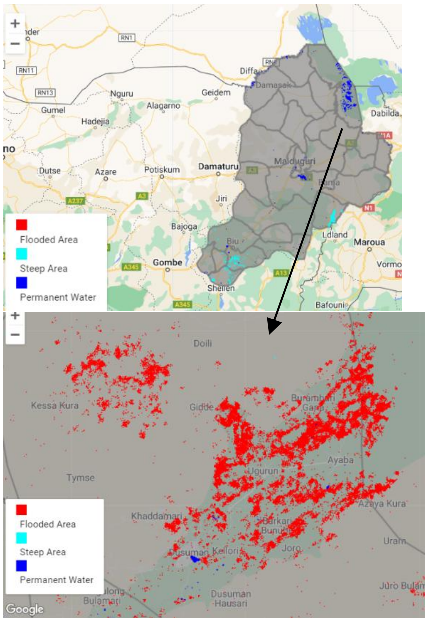

Figure 5: Flooded areas in Borno State

Rivers State: Figure 6 showed spread of the flood across most part of the State. Majorly, it is surrounded by water bodies and also serves as flood channel to the sea from other parts of the country with impact on fishing activities.

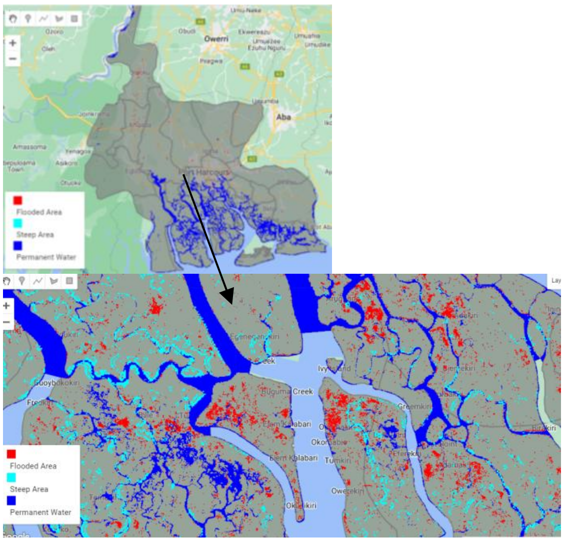

Figure 6: Flooded areas in Rivers State

Ebonyi State: : It could be seen from figure 7 that only a small portion of the state was affected, as depicted in Table 1 which does not affect agricultural produce

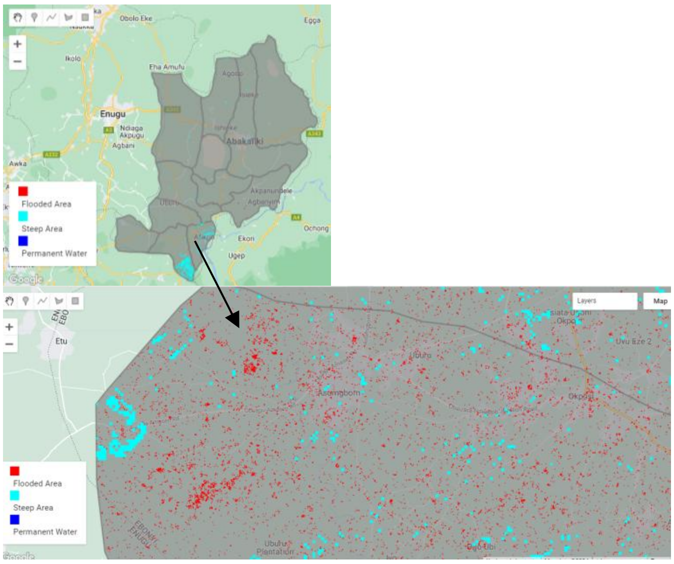

Figure 7: Flooded areas in Ebonyi State

Kogi State: Figure 8 showed impact of the flood affecting southern part of the state more. Also, being a confluence state with two major rivers in Nigeria (Benue-Niger). The flood affected several hectares of both cropland and fishing acivities.

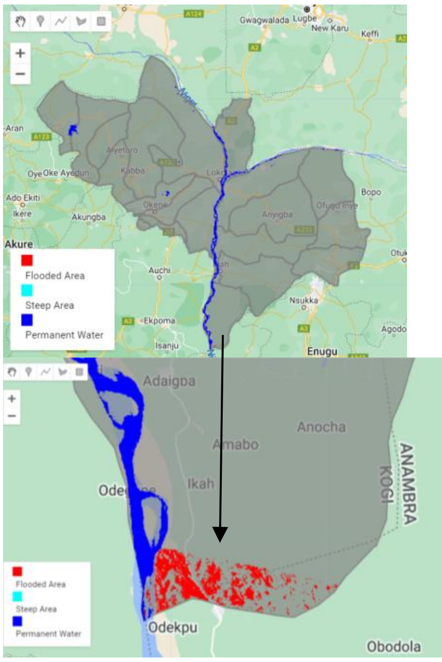

Figure 8: Flooded areas in Kogi State

Ondo State: From figure 9, it could be seen that the severity of the flood in the state is at the coaster areas, which does not affect agricultural produce except fishing activities.

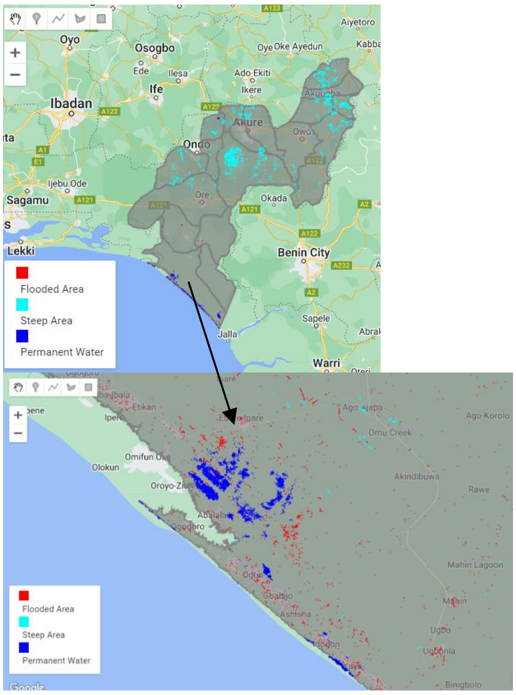

Figure 9: Flooded areas in Ondo State

Note: There was no enough flood imagery for Ogun, Oyo, Osun and Ekiti, Bauchi, FCT States during this research activity.

9.1. Extraction of Flood Numerical Values

Table 1 offers a comprehensive tabular summary and insight into each state's landmass, the total area affected by the flooding and the corresponding percentage of the affected areas relative to the regions of interest. It also contains the total population and affected cropland in each state that were exposed to the 2022 flood. This detailed analysis contributes to a nuanced understanding of the spatial and quantitative dimensions of flooding impacts across the various states under investigation.

Table 1: showing information about the flood in each state

State	Total Area (Ha)	Flooded Areas (Ha)	% of land Flooded	Total Population Exposed	Affected Cropland
Lagos	380,099.09	1,323	0.348	0	0
Ogun	1,616,343.43	4,810	0.298	11,911	174
Ondo	1,453,154.91	1,032	0.071	4,407	0
Anambra	461,013.05	42,207	9.155	183,532	16,550
Delta	1,684,750.87	73,892	4.386	162,664	2,622
Kogi	2,906,467.33	54,196	1.865	51,293	5,036
Rivers	876,521.39	15,152	1.729	75,678	0
Ebonyi	621,562.13	7,232	1.164	297	0
Borno	7,187,666.58	268,979	3.742	39,285	28,638

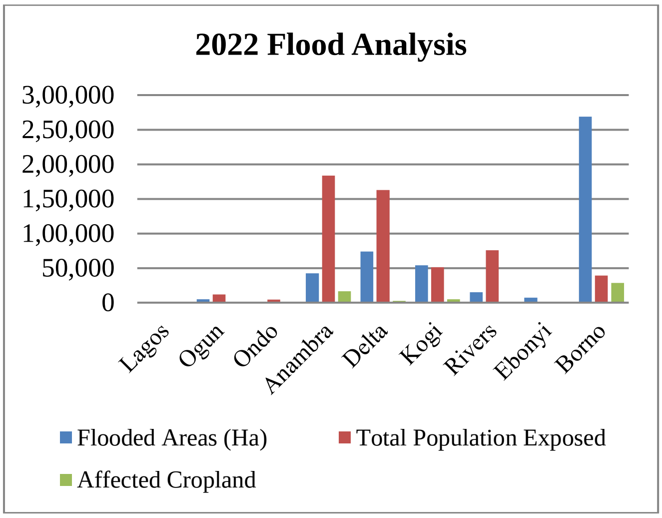

Chart 1: Showing the 2022 flood impact across the states.

10. DISCUSSION

From table 1 it was revealed that Borno State had the largest flooded landmass (268,979 hectares) during the year under investigation, followed by Delta State (73,892 ha), Kogi State (54,196 ha), Anambra State (42,207 ha) and Rivers State (15,152 ha). However, comparing the total landmass of the states with the flooded areas, findings revealed that Anambra had 9.155% of its landmass flooded, which is the highest followed by Delta State with 4.386%, Borno State 3.742%, Kogi State 1.865%, Rivers State 1.729% and Ebonyi State 1.164%. Conversely, the three states in the southwestern part of the country namely Lagos, Ogun and Ondo States were not seriously affected like other states mentioned above, as they only have few portion of their landmass flooded, showing 0.348%, 0.298% and 0.071% respectively. Furthermore, integration of population data and cropland data revealed the socio-economic impact of the 2022 flooding in the states investigated. Anambra State had the highest number of her population with 183,532 people exposed to the flooding, followed by Delta State with 162,664 population exposed, Rivers State 75,678, Kogi State 51,293, Borno State 39,285 and Ebonyi 297. In the southwestern part, 11,911 population were exposed in Ogun State, 4,407 in Ondo State while Lagos had none, which might be due to the fact that the state had taken proactive measures to curtail the flood because of her constant yearly exposure. In the same manner, Borno State had 28,638 hectares of its agricultural land exposed to the flooding, followed by Anambra State with 16,550 ha, Kogi State 5,036 ha, Delta State 2,622 ha and Ogun State 174 ha. States like Lagos and Ondo in the southwestern part, Rivers and Ebonyi in the southeast did not have any of their agricultural land exposed to the 2022 flood. Finally, results showed the socio-economic implications of the impact of the flood in the areas investigated with a total of 529,061 persons exposed in the country and a total of 468,823 hectares of landmass heavily flooded. Out of this, 53,020 hectares were agricultural land, which suggests one of the reasons for the current very high cost of agricultural products in the country during the subsequent years (2023 and 2024).

This is corroborated by the recent information released by the National Bureaus of Statistics (2024) saying that as at August 2024, the price of 1kg beans brown stood at N2,574.63 indicating 271.55% price rise on a year-on-year basis from N692.95 recorded in August 2023. The price of 12 piece of medium size eggs increased by N121.92% from N1,031.55 in August 2023 to N2,289.19 in August 2024. It stated further that the average price of 1kg local rice increased by 148.41% - from N737.11 in August 2023 to N1,831.05 in August 2024, while the average price of 1kg of yam tuber increased by 188.31% - from N576.39 in August 2023 to N1,661.80 in July 2024.

11. CONCLUSION

Findings of this research justified the reason government must take proactive measures towards climate change mitigation and adaptation for sustainable growth, to forestall both immediate and long-term devastating impacts of climate change on the socio-economic lives of the people. It is a fact that the impacts will be felt earlier by the low-income earners because their source of livelihood depends majorly on the environment. However, long-term effects will soon snowball to every strata of life, from the very poor to the very rich, because every lives depend on food for survival that are majorly produced by the low-income earners in the developing countries like Nigeria and others. The rebounding effects will also affect the developing countries. A good example is the current price of cocoa. Future research would be to develop predictive models that use satellite-derived data, to forecast crop yields in flood-prone areas, one from each geo-political zone of the country. To assess how varying flood intensities and durations affect staple crops like rice, maize, and cassava.

12. ACKNOWLEDGMENTS

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