EVALUATION OF THE NILE RIVER FLOODING IN THE KHARTOUM CAPITAL USING SENTINEL-1 IMAGERY

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ABSTRACT: In the past few months historical rainfalls have been recorded in the African great lakes area and on the Blue Nile basin. This significant rainfall has led to major floods along both the Blue and White Niles resulting in a devastating loss of life, property, and wealth in both Ethiopia and Sudan. Khartoum, the capital city of Sudan, witnessed the highest level of the Nile River since the previous highest levels in 1988. This study aims to map the flood-damaged area around the two main tributaries of the Nile River; the White Nile and the Blue Nile. This study evaluates the flooded area around both the White Nile and the Blue Nile inside Sudan using Synthetic Aperture Radar (SAR) technology. This technology is an inevitable data source for flood mapping and monitoring due to it is the ability to acquire data over Earth's surface during any weather conditions and day or night. Sentinel-1 data (C-band) presents a valuable data source to map the flood-damaged area due to it is sensitivity to water bodies and moisture content and more important a free data access to the Sentinel-1 within 24 hours from acquisition. Moreover, the temporal resolution of Sentinel-1 data enables flood mapping in near real-time. Our approach combined elevation and land cover data with Sentinel-1 data to evaluate the flood-damaged area. Mapping the flood-damaged areas relied on the SAR statistics after radiometric and geometric corrections. Classification techniques have been performed to map the flooded areas and land cover data have been superimposed to separate the main water body from the flood-damaged area. Sentinel-1 data acquired during Fall (June, July, and August) have been processed. A comparison between the flooded areas in the White Nile and the Blue Nile has been conducted to evaluate the damage contribution at Khartoum capital. The processed data showed that the flood event started at the White Nile in the middle of July while the flood event started at the Blue Nile late by the middle of August. This approach presents a free tool for flooding disaster monitoring for early warning to enable fast flood response.

1. Introduction

Floods are one of the most destructive natural disasters for human lives and infrastructures as roads and buildings. Flooding is the submerging of the land, normally considered dry, by the overflowing excess of water. Protecting lives and property from this disaster requires continuous mapping and monitoring for the inundation areas. Flood inundation maps provide a quick assessment of the flood situation, occurred damage, and improve the response of the crisis management sector. Damages that occurred from floods make the mapping of the inundation areas very challenging especially when the communication and transportation infrastructures are affected.

Satellite-based Earth observation (EO) data provides synoptic views with an appropriate temporal and spatial resolution for potential flood regions. Satellites EO data covers a wide area in a small-time which is very essential for flooding disaster management. Synthetic Aperture Radar (SAR) sensors have the advantage over the optical sensors by it is capability to operate independently of the weather condition and day time (day or night). This advantage emerged the SAR sensors as an essential tool for near-real-time flood inundation mapping.

European Space Agency (ESA) provides the first global operational SAR satellites (Sentinel-1) data free of charges for the global public. Sentinel-1 constellation is composed of two satellites; Sentinel-1A and Sentinel-1B were launched in March 2014 and 2016, respectively, and it is operating in C-band with 12 days revisit period. SAR sensors measure the amount of the backscattered energy from the ground targets depending on their surface roughness, viewing geometry, and electrical properties. Investigating these parameters for water surfaces is essential for flood inundation classification.

Khartoum city is the capital of Sudan located at the eastern center of the country between 15- and 16-degrees latitude north and between 32- and 33-degrees longitude east (figure 1). It is characterized spatially by an elevation of 386 m above mean sea level. Khartoum is known as the meeting point (the confluence) of the two main tributaries of the Nile River; the Blue Nile flowing from Tana Lake in Ethiopia and the White Nile flowing from African Great Lakes around the East African Rift. Khartoum is characterized by a hot desert climate with an average annual temperature of 32° C and annual precipitation of 135 mm. There are two seasons. The dry season very long extends from November to May with the highest temperature in May with 46° C. The rainy occurred between June and August when the Intertropical Convergence Zone moves northerly (flooding season).

In this study, we evaluated the exploiting of Sentinel-1 data for flood inundation mapping and monitoring over Khartoum city. We focus on the evolution of the flooding from both the Blue Nile and White Nile in order to assess the progress of the disaster from both rivers and the impacts on the Khartoum capital. Maps that trace the evolution of the flooding disaster along the two rivers have been generated and comparison was discussed.

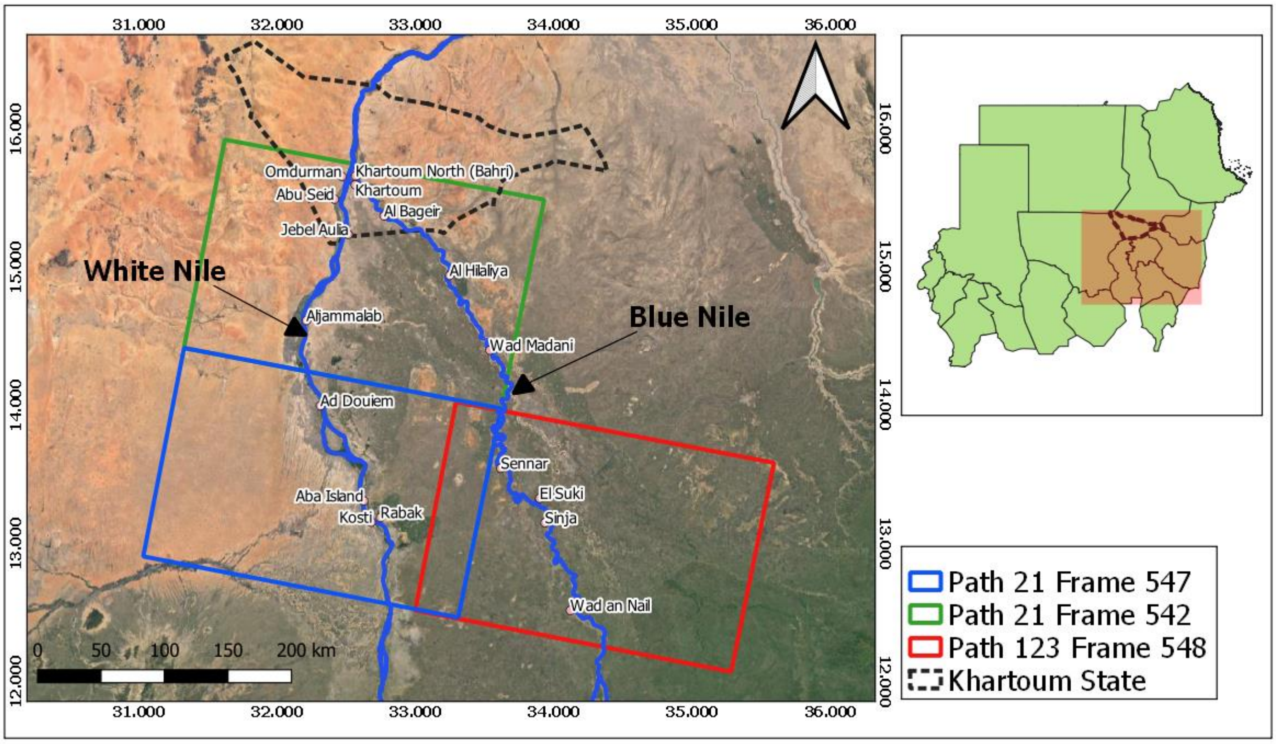

Figure 1. Location of the study area with the footprint of the Sentinel-1 data. Blue and green footprint represents the same path 21with frame no. 547 and 542 respectively. Dots polygon represents the Khartoum state boundary.

2. DATA & METHODS

In this study, we used 12 Sentinel-1 Ground Range Detected (GRD) images acquired from 3 different frames to cover the area of the Blue Nile and White Nile inside the boundary of Sudan. Level-1 GRD data acquired in Interferometric Wide (IW) mode with 250 km swath and range and azimuth resolution of 10 m is composed of focused SAR data that was detected, multilooked, and projected in ground range using an Earth ellipsoid model (Torres et al. 2012). We only used the like polarized channel VV (vertical transmit and vertical receive). Ancillary data as Digital Elevation Model (DEM) from Shuttle Radar Topographic Mission (SRTM) 1 arc second was used for geometric correction and land use/land cover data from africover provided by Food and Agriculture Organization (FAO) with the SRTM data were used to constraint the classification of the flood inundation. Sentinel-1 data have been downloaded from Alaska Satellite Facility (ASF) for the period between 1 July to 30 August 2020 (Table 1).

Table 1. Summary of the Sentinel-1 data used in this study

Khartoum	White Nile	Blue Nile
13-07-2020	13-07-2020	14-07-2020
25-07-2020	25-07-2020	26-07-2020
18-08-2020	18-08-2020	19-08-2020
30-08-2020	30-08-2020	31-08-2020

Sentinel-1 data have been processed via ESA open source Sentinel Application Platform (SNAP). Pre-processing steps were prepared in the graph processing tool in order to speed up the procedure by using the batch processing. Pre-processing (figure 2) includes update orbit information, noise removal, calibration, filtering, and geometric corrections (Filipponi 2019). Orbit information stored within SAR products metadata is not accurate and for providing accurate satellite position precise orbit information has been downloaded and updated. The second step in the pre-processing is to normalize the backscatter signal within the entire scene by applying Thermal Noise Removal operation. Then, the Border Noise Removal has been applied to remove the intensity noise and invalid data on the image edge.

After that, the calibration process was applied to convert the digital values to a more comparable backscatter amount, known as the backscatter coefficient which is the amount of backscatter energy per unit area. Then, speck filtering, specifically the Lee Sigma filter, was applied to enhance the image quality by reducing the speckle in the image. Speckle is introduced in SAR images due to the interference of waves from multiple scatterers result in grainy noise. Subsequently, terrain correction was performed using SRTM data in order to outweigh the distortions due to the side-looking geometry and re-orient the image as close as possible to the real world. Finally, a logarithmic transformation has been used to convert the backscatter coefficient to dB.

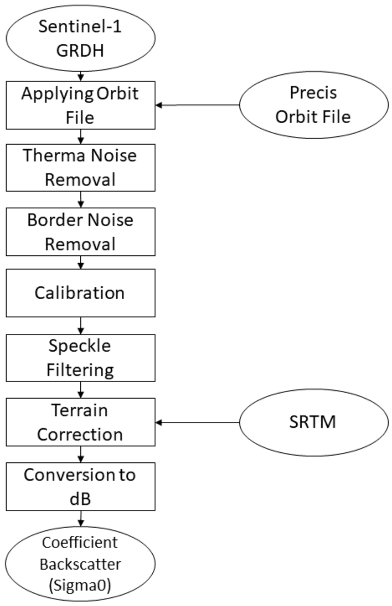

Figure 2. Flow chart for the pre-processing steps required for the Sentinel-1 GRD product.

A thresholding classification technique was implemented to classify the SAR images into two classes, water and no water (Manjusree et al. 2012). Water surfaces appear as a smooth surface to the radar sensor which characterizes by specular reflection when the most transmitted wave is reflected away from the sensor and the least amount of energy is detected. Thus, water surfaces appear as a dark object in SAR images (Woodhouse 2006). A threshold was determined from the image histogram to distinguish between water and non-water classes. Water class includes the main water body represented by the Blue Nile, White Nile, and Nile River with the flood inundation areas. In order to exclude the main water body, land cover data was used to mask out the pixels of the water body from the water class. More constraint for the flood inundation areas was applied by masking out the selected pixels (low intensity) with high elevation variation in comparison with the elevation of the water body. This results in more reliable flood inundation areas. This process was applied for all acquired SAR images and the final flood inundation pixels were superimposed over Google Earth image for comparison.

3. RESULTS & DISCUSSION

In this section, we will present the evolution of the flooding disaster from the White Nile and the Blue Nile outside the Khartoum state separately, then we present the progress of the flooding inside the Khartoum state. The first flooding event at the White Nile was detected on 13 July which affects small parts around Kosti and Rabak while the most damage was around Ad Douiem (Figure 3). On 25 July the flood event was increased to include Aba island and extended north to Aljammalab and continuing to the south of Jebel Aulia. The flood inundation areas were increased significantly on 18 August the most areas around the White Nile river. The classified image on 30 August showed the entire area around the White Nile is flooded from the south boundary of Sudan till the Khartoum state.

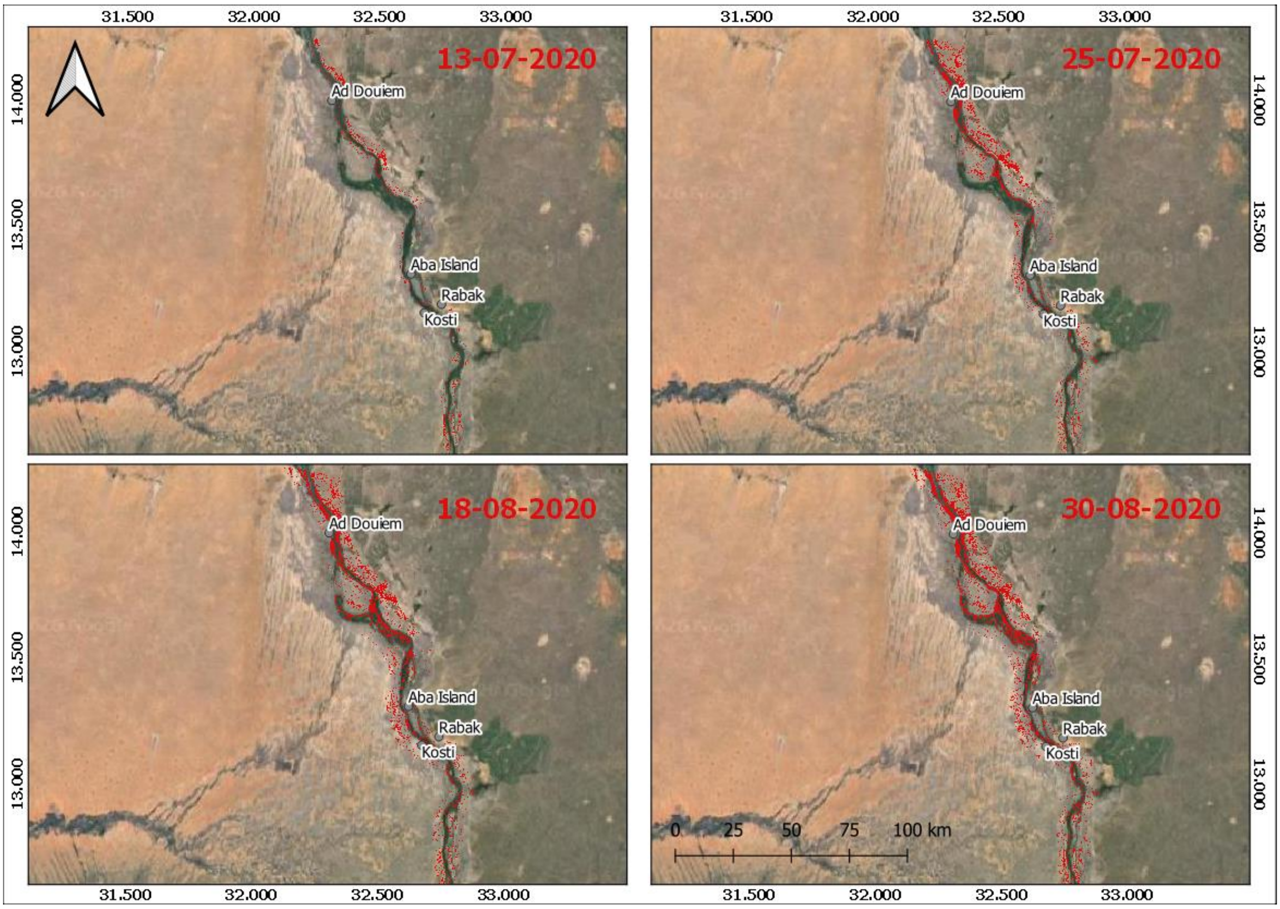

Figure 3. Shows the progress of the flood event from the White Nile (blue frame in figure 2) between 13 July and 30 August. The red color represents the flood inundated areas.

Unlike the White Nile, the evolution of the flooding at the Blue Nile was first detected on 25 July by small areas north of Sennar city and around Sinja (figure 4). The evolution of the flood at the Blue Nile was extending slowly and by 18 August more areas north of Sennar were flooded and small areas around Al Hilaliya with the western part of Umm Shawkah. On 30 August the flooded areas were significantly extended especially around Sinja and at the west bank of El Suki. Flooding events at Khartoum state were detected on 18 August where concentrated around the White Nile from Jebel Aulia through Abu Seid to the confluence with the Blue Nile (figure 5). On the other side, the flooding areas from the Blue Nile inside the Khartoum state were smaller and sparse around Butri and Suba. Tutti island is located at the confluence and recorded flooding events from both rivers. The flooding areas were increased sharply on 30 August in different areas in Khartoum state such as Sharq Al Neel, Abu Rouf, Tutti island, and some parts at Khartoum North (Bahri).

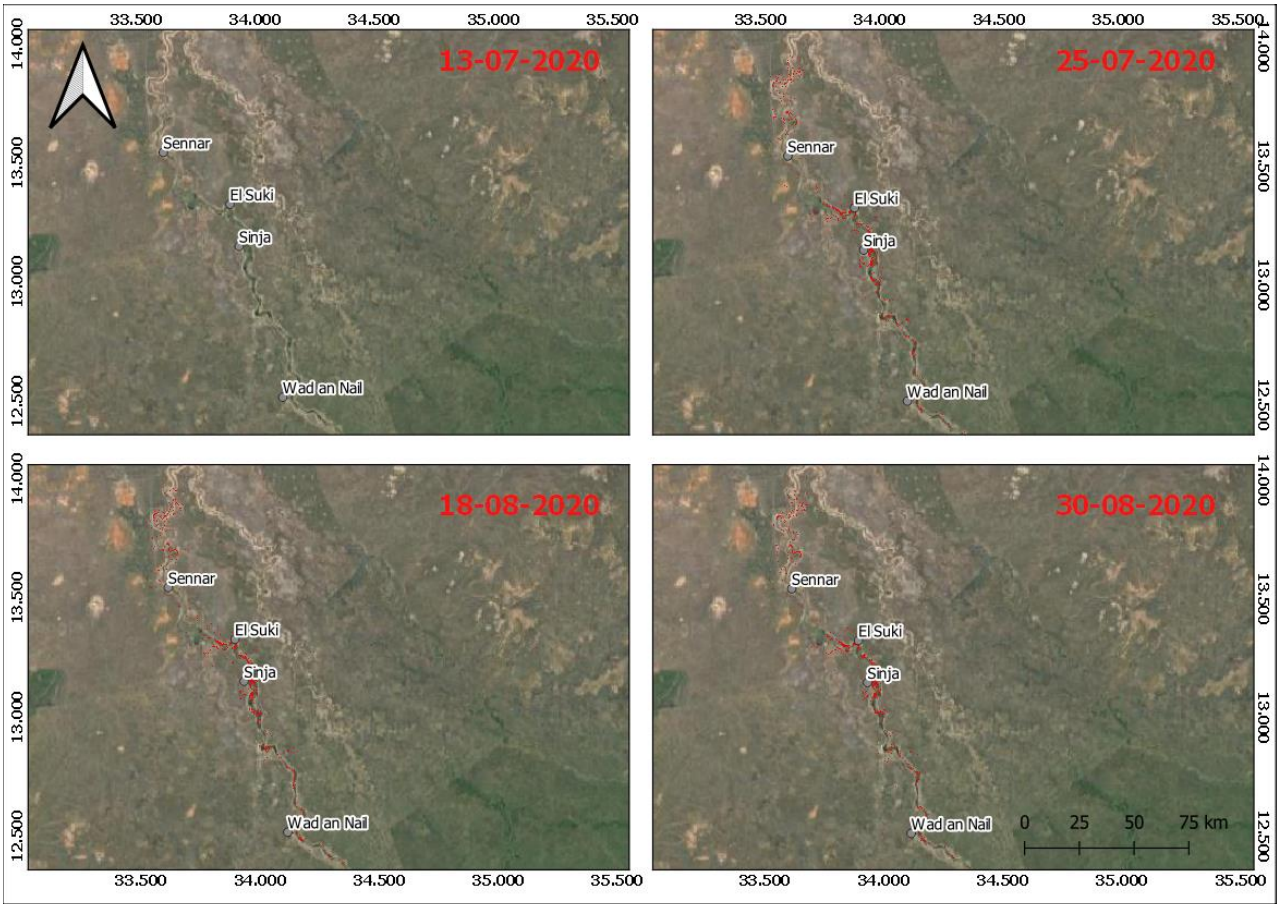

Figure 4. Shows the progress of the flood event from the Blue Nile (red frame in figure 2) between 13 July and 30 August. The red color represents the flood inundated areas.

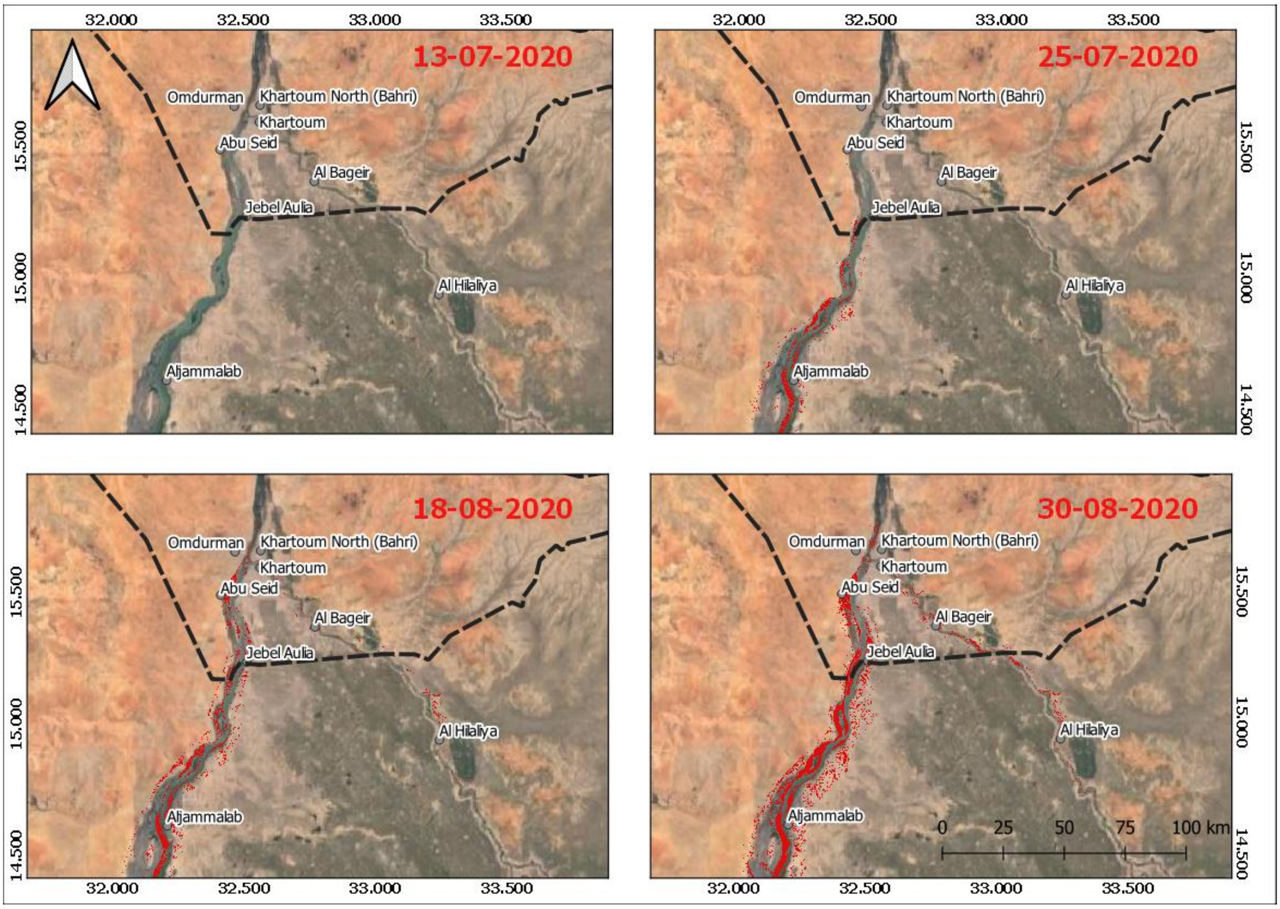

Figure 5. Shows the progress of the flood event from the White Nile and the Blue Nile at Khartoum (green frame in figure 2) between 13 July and 30 August. The red color represents the flood inundated areas.

The recent flood events were detected at the White Nile on 13 July while the first detection of the flood events at the Blue Nile and the Khartoum was on 25 July. This can be related to the historical recorded rainfall at the African Great Lakes during months before the flooding disaster hits the Khartoum state. Many losses of lives and property have been reported in Khartoum during the last flooding events but not mainly because of the flooding strength and more due to lack of a good infrastructure to hold such events. Moreover, the lack of monitoring of the precipitation at the source of the Blue Nile and White Nile to predict the early events and responses to avoid more damage.

4. CONCLUSION

This study provided a useful mapping and monitoring of flood events in near real-time and facilitated the quick response for the crisis management free of charge by utilizing Sentinel-1 SAR data. The monitoring showed that the flooding events started first at the White Nile then the events followed at both Blue Nile and Khartoum.

Acknowledgement

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