Sadi International journal of Science, Engineering and Technology
ISSN: 2837-1941| Impact Factor : 6.26
Volume. 10, Number 3; July-September, 2023;
Published By: Scientific and Academic Development Institute (SADI)
8933 Willis Ave Los Angeles, California
https://sadijournals.org/index.php/sijset|editorial@sadijournals.org

INNOVATIVE INSIGHTS WITH SENTINEL-1: REVOLUTIONIZING FLOOD MAPPING AND BEYOND

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https://doi.org/10.5281/zenodo.8239407

Abstract: Satellite technology has become an indispensable tool for diverse environmental applications, and the Sentinel-1 satellite system, a European Synthetic Aperture Radar (SAR) satellite operational since 2014, plays a pivotal role in this context. This study delves into the multifaceted utility of Sentinel-1 in various environmental domains, encompassing impact assessment, flood mapping, environmental assessment, humanitarian operations, land cover mapping, oil spill detection, urban impervious surface mapping, land surface applications, landscape changes, and maritime surveillance. The constellation of two polar-orbiting Sentinel-1 satellites operates day and night with C-band SAR imaging, facilitating the acquisition of high-quality imagery regardless of weather conditions. In the realm of flood mapping, recent research has showcased the efficacy of Sentinel-1's change detection and thresholding methodology for assessing flooding extents. This methodology revealed correlations with established flood maps and even identified pluvial flooding that had eluded conventional flood mapping methods. Moreover, Sentinel-1's potential to extract inundation information from SAR images has been demonstrated in vegetated areas along rivers, where the change detection method proved particularly effective. For assessing damage caused by flood events, Sentinel-1 data have been instrumental in identifying and quantifying damaged buildings, aiding in disaster response and recovery efforts. This study zooms in on a specific study area, positioning it within a broader geographical context. The research area, illustrated in Figure 1, is defined by distinct longitudes and latitudes. Through a comprehensive analysis of Sentinel-1 data and its application in diverse environmental scenarios, this study offers insights into the satellite's capabilities and contributions. The research underscores the significance of Sentinel-1 in enhancing our understanding of environmental dynamics and facilitating effective decision-making in disaster management, resource allocation, and environmental conservation.

Keywords: Satellite technology, Sentinel-1, Synthetic Aperture Radar (SAR), environmental applications

I. INTRODUCTION

Satellite technology such as sentinel-1 has been of great importance to humanity and is being used in diverse environmental applications like Impact Assessment (Braun et al, 2016), Flood mapping (Amitrano et al, 2018;

Psomiadis, 2016: Elkhrachy, 2018; Clement et al, 2018), Environmental assessments (Braun et al, 2015), Humanitarian operations (Lang & Rogenhofer, 2018; Kranz et al, 2016), Land cover mapping (Abdikan et al, 2016), Oil spill detection and mapping (Kolokoussis & Karathanassi, 2018), Urban impervious surface mapping (Tan et al, 2015), Land surface applications (El Hajj et al, 2016), Landscape changes (Braun & Hochschild, 2017), Maritime surveillance (Greidanus & Santamaria, 2014).

Sentinel-1 is the European Synthetic Aperture Radar (SAR) satellite operational since 3 October 2014. It is designed to provide enhanced revisit frequency, coverage, timeliness and reliability for operational services and applications requiring long time series. The Sentinel-1 mission comprises a constellation of two polar-orbiting satellites, operating day and night performing C-band synthetic aperture radar imaging, enabling them to acquire imagery regardless of the weather (Geudtner et al, 2014). Clement et al, (2018), who used change detection and thresholding methodology to determine the extent of flooding in Yorkshire, UK, observed that the mapped results showed a good correlation with the Environment Agency Flood Maps for Planning (EA FMP) and the satellite data identified pluvial flooding not highlighted by the EA FMP. Addae (2018), who used the change detection method of image differencing and ratioing to extract inundation information from the Sentinel-1 SAR images, revealed that the inundation within the vegetated area along the river was comparatively better detected with the change detection method and suggested that Sentinel-1 is suitable to effectively extract inundation extent of open water and vegetation inundation. Another study by Som-ard (2017), who carried out assessment of damaged buildings from flood event using Sentinel-1 data, reported that “the numbers of damaged buildings were high in Khlong Daen (726 features), Tha Bon (645 features), and Ranot sub-district (604 features), respectively”.

The study area (fig. 1) is positioned within longitudes 7.736E-7.938E and latitudes 6.706N-6.989N respectively. Lokoja (the capital of Kogi state which is referred to as the confluence state because of the intercession of the Nigeria’s two main rivers – the Niger and the Benue) is often inundated with flooding during heavy rainfall especially between July and October. This has often caused loss of lives, significant damage to properties, environmental degradation and its associated hazards, loss of agricultural crops and land. This study was motivated by the recent flooding encountered in the study area as a result of heavy rainfall that took place from 23rd August to 28th September, 2018. The study is aimed at assessing the impact of the flood on farmlands, settlements and roads by delineating the inundated areas and its dynamic changes within the period using Sentinel-1 SAR data.

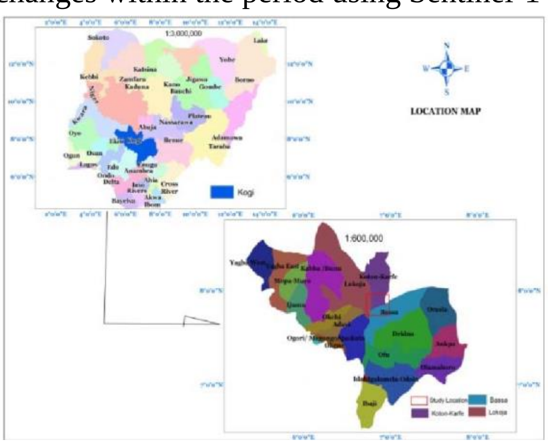

Fig. 1: Study Area

II. MATERIALS AND METHOD

2.1. Materials

The data sets and software used for this study are ESA Sentinel-1 SAR imagery, SNAP (Sentinels Application Platform) version 6.0 Software, QGIS 3.2 software, ARCGIS 10.6 software, Google Earth Pro and Elshayal SMART GIS Software. SNAP Software, which is an open source common architecture for ESA Toolboxes, was used for preprocessing and extraction of flooded area. QGIS 3.2 was used for inter-conversion of data formats and ARCGIS 10.6 was used for the presentation and visualization of flooded areas and to display the dynamic changes within the period of flood at the study area. . Earth Imagery from Google Earth Pro and the world imagery base layer from AGOL were used for verification of all the images downloaded, verification of extracted flooded areas, extraction of buildings and farmlands and assessment of flood impacts on the environment. Elshayal SMART GIS Software was used to download Google Earth imagery for the study area.

The Sentinel-1 radar data were obtained from satellite images produced by satellite sensors with a repeat cycle of 12 days which ensures consistent long-term data coverage and data archive for systematic flood mapping and monitoring purposes. These Sentinel-1 images can be acquired through the Sentinels Scientific Data Hub, downloaded manually from Copernicus Open Access Hub or in an automated way from API (Application Programming Interface) Hub using OpenSearch API and Open Data API. The imageries acquired include the following:

S1A_IW_GRDH_1SDV_20180718T174539_201807
18T174604_022852_027A5B_3BF3.zip
S1A_IW_GRDH_1SDV_20180823T174541_201808
23T174606_023377_028B15_6A66.zip
S1A_IW_GRDH_1SDV_20180916T174542_201809
16T174607_023727_02963F_6B7F.zip
S1A_IW_GRDH_1SDV_20180928T174543_201809
28T174608_023902_029BEE_3B4D.zip

2.2. Method

Broadly speaking, the methodology ranges from collection of satellite imageries to data processing and then presentation of work in the form of maps and tables. The downloaded Sentinel-1 data was radiometrically calibrated and geometrically corrected. The work flow for the pre-processing work is shown in Fig. 2

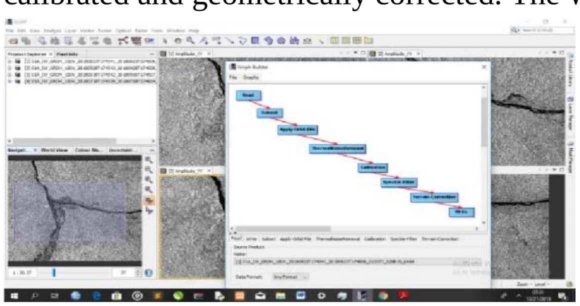

Fig. 2: Work Flow for pre-processing

The orbit state vectors provided in the metadata of a SAR product were refined with the precise orbit files which are available days-to-weeks after the generation of the product. The orbit file provides accurate satellite position and velocity information. Thermal noise removal was carried out in order to enhance the precision of radar reflectivity estimates. Sentinel Level-1 products from ESA (European Space Agency) provide a noise LUT (Look Up Table) for each measurement dataset, provided in linear power, which can be used to remove the noise from the product. The calibration operator was next added to provide imagery in which the pixel values can be directly related to the radar backscatter.

A speckle filter was applied to reduce the noise-salt and paper effect in the images, the deformations due to the side looking geometry of the sensor and the terrain were corrected using the Shuttle Radar Topography Mission Digital Elevation Model version 3.0 (Farr et al., 2007), and finally a correction of the local incidence angle was applied. After these initial steps, the Sentinel-1 data was further geometrically and radiometrically corrected and transformed to a geometry that can be combined with the other data sets. All these pre-processing works were done by the SNAP version 6.0 software.

After the pre-processing stage and focusing on the study location, geometric corrections were further carried out before mapping the flooded areas by a kind of unsupervised classification called 'thresholding'. It is an unsupervised classification because a histogram of the filtered backscatter coefficient and a threshold value of 0.04 intensity unit were applied in order to separate the water pixels from the non-water pixels (Brown et al., 2016). The threshold value was obtained from statistical analysis of sample sites within the flooded area. After this first pass, we further refined the results by superimposing it on Google Earth platform. In the final analysis, maps of flooded areas, dynamic changes and flood impacts within the period of study (July to September, 2018) were produced. The extracted flooded areas was further overlaid on a world imagery base layer hosted by AGOL and Google Earth global platform to verify its level of agreement with existing imagery of the location.

III. RESULTS AND DISCUSSION

The maps of the flooded areas are shown in fig. 3. The month of July is taken as the normal state of the Niger River while August and September show the extent of the flooding. The month of September has more adverse effects on the environment and social economic lives of the residents leading to loss of properties, farm produce and traffic jam on the Lokoja-Abuja road. There was a high rise in water level especially in September which increased the flooded areas from 14.7sqkm in August to 317sqkm.

This led to setting up of temporary camps for victims of the flood as more houses get submerged in the confluence city as confirmed by the Kogi State Government(https://www.premiumtimesng.com/regio nal/north-central/282959-kogi-sets-up-camps-forflood-victims.html).

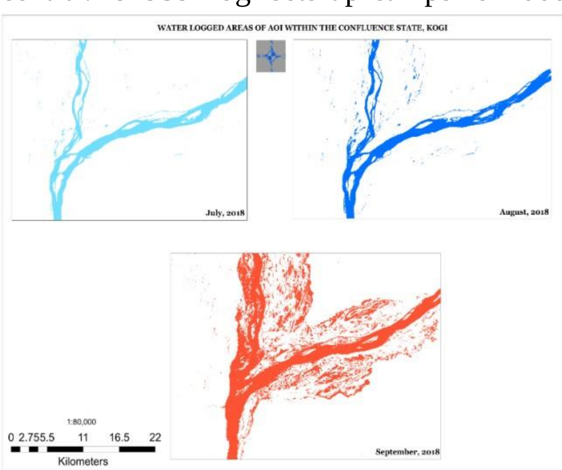

Fig. 3: Map of flooded areas

The dynamic change map of the study area is shown in fig 4. This map shows the dynamics of the flood waters meaning that it delineates the movement of flood waters as the heavy rainfall continued to its peak in the month of September. Farmlands, agricultural produce, shops, supermarkets, hotels, roads were mostly affected and residents sought for refuge in Wada Estate and Old Poly Quarters in the state's capital city (a place set up by the Government to accommodate the flood victims).

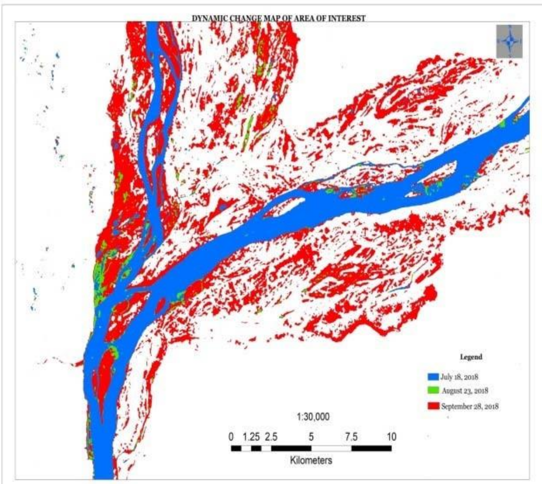

Fig. 4: Dynamic change map of the flooded areas

Fig. 5 shows the map of the extracted flooded areas overlaid on a world imagery base layer hosted by AGOL (ESRI's ArcGIS Online) and Google Earth global platform in order to assess the flood impacts on the environment. The multiple satellite images (July, August and September) of the region over the study period enabled tracking of the advance and retreat of the flood waters. As it can be observed, the white parches in the satellite imagery indicate built up areas and some of them were submerged in the flood waters.

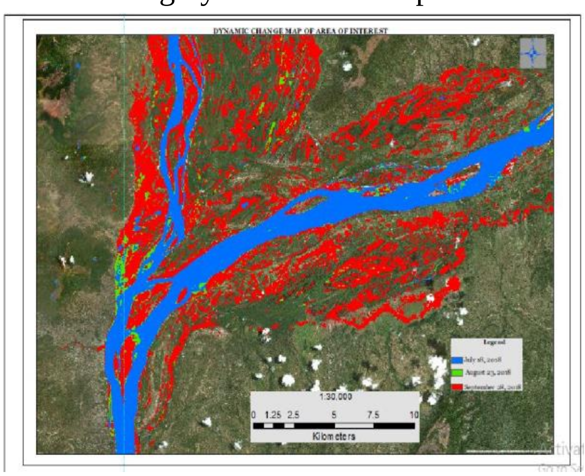

Fig. 5: map of flooded areas overlaid on satellite imagery

Table 1 gives a summary of the impact assessment carried out from the maps of the flooded areas. The body of water forming the coastline was digitized as polygons and approximate areas of coastline were extracted as shown in the table.

Table 1: Summary of impact assessment

Month (Time Series)	Appr. Area of Coastline(Sq.Km)	Appr. Number of Buildings Submerged	Major Roads Affected	Appr. Area of Farmlands Affected(Sq. Km)
July	111(Normal State)	Nill	Nill	Normal State(Nill)
August	147	3	Nill	14.7
September	374	211	Beach road, Lokoja - Otukpo Road, Hammed Bello Way.	317

These results confirm the statistical flood impact information released on the 9th of September, 2018, by the Kogi State Emergency Management Agency "that a total 88 households arrived temporary accommodation camps set up by the state government as victims of the flood" (https://www.premiumtimesng.com/regional/northcentral/282959-kogi-sets-up-camps-for-floodvictims.html).

IV. CONCLUSIONS

This study (which used change detection and histogram thresholding method to extract the flooded areas from Sentinel-1 SAR data in order to assess the impact of flooding caused by heavy rainfall that took place in Lokoja, Kogi State from 23rd August to 28th September, 2018) revealed that 211 buildings (including shops, supermarkets, hotels, churches and mosques), 3 major roads and 317sqkm of farmlands were adversely affected especially in the month of September. It can be concluded that the advancement in satellite remote sensing has greatly improved man's proper understanding of her environment and the various factors affecting it.

The results of this study can be used for effective planning, assessment, mitigation and rehabilitation exercises. In addition, other forms of analyses could be carried out to improve upon these results. The improvements could come in different ways like provision of high resolution imagery of the study location, ground control points over the study area, and ground truthing. It is therefore recommended that relevant agencies like the Kogi State Emergency Management Agency should encourage research works in the area of Remote Sensing for Disaster Management in order to curb such future occurrences.

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