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Flood Inundation and Monitoring Mapping in Nigeria Using Modis Surface Reflectance

Mangut Yohanna Silas[1*], Salami Ayobami Taofeek[2], Adepoju Kayode Adewale[2], Samson Samuel Adeyemi[1] and Danladi Victor[1]

[1]Cooperative Information Network (COPINE), National Space Research and Development Agency (NASRDA), Obafemi Awolowo University Campus, Ile-Ife, Osun State, Nigeria.
[2]Institute of Ecology, Obafemi Awolowo University, Ile-Ife, Osun State, Nigeria.

Authors' contributions

This work was carried out in collaboration between all authors. Author MYS designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors SAT and AKA managed the analyses of the study. Authors SSA and DV managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Nigeria is witnessing the effect of climate change majorly through flood events. Recent flood disaster in Nigeria posed a threat on people, communities, institutions as well as ecosystem. Floods are common in Nigeria during the peak of raining season (June – October). Remote sensing images and Geographical Information System (GIS) can be efficient tools to determine flood inundated areas. The study developed the sensitivity of water indices to flood water detection and examine the spatial extent of flood inundation -+using MODIS surface reflectance data in Nigeria. In this context, the study involved the use of land surface water index to assess flooding risk at regional scale in Nigeria by using Moderate Resolution Imaging Spectrometer (MODIS) 8th day time series data for the periods 2010 and 2012. Flood events are developed from Enhance Vegetation Index (EVI), Normalized Difference Vegetation Index (NDVI), Normalized Difference

**Corresponding author: E-mail: mangsyl@yahoo.com;*

Water Index (NDWI), and Land Surface Water Index (LSWI). In order to limit water detection to cloud conditions, MODIS data cloud mask was used to filter the cloudy conditions. The result showed that the water indices (EVI, NDVI, NDWI and LSWI) were highly effective and sensitive in flood water detection. The maximum extent of flood that occurred in October 2012 was estimated to be 11.14 % while in the flood event of September 2012 the total flood extent was 13.15 % of the total land area of Nigeria. The study concluded that, MODIS products had a great advantage in the high-frequent observation while water indices integrated were very effective for flood inundation mapping technique using MODIS surface reflectance products for the entire country of Nigeria.

Keywords: Flood mapping; remote sensing; GIS; MODIS; EVI; NDVI; NDWI; LSWI.

1. INTRODUCTION

Floods are natural phenomena which occur from time to time everywhere that rivers exist. Flooding may occur as a result of heavy rain, dam collapse, dam release, dam overflow, river overflow. Flooding is one of the most frequent and far-flung environmental hazards and of various magnitudes. It occurs in most terrestrial portions of the globe, causing huge losses in terms of damage and disruption to economic livelihoods, businesses, infrastructure, services and public health [1] The effects of natural hazards such as floods can be felt at local levels, affecting communities and neighborhoods, or at regional or national levels, affecting entire watershed and/or at regional scale [2]. Nigeria has lost a lot of lives and properties worth millions of naira in the last three (3) decades, directly or indirectly to flood. It has been estimated that more than 700,000 hectares of useful land for agricultural and communities are rendered useless due to annual floods [3]. Nigeria had her share of flood events which has taken a toll on lives and properties. In Nigeria, aside from droughts, floods cause almost 90 percent of damages resulting from natural hazards [4]. Many studies have been carried out on flood inundation in Nigeria. However, attention has not been paid on the detection and determination of sensitivity of water index to flood water detection using MODIS surface reflectance data. Also, the status of flood inundation in time and space using high temporal resolution satellite images with broad coverage is yet to be documented in Nigeria.

The 2012 flood event in Nigeria brought a devastating and unexpected hardship to the affected victims in some states, hence there is need to the use of geospatial technique for mapping and analysis of flooding event for effective mitigation, planning and managing emergencies [5]. Remote sensing images can be effective and efficient tools to determine flood inundation areas [6]. The application of satellite captured earth observation imagery for monitoring and mapping events has been useful in numerous crises situations. Right after its launching in December 1999, Moderate Resolution Imaging Spectro-rodiometer (MODIS) satellite with its moderate-resolution optical sensor of 250–500 m becomes useful tools for scientific studies and research [7]. MODIS data collections are derived from both the Terra MODIS and Aqua MODIS instruments. MODIS datasets are available for download and also monitoring nationwide flood disaster all over the world with a spatial and temporal changes. Water detection algorithm based on reflectance ratio of MODIS band 1 and 2, and a threshold on band 7 were used to provisionally identify pixels as water [8]. Many other water-body identification methods have also been developed. Thresholds for distinguishing between water and land pixels are derived based on the reflectance of the near-infrared channel. Remote sensing-based index algorithms designed to detect surface water are simple concepts, relying mainly on spectral indices such as, Land Surface Water Index (LSWI) [9], Normalized Different Vegetation Index (NDVI) [10], Enhanced Vegetation Index [11,12], and Normalized Different Water Index (NDWI) [13].

Flooding is one of the most frequent and widespread environmental hazards in Nigeria. However, compared to the wide range of research conducted in other countries, research works carried out in Nigeria on determination of flood inundation monitoring using MODIS have been very few. Status of flood inundation is important in evaluating the relationships between variations in the water regime, local agricultural activity, and ecosystem. This study focused on the sensitivity of water indices to floodwater detection in the entire Nigeria.

2. MATERIALS AND METHODS

2.1 Study Area

Nigeria is country located in West Africa, Africa Continent, with the population of about 140 million people (NPC, 2006). Nigeria lies between latitude 4° 00' N to 14° 00' N; and longitude 3° 00' E to 15° 00' E (Fig. 1). The area of the country is 923,768 km^2 of which the water bodies have covered about 13,000 square km^2, (Nigeria Fact Sheet, 2001). A north-south length of about 1,046 km and a west east breadth of about 1287 km. Total land boundary is about 4,037 km. Nigeria is characterised with dry and wet seasons. The three climate accorded to the south, Central and North region includes; Tropical rainforest, Tropical savanna and Tropical dry climate respectively.

2.2 Methods

Following significant floods in 2010 and 2012 in Nigeria, fieldwork was conducted across the study area to acquire the Global Positioning System (GPS) coordinate of the flood affected areas as a referenced dataset for analysis and validation. Also, two years' monthly average rainfall dataset covering 45 stations was obtained from Nigerian Meteorological Agency (NIMET), multi-temporal MODIS images and high resolution images with a resolution of 500m for inundation mapping with flood monitoring was selected. First, The TERRA and AQUA MODIS surface reflectance data (MOD09GA and MYD09GA) were downloaded from the NASA LP DAAC (Land Processes Distributed Active Archive Centre) website: http://reverb.echo.nasa.gov/reverb. The images were imported and layer stacked in Erdas Imagine 9.2. The projection of the Swarth to grid data done using the MODIS Swarth Reprojection Tool (MRTSwarth). MRTSwarth provides the capability to transform MODIS data from swarth format to a uniformly gridded image that is geographically referenced according to user-specified projection and resample parameters. The MODIS dataset were further subst to area of interest using the Nigerian boundary. The first step is to detect cloud cover pixel from the image. If blue reflectance (Band 3 of MODIS) is equal to or greater than 0.2 [14], [12] it is considered a cloudy pixel. A cloud mask was applied using the accompanying

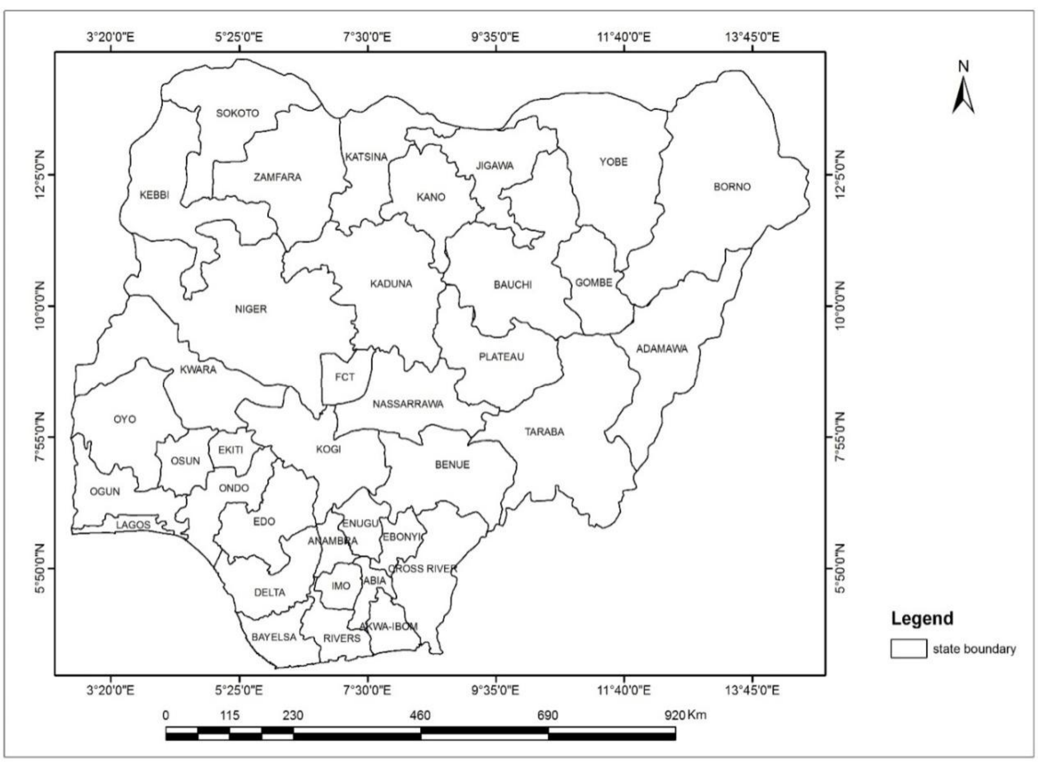

Fig. 1. Map of Nigeria showing the 36 states and the Federal capital

MODIS band (band 3) which contains information on cloud and cloud-shadow location. As MODIS data are available twice daily (one from Aqua and one from Terra), any overlapping data were combined such that nulls or cloud pixels are replaced by the other image.

LSWI, NDVI, EVI and NDWI indices were used to determine their sensitivity towards flood water detection. Discrimination of Water-related pixel was conducted and estimated in accordance with the pioneering method developed by [11,12]. Water indices were exclusively used to discriminate Flood, Non-Flood and mixed pixel as shown in Fig. 2. Sensitivity of the various indices to detect flooded water related features was achieved using the referenced ground truth locational coordinate points acquired during the flooding event. The referenced ground truth points were further used as a training point for thresholding. Thresholding of the reflectance value and mapping different land use land cover was achieved using rule-base classification method whereby; EVI value greater than 0.3 was classified as non-flood features. EVI value of less than or equal to 0.3 was classified as mixed pixels while EVI value of longtime water bodies were less than 0.05. The mixed pixels include other land use with water reflecting characteristics.

3. RESULTS AND DISCUSSION

3.1 Monthly Distribution of Rainfall

Average monthly rainfall intensity over the study area for the period of two years (Fig. 3) shows that between January and April the rainfall distribution ranges between 7.35 – 102.46 mm in 2010 and 12.55 – 92.08 mm in 2012, May to August show the range from 160.83 – 281.57 mm in 2010 and 196.94 – 252.11 mm in 2012, while the remaining months of the year from September to December ranges between 278.40 – 4.82 mm in 2010 and 258.64 – 7.53 mm in 2012 respectively.

3.2 Sensitivity of Water Indices to Flood Water Detection

The indices; EVI, LSWI, NDWI, and NDVI map (Fig. 4) shows the sensitivity of the indices to flood water detection. The spectral responses of EVI, LSWI, NDWI and NDVI to water detection indicates that the value of water carries a positive to negative value where the spectral values ranges between – 3.5 to 0.1. The performance and sensitivity of the indices in water detection was assessed using a referenced coordinate point for validation. The result across waterbody shows that, the EVI value was -3.085506, NDVI -0.255603, NDWI -0.465904, and LSWI 0.105571 respectively.

3.3 The Flood Extent of Nigeria in the Years 2010 and 2012

The result of the analysis carried out on the MODIS data to extract water related pixels showing the flood extent in Nigeria of the years 2010 and 2012 are shown in figs. 6a, 6b, 6c, and 6d respectively. Figs. 6a and 6c illustrate the water body of Nigeria during the dry season prior to flood in 2010 and 2012 while Figs. 6b and 6d illustrate the inundation map of Nigeria in

Table 1. Summary of indices used to detect the extent of the flood events

S/No.	Indices	Equation	Reference
1	Normalized Difference Vegetation Index	$NDVI = \frac{P_{NIR} - P_{RED}}{P_{NIR} + P_{RED}}$	13
2	Normalized Difference Water Index	$NDWI = \frac{P_{RED} - P_{SWIR}}{P_{RED} + P_{RED}}$	14
3	Enhanced Vegetation Index	$EVI = 2.5 * \frac{P_{NIR} - P_{RED}}{P_{NIR} + 6 * P_{RED} - 7.5 * P_{BLUE} + 1}$	18, 19
4	Land Surface Water Index	$LSWI = \frac{P_{NIR} - P_{SWIR}}{P_{NIR} + P_{SWIR}}$	20

Where, P_{NIR} is the reflectance of near infrared (481 – 875 nm, MODIS Band 2),
P_{RED} is the reflectance of red (621 -670nm, MODIS band 1)
P_{BLUE} is the reflectance of blue (459 – 479 nm, MODIS band 3)
P_{SWIR} is reflectance of short-wave infrared (1628 – 1652 nm MODIS Band 6) of the solar spectrum.

October 2010 and September 2012. The study was able to determine the maximum extent of flood in the year 2010 and 2012 as shown in table 2. In October 2012 from the combination of Aqua and Terra (MOD09A1 and MYD09A1), the flood extent was estimated to about 102,923.79498 km^2 representing 11.14 % of the total country while, in the flood event of September 2012 we found out that the total flood extent was about 121,476.699231 km^2 representing 13.15 % of the entire country. The total longtime water body was estimated as 13,276.224535 km^2 (1.44%) and 13,479.339002 km^2 (1.46%) in October 2010 and September 2012, mixed pixel was also estimated as 421,089.364228 km^2 (45.59%) and 469,001.829278 (50.77%) in October 2010 and September 2012 respectively. The bar chart (Fig. 7) shows the total water pixels extracted as represented in Table 2.

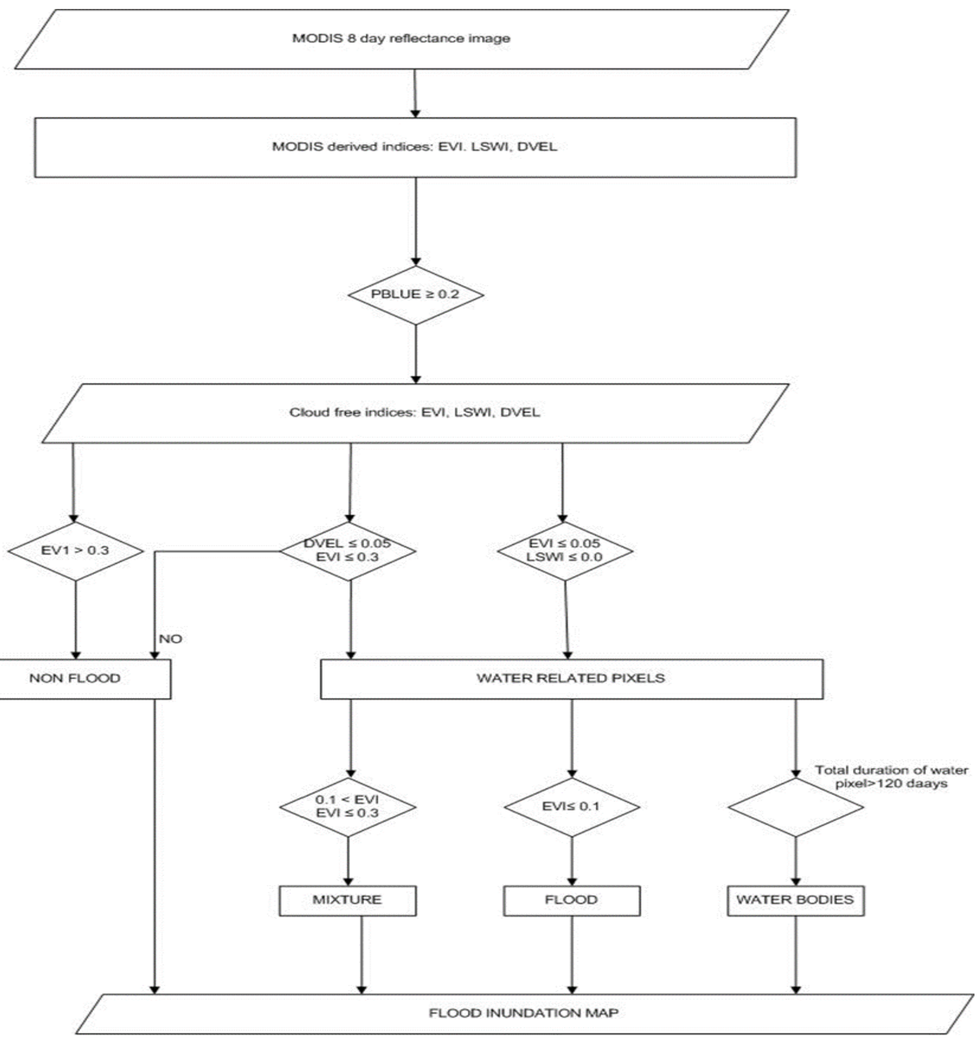

Fig. 2. Flood chart for developing flood inundation map using MODIS data

Table 2. Values of water related pixels extracted from MODIS EVI (2010 and 2012)

Date	Longtime water body(km^2)	Mixed pixel(km^2)	Flooded water(km^2)
2010 October	13,278.224535	469,001.829278	102,923.796498
2012 September	13,497.339002	421,089.364228	121,476.699231

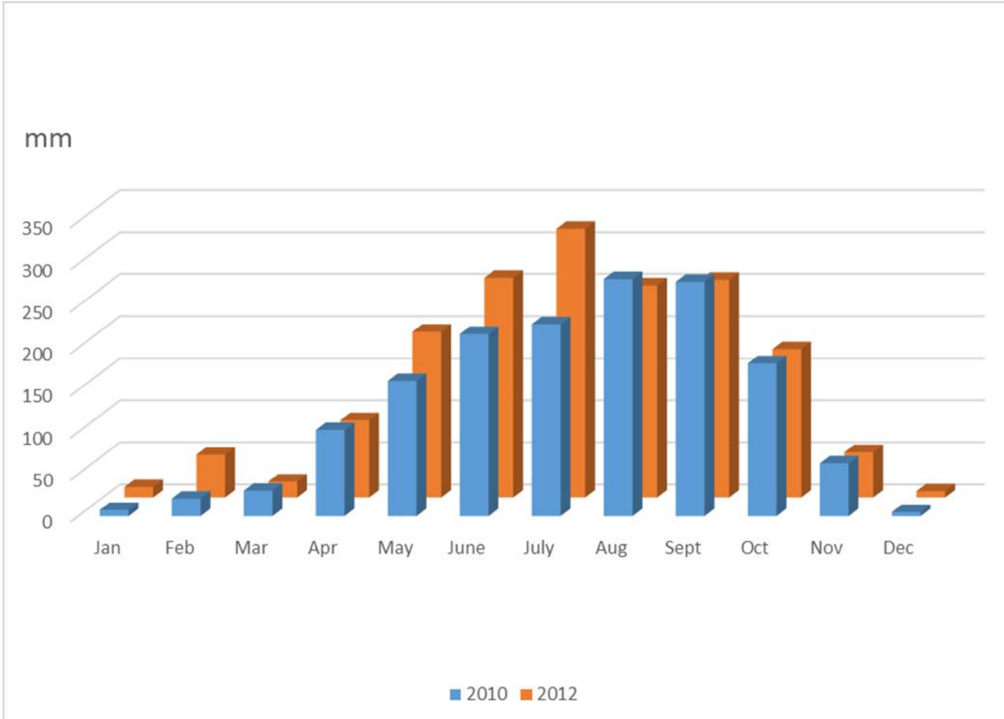

Fig. 3. Monthly average rainfall distribution of all the stations in the years 2010 and 2012

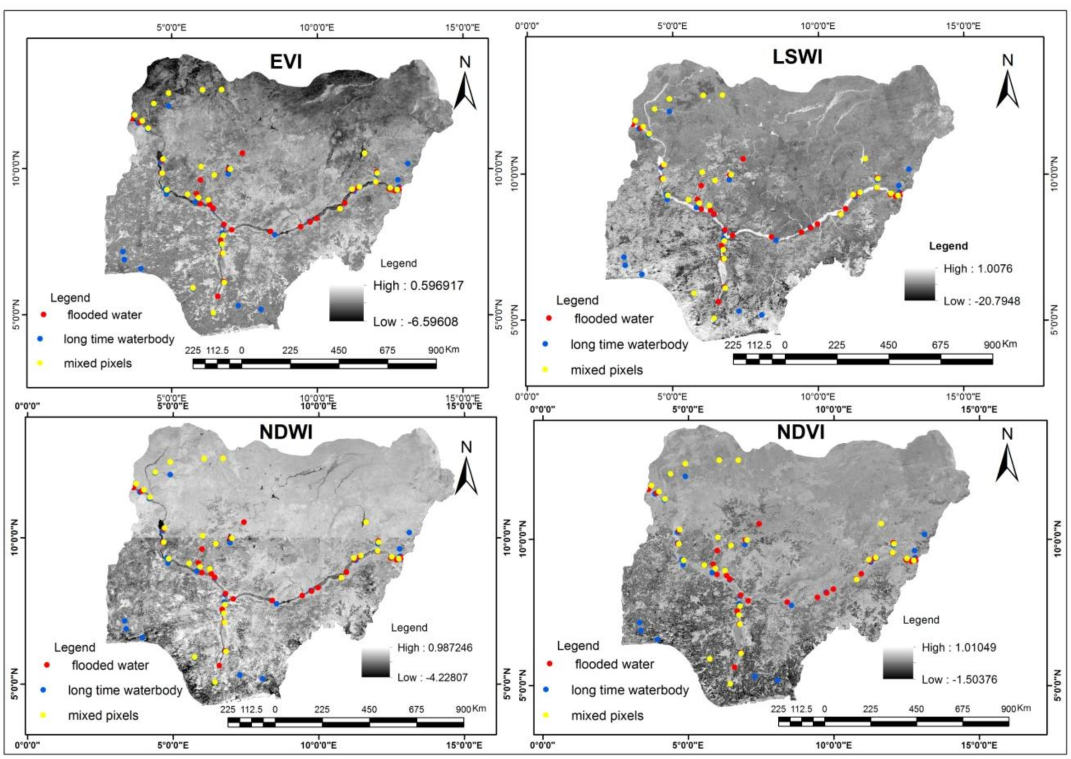

Fig. 4. Map of the different water indices of EVI, LSWI, NDWI and NDVI

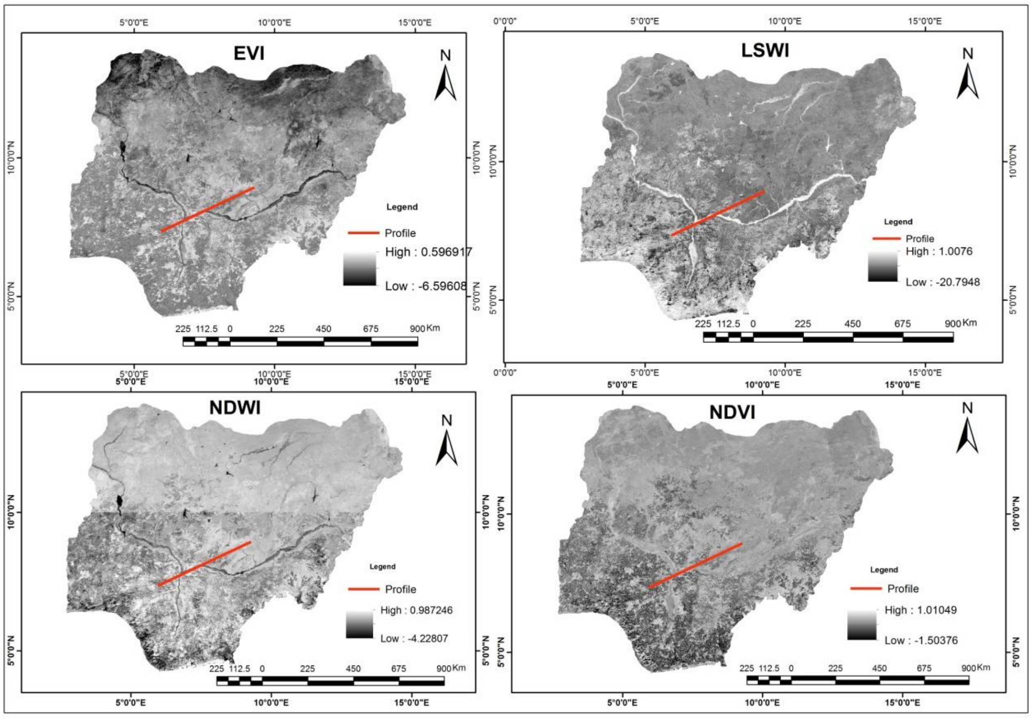

Fig. 5a. The spatial profile of the sensitivity of water indices to water detection

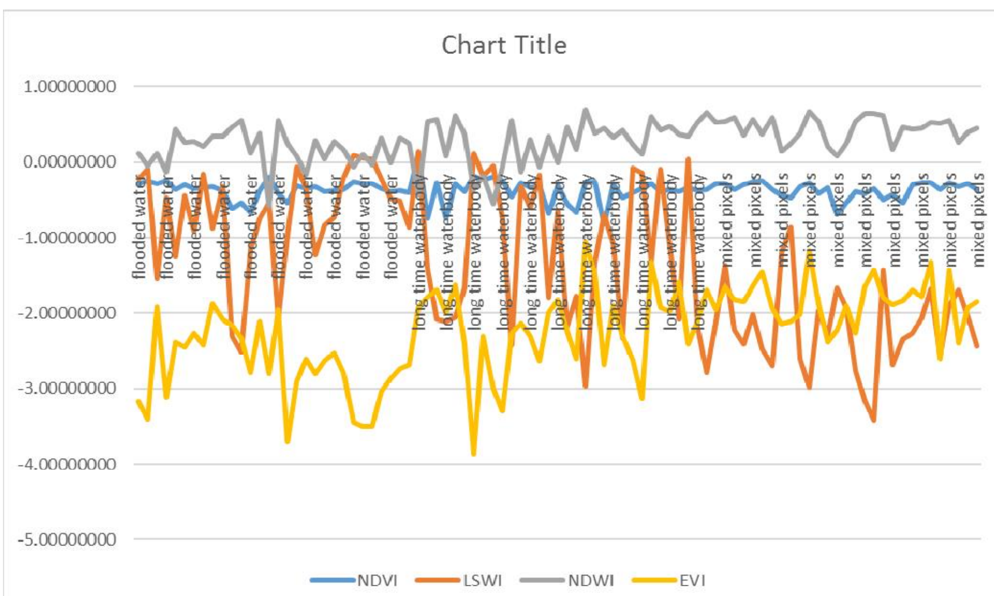

Fig. 5b. The spatial profile of the sensitivity of water indices to water detection

3.4 Research Findings

The most important hydrological component that played a major role in flood inundation of 2010 and 2012 were rainfall and the release of water from dam outside Nigeria. This coincides with the work of [15]. The co-occurrence of the incessant rainfall event and the release of water from Ladjo Dam in Cameroon at the inundation period makes it highly difficult to clearly separate the contribution of each of these two important hydrological input to the flood event. However, the result of MODIS reflectance data gives an impression that more water than usual was ejected in this period in the different parts of Nigeria which resulted to this terrible flood inundation.

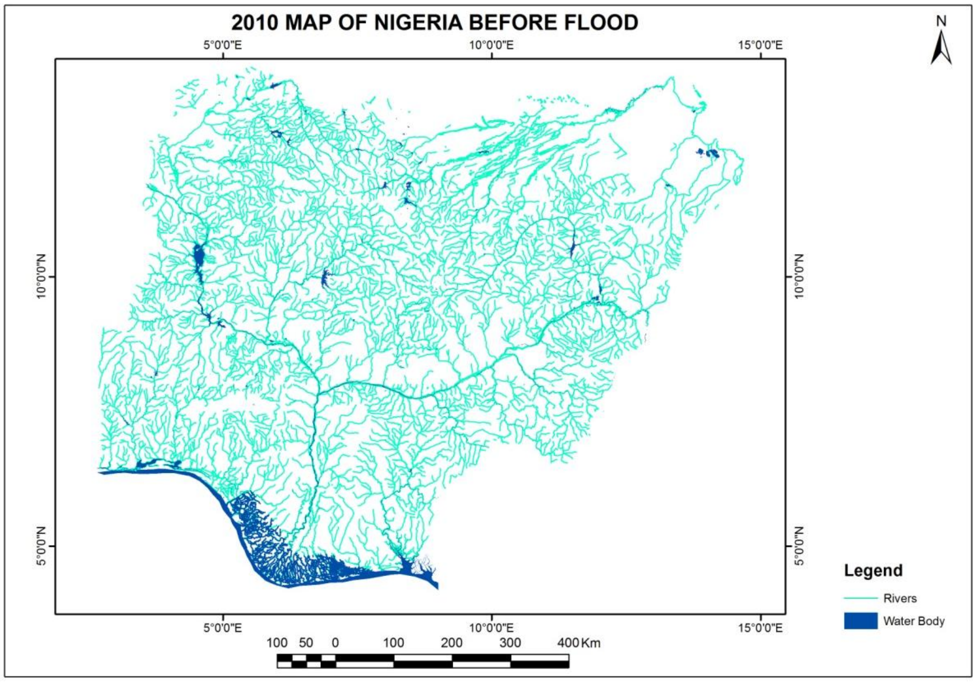

Fig. 6a. Map of river/water body prior to flood (2010 dry season)

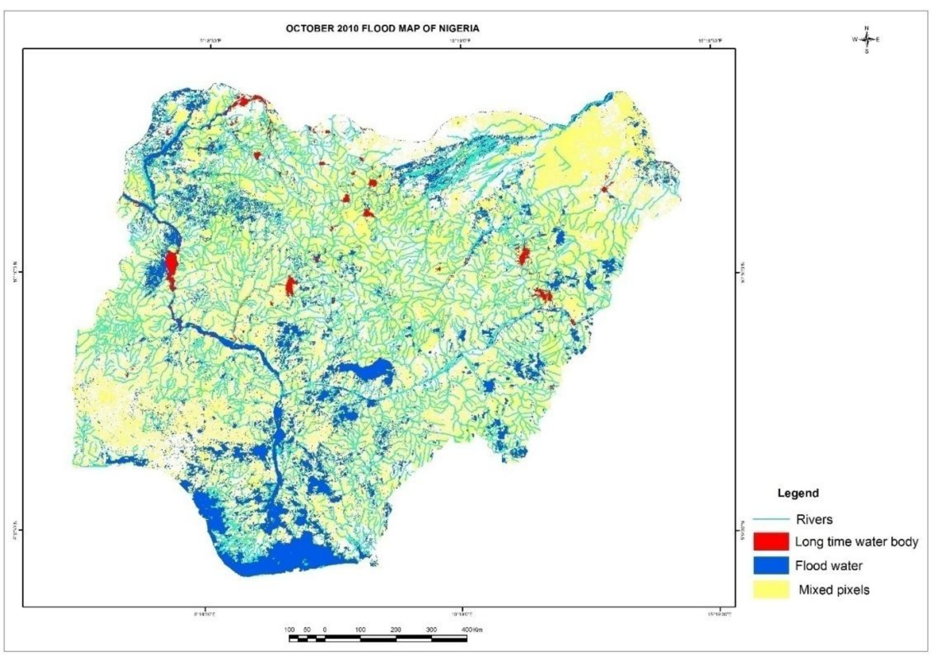

Fig. 6b. Map of river/water bodies during flood (October 2010)

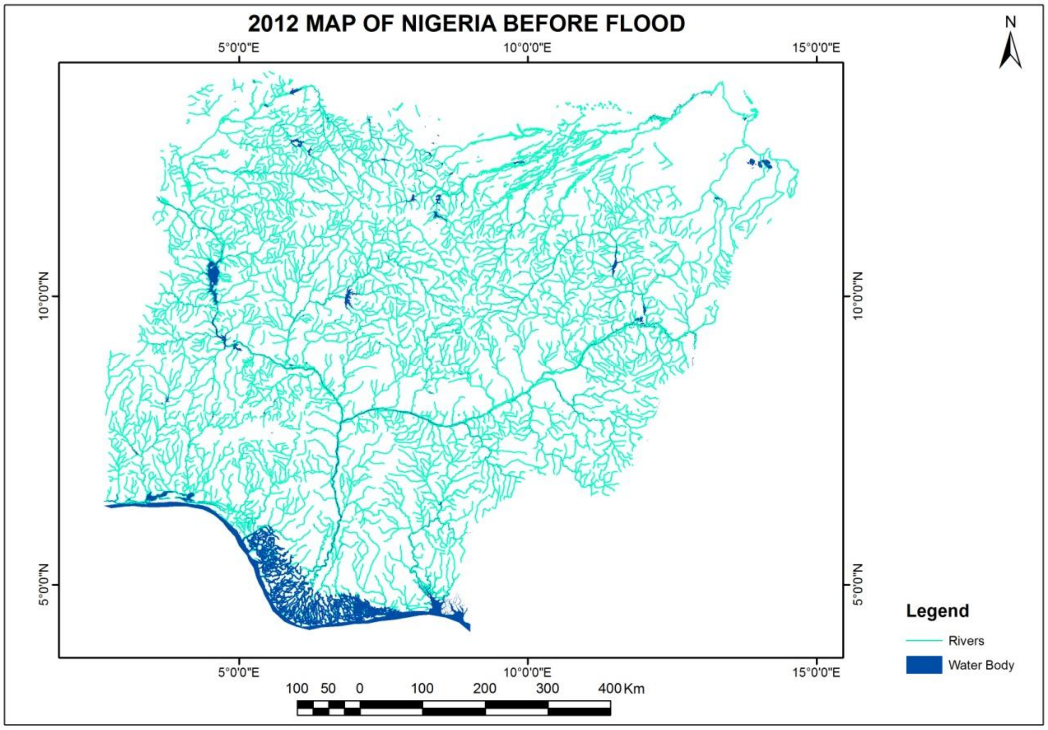

Fig. 6c. Map of river/water body prior to flood (2012 dry season)

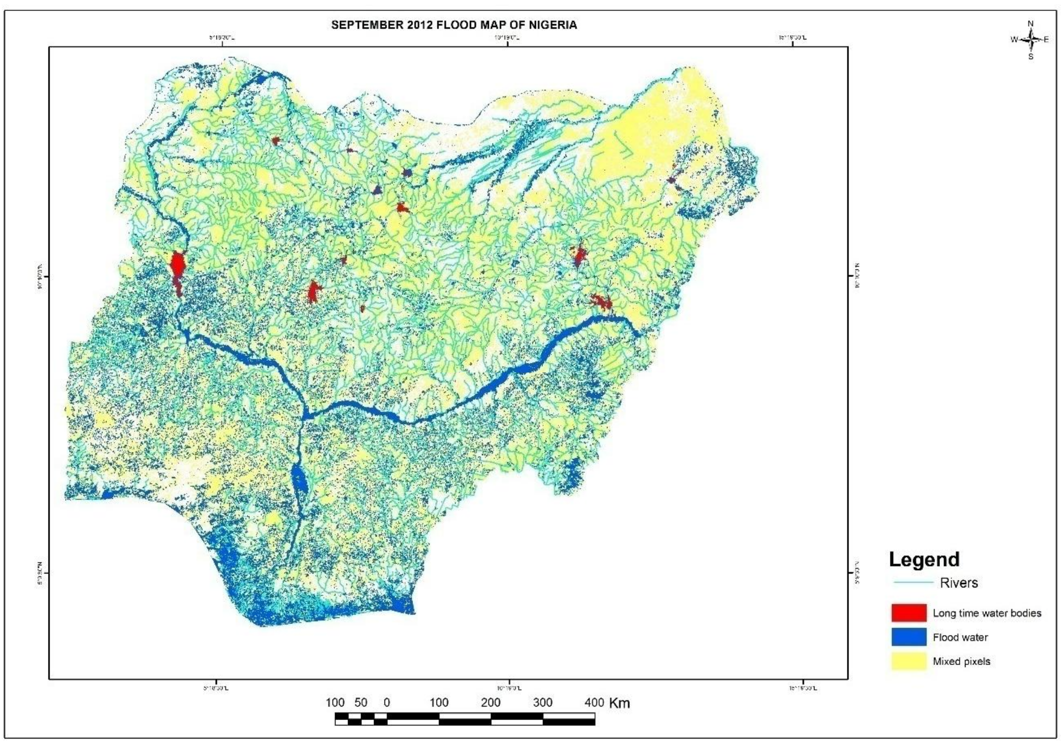

Fig. 6d. Map of river/water bodies during flood (september2012)

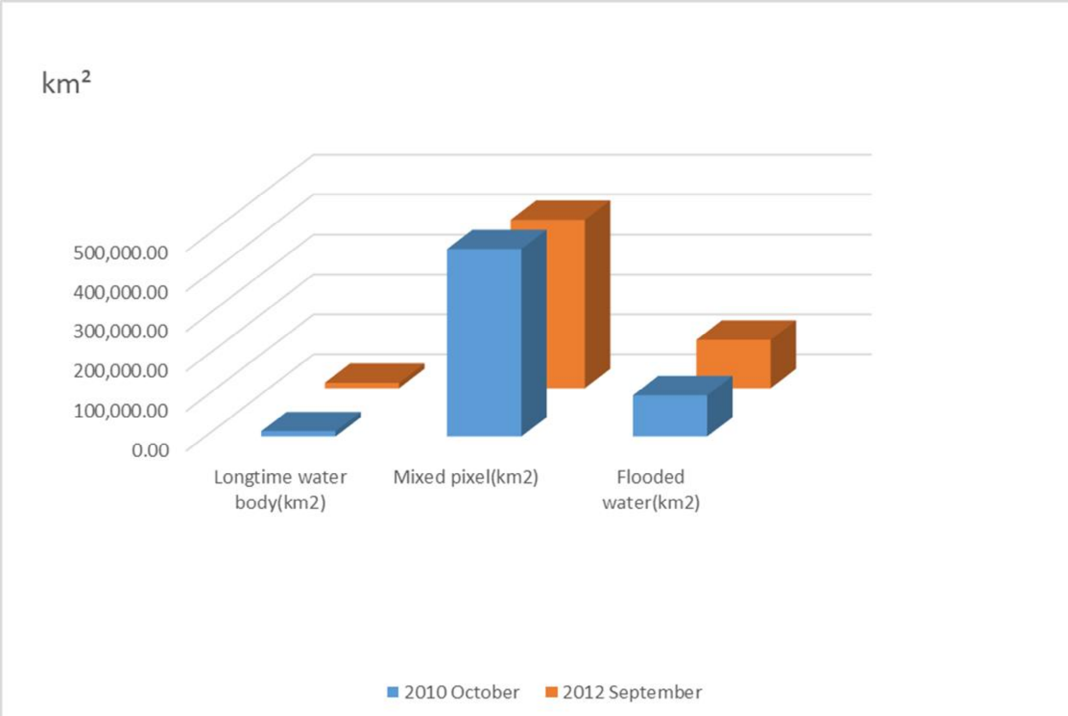

Fig. 7. Flood extent of the year 2010 and 2012

The rainfall regime for the period between months of January to march off the year 2010 and 2012 revealed low rainfall. In 2010, rainfall began to rise from the month of April until it reached its highest peak in the month of August and it started declining until it reached its lowest peak of the year in the month of December 2010. Also in 2012, rainfall began to rise until the highest peak was reached in July. Though there was a short fall in the amount of rainfall in August 2012 but with a sharp rise again the month of September and it began to decline again until it reached the lowest peak of the year in December 2012 (Fig. 3). From the result, it is evident that several factors were responsible for the October 2010 and the September 2012 flood event. Apart from the heavy rainfall experienced in the year 2010 and 2012 other factors that contributed to the October 2010 and September 2012 flooding were, dam failure, release of water from dams, un-planned development among others. This corroborates with the works of [3] and [16].

The result of comparing the sensitivity of the different water indices indicates that all the indices have similar negative values ranging from – 3.5 to 0.1 and this displays their similarities in water identification (Figs. 5a and 5b). These indices presented nearly the same performance of the proposed method except for the conflicting signature between cloud shadow and water pixels. EVI was used to map out flood because it has high reflectivity of moisture. EVI of water bodies is less than 0.05 or even negative value throughout the year this makes it more effective than other indices in flood water detection. It was evident that all the water indices were highly effective and sensitive in flood water detection. It was also evident and clear that the optimal value of the EVI threshold at less than or equal to 0.1 (EVI <= 0.1) represents flood water. This corroborates the findings of [17] while mapping Flood Inundation Map of Bangladesh using Modis Surface Reflectance Data which revealed that, water-related pixel has EVI less than 0.1, considered as Flood pixel.

From the result, significant flood was recorded in October 2010 and September 2012 in Nigeria with a variation in the magnitude of the flood in the two years. It was also evident from the result of the flood extent maps of October 2010 and September 2012 that flood events vary from year to year but the sudden upsurge was noticed in 2012 (Figs. 6b; 6d; Table 2). The comparison of the coverage of water body during the dry season prior to flood in January 2010 and 2012 as well as during flood in October 2010 and

September 2012 shows clearly that there was a significant rise in the water level exceeding the natural paths of river Niger and Benue thereby causing a lot of havoc to lives, properties, croplands, settlements, vegetation. Large numbers of population were displaced.

4. CONCLUSION

In conclusion, this study has been able to provide insight into understanding of the physical and climatic factors and also the process that bring about flood event.Water indices were integrated for flood inundation mapping technique using MODIS surface reflectance products for the entire country of Nigeria.The study revealed that, at the global scale flood is now a very serious disaster that is ravaging the environment, resources, human and animals population, infrastructure, agricultural products etc. Mitigation measures needs to be taken so as to reduce vulnerability and risk in case of future occurance. More studies should be carried out in order to overcome the negative influence of weather on the effectiveness of satellite imageries for proper identification and mapping of flood disaster and other related environmental problems. The combination of Aqua and Terra MODIS data shows that between 14thand 22nd of October 2010 and 15thand 23rd of September 2012, a significant part of the country was inundated. The magnitude change between 2010 and 2012 flooding was estimated to be 8.2% increase.

The study concluded that, MODIS products had a great advantage in the high-frequent observation while water indices integrated were very effective for flood inundation mapping technique using MODIS surface reflectance products for the entire country of Nigeria.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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