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Original Article

Sentinel 1 SAR-Based Flood Detection and Mapping: Myanmar Two Consecutive Years Case

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Abstract - *Various factors, such as climate change and deforestation, can drive more regular flooding. Flood events are becoming normal in Myanmar, even in consecutive years; the case analyzed in the present study is a flooding event that affected Myanmar in July 2015 and June 2016. The situation was even worse in this case since Cyclone Komen also struck the country in July 2015. Given this natural disaster that affected Myanmar, the present study has the main objective of using microwave satellite technology to process and analyze Sentinel 1 datasets through the SNAP platform using a thresholding method to identify and map flooded areas in 2015 and 2016. Given the proposed methodology, it was possible to process the datasets of this Synthetic Aperture Radar (SAR) and determine that a total area of 1,924 Km2 was affected by the flood in July 2015 and a total area of 3,248 Km2 where affected by the flood in August 2016 in the study area.*

***Keywords* -** *Flood, Microwave satellite, Sentinel 1, Threshold, SNAP, SAR.*

1. Introduction

European Union (EU) Floods Directive defines a flood as a natural event where a piece of land that is usually dry suddenly gets submerged under water [1]. Flooding may occur when water bodies such as lake, river, or ocean overtop or breaks levees. Floods can also occur when the flow rate exceeds the capacity of the water body, particularly at bends or meanders in the waterway. Besides, it may happen when rainwater is accumulated on a saturated ground area [2].

Several factors drive more regular flooding, including climate change, new phenomena such as El Niño and La Niña and the forest effect due to illegal logging. Floods could develop gradually. However, other flood events can develop in just a few minutes, even without visible signs of rain; these types of flood events are categorized as flash floods [3]. Additionally, the affectation could be extensive, covering entire river basins, or can be local, impacting a specific community or neighborhood. Flooding is hazardous and can potentially wipe away an entire city, coastline or area and cause extensive damage to life and property [4]. It also has great erosive power and can be highly destructive.

In Myanmar, flooding during monsoon season is becoming normal; some towns, such as Bago, are hit nearly every year [5]. Nevertheless, a disaster on this scale, like the 2016 flooding, over two consecutive years (2015 and 2016) [6], is prompting many to ask whether regular mass floods will become the new typical and, if so, what could be driving this change.

Space technology could be a potential tool to identify and monitor natural disasters. For example, for flood identification, mapping and assessment, both optical and microwave satellite sensors are currently used [34]. However, microwave sensors can penetrate cloud coverage and provide information during the day or night and under any weather condition [8].

Some optical sensors used for flood assessment are Landsat, Sentinel 2, and MODIS [34], among others; from where different indexes such as Normalized Difference Water Index (NDWI) and Modified Normalized Difference Water Index (MNDWI) can be used to identify flooded areas [9, 10, 11].

Additionally, the use of microwave remote sensing for the identification of flood areas [8], usually the Synthetic Aperture Radar (SAR) is the most suitable type of microwave sensor for this particular application; some SAR sensors that could be mentioned are Sentinel 1, SIR-C, Radarsat, among others [34]; from where the specular reflection, characteristic of smooth surfaces such as water, could be used to identify flooded areas [12].

Since water surfaces have unique backscattering properties, this kind of surface act as a specular reflector and causes incoming microwave radiation to be reflected away from the sensor [13]. As a result, water surfaces appear dark in SAR imagery [14].

Most existing flood delineation methodologies using SAR sensors rely on the specular properties of calm water surfaces and a thresholding definition. As observed in [15, 16, 17], procedures mainly apply the classification of an image into flooded and non-flooded portions using a threshold value, which can be determined manually by visual inspection or an automatic technique analyzing its corresponding histogram.

Given the occurrence and damage in two consecutive years due to flooding in the study area in Myanmar, the main objective of this project is to analyze SAR images from Sentinel 1 satellite to identify and map the affectation of a flood and disaster that took place in these consecutive years. The first event occurred in July 2015, and the second event occurred in June 2016. In order to identify flooded areas, the backscattering properties of water surfaces are analyzed. A threshold value is defined to classify the content of an image into flooded and non-flooded portions, analyzing the histograms of the processed images.

2. Methodology

2.1. Study Area

Republic of the Union of Myanmar is a sovereign state in South East Asia bordered by China, Bangladesh, Laos, India and Thailand. Myanmar's size is 676,578 Km2, its capital city is Naypyidaw, and Yangon, also called Rangoon, is its largest city. About one-third of Myanmar's total perimeter of 5,876 Km forms an uninterrupted coastline of 1,930 Km along the Bay of Bengal and the Andaman Sea. [18, 19].

This study will analyze and compare two flood events in 2015 and 2016. The timeline of these flood events began on 16 July 2015, when heavy monsoon rain fell on Myanmar, causing that water bodies such as rivers and creeks to overflow and flooding low-lying areas around waterways. In addition to the rainfall, mismanagement of irrigation projects and deforestation contribute to the flooding, and also Cyclone Komen, which struck in July 2015, also made the situation worse [20].

The flooding event of 2015 was the worst to affect the country for decades, destroying farmland, roads, rail tracks, bridges and houses. According to the UN Office for the Coordination of Humanitarian Affairs (OCHA), this flood event affected 12 states of the country, resulting in about 103 deaths and affecting up to 1,000,000 people, leading the government to declare a state of emergency on 30 July [21].

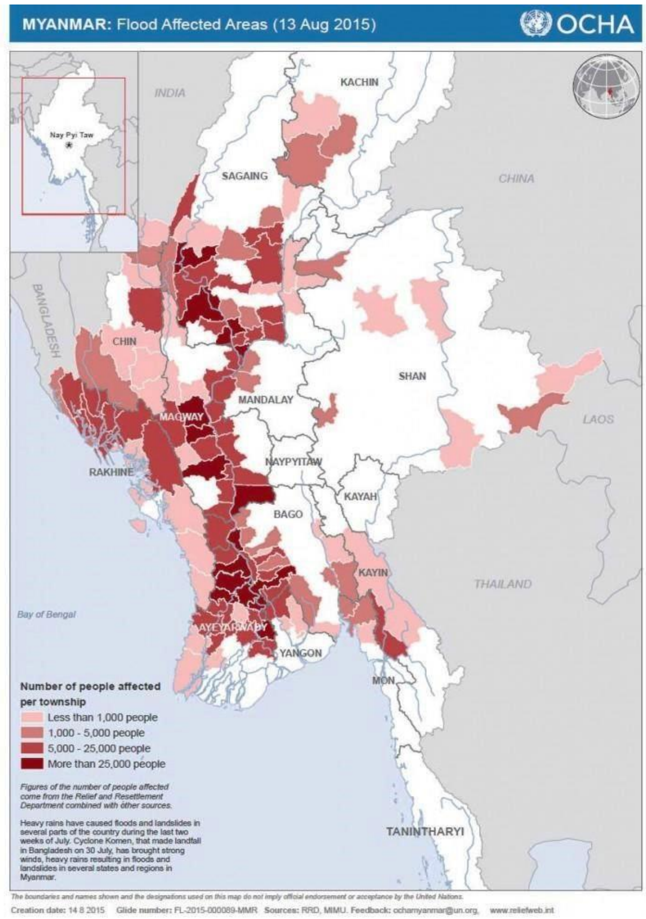

Fig. 1 Myanmar Flood Affected Area, August 2015

According to information from the Government's Relief and Resettlement Department (RRD), by August 2015, over 156,000 people had been affected across Ayeyarwady, Bago, Chin, Kachin, Kayin, Magway, Mandalay, Mon, Rakhine, Sagaing, Shan, and Yangon [22].

Myanmar's Ministry of Agriculture, with the help of the United Nations Office for the Coordination of Humanitarian Affairs (OCHA), presented, as can be observed in Fig. 1, the flood map, from where one can keep the flood-affected areas in the event of 2015. Besides, it was reported that 17 million people live in the most affected areas of Myanmar [21, 22].

Moreover, the United Nations Resident and Humanitarian Coordinator in Myanmar reported all the damages in the study area. It was mentioned that more than 1.29 million acres of farmland had been inundated, damaging 687,200 acres in total [35]. Besides, 15,239 houses were destroyed [21].

In 2016, flooding also affected the same study area; in this case, authorities reported rains since June, affecting five states and regions of Myanmar. According to the initial reports from the Government Relief and Resettlement Department, the magnitude of the rainfall was extreme, registering 88 mm in 24 hours, and at least 26,000 people were affected [24]. OCHA reported that heavy monsoon flooding through June, July and August temporarily displaced roughly half a million people in 11 states and regions in the country [25]. The flooding also damaged schools, fish farms, agricultural land, roads, bridges and communal buildings.

According to Myanmar's Relief and Resettlement Department and Ministry of Social Welfare, 11 states or regions across the country were impacted: Kachin, Kayin, Ayeyarwady, Bago, Magway, Mandalay, Mon, Chin, Sagaing, Shan and Yangon, affecting around 477,360 people. [26].

RRD reported that the affected regions are: Mandalay, Mon, Ayeyarwady, Bago, Chin, Magway, Kayin, Kachin, Sagaing, Shan, and Yangon. The worst-hit regions are five, considering the number of affected people [25]:

Fig. 2 Myanmar Flood Affected Area, July 2016

Table 1. People Affected in Myanmar's Flood 2016

No.	Region	People Affected
1	Ayeyarwady	74,989
2	Bago	53,357
3	Mandalay	107,200
4	Magway	204,365
5	Sagaing	27,996
	Total:	467,907

As can be observed in Table 1, 467,907 people were affected due to the heavy rain from June to august of 2016, with almost half a million people affected for the second consecutive year.

As shown in Fig. 2, the affected townships and the worst-hit areas are along the overflowing Chindwin and Ayeyarwady rivers [26].

2.2. Datasets

For this project, one will use the Sentinel 1 datasets. Sentinel 1 is a space mission consisting of a constellation of two satellites carried out by the ESA (European Space Agency) and funded by the European Union within the Copernicus Programme [27]. Sentinel 1A was launched on 3 April 2014, and Sentinel 1B on 25 April 2016 in a Soyuz rocket from the launcher site Kourou, French Guyana.

However, Sentinel 1B reached the end of its useful life this year, 2022 [29,36]. For this reason, only Sentinel 1A was used for the present study. The payload of Sentinel 1 is a Synthetic Aperture Radar (SAR) which operates in the C band at a centre frequency of 5.405 GHz.

Sentinel 1 provides continuous imagery during the day and night, regardless of conditions [27], which is an essential characteristic for emergency response during extreme weather conditions and is beneficial for monitoring areas prone to long periods of darkness or cloud coverage.

Sentinel 1 has different operational modes [30]:

- Interferometric wide-swath mode (IW) at 250 km and 5×20 m resolution.
- Wave-mode (WV) images of 20×20 km and 5×5 m resolution (at 100 km intervals).
- Strip map mode (SM) at 80 km swath and 5×5 m resolution.
- Extra wide-swath mode (EW) of 400 km and 20×40 m resolution.

The following datasets will be used to perform the analysis:

Table 2. Selected Datasets

Date	Dataset
18/07/2015	S1A_IW_GRDH_1SSV_20150718T114605_20150718T114630_006865_00942A_1309
05/08/2016	S1A_IW_GRDH_1SSV_20160805T114607_20160805T114632_012465_0137A7_ACBC

Both selected datasets were acquired in Interferometric Wide swath (IW). The product type was GRD. The image was acquired in vertical-vertical (VV) polarization configuration.

2.3. Image Processing

The following methodology was followed to identify the flooded areas:

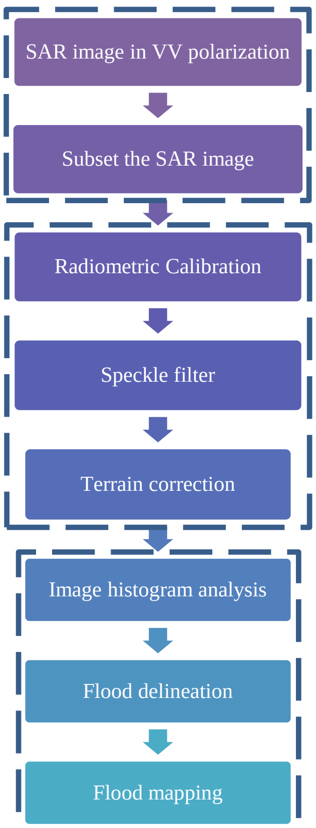

Fig. 3 Proposed methodology

The methodology presented in Fig. 3 was developed in ESA's Sentinel Application Platform (SNAP); this Platform is used to exploit Sentinel data, mainly using toolboxes and functionalities developed by the scientific community [31]. SNAP supports different formats such as GeoTIFF, GeoTIFF-BigGeoTEF, JPG and the BEAM-DIMAP (SNAP Standard format).

2.3.1. Radiometric Calibration

The raw SAR image was read in SNAP. Subsetting the image to reduce the processing time on the computer was essential. Afterwards, a radiometric calibration was developed; this step was necessary to create a quantitative interpretation since the pixel values are directly related to the radar backscatter of the scene.

2.3.2. Speckle Filter

In the next step, a speckle filter was applied, the Gamma Map Filter [32] used, where a window with the size of 5x5 was moving across the image to smooth the image and reduce the number of speckles.

2.3.3. Terrain Correction

Moreover, a terrain correction step was developed, and the SRTM 3secc, auto-downloaded by SNAP, was used as a Digital Elevation Model (DEM). The method used for the DEM and image resampling was bilinear interpolation. The pixel spacing was set at 10 meters, and the map projection used was “WGS84 (DD)”. This terrain correction step was performed to compensate for the topographical variation and the satellite sensor tilting to improve the SAR scene's geometric representation.

2.3.4. Image Histogram Analysis

The image histogram analysis was developed for both years. Examining the histogram is necessary to define the water and land differentiation threshold.

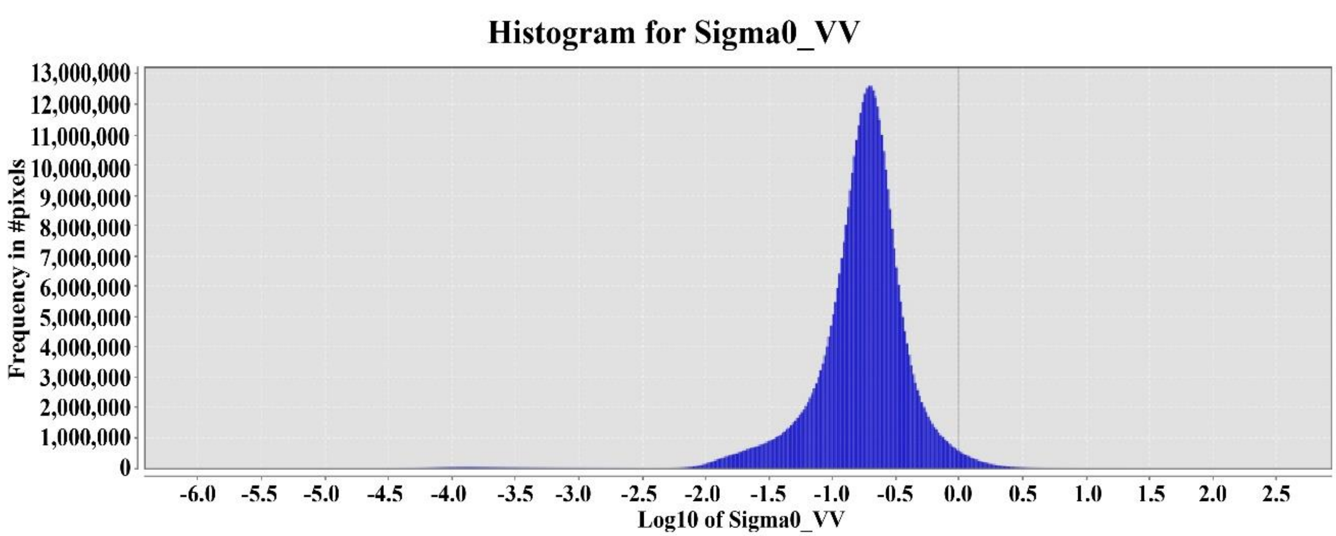

Fig. 4 Histogram of SAR dataset of 2015

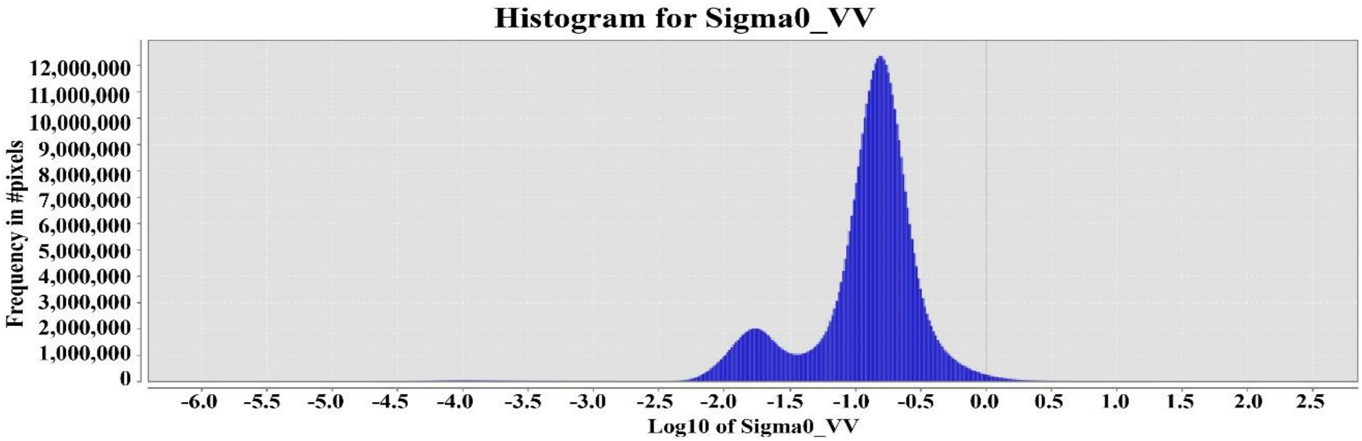

Fig. 5 Histogram of SAR dataset of 2016

In Fig. 4, a unimodal histogram is observed with a central peak at -0.67. However, in Fig. 5, a bimodal histogram is shown, where two peaks are defined, the first represents the water content and has a central value of -1.89; the second represents the terrain and has a central value of -0.77.

Where:

v_{min} = The minimum value of the histogram valley

T = Threshold to differentiate water from land

The following threshold is obtained by applying the equation with the histogram data of the SAR image of the study area for 2015:

$$T_{2015} = 10^{-1.18}$$

$$T_{2015} = 0.066$$

Applying the equation with the histogram data of the SAR image of the study area for 2016, the following threshold is obtained:

$$T_{2016} = 10^{-1.3}$$

$$T_{2016} = 0.05$$

Both threshold values were determined at 0.066 and 0.05 for 2015 and 2016, respectively. Afterwards, the delineation of the flood in the study area is carried out, and finally, the results are mapped.

3. Results

The flood delineation with the previously defined threshold is given as follows:

As observed in Fig 6. flooded areas in Myanmar are red-colored. Fig. 6 (A) shows the SAR image's flood delineation results obtained for 2015. It can be determined that this year's flood event was not as severe as seen in the SAR image processed in 2016, as shown in Fig. 6 (B). This result could be because this dataset was from July 2015, when the flood event of that year was still beginning. Furthermore, analyzing the dimension and extent of the area damaged in the flood event of 2016 could be because the dataset processed was from August 2016, when the flood event was in the peak of rain. As observed in both images, it is possible to identify areas that used to be dry-looking wet due to heavy rains that occurred on those dates, especially in 2016.

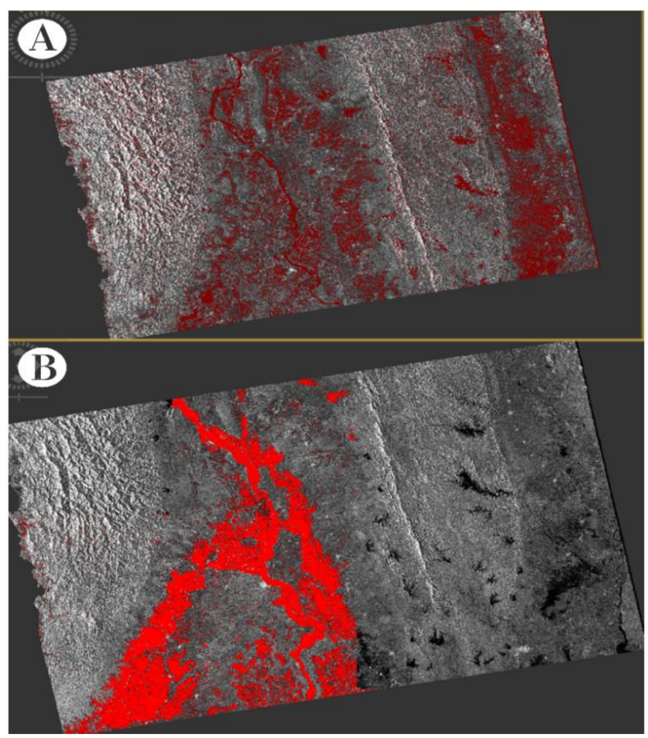

Fig. 6 A) Flood delineation of 2015, B) Flood delineation of 2016

Besides, in Fig. 7 it can be observed the flood mapping results of 2015:

The flood delineation map is observed in Fig. 7, where the flooded areas are red-colored. Analyzing this map shows that the central regions affected at that date in the study area were Ayeyarwady and Bago. Also, it has been calculated that a total area of 1,924 Km2 was affected by the flood in July 2015.

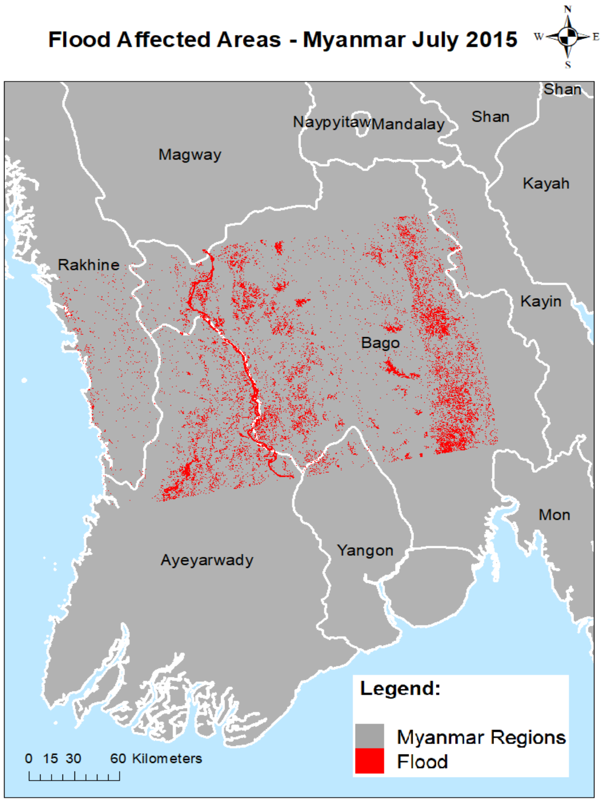

Fig. 7 Flood Affected Areas – Myanmar July 2015

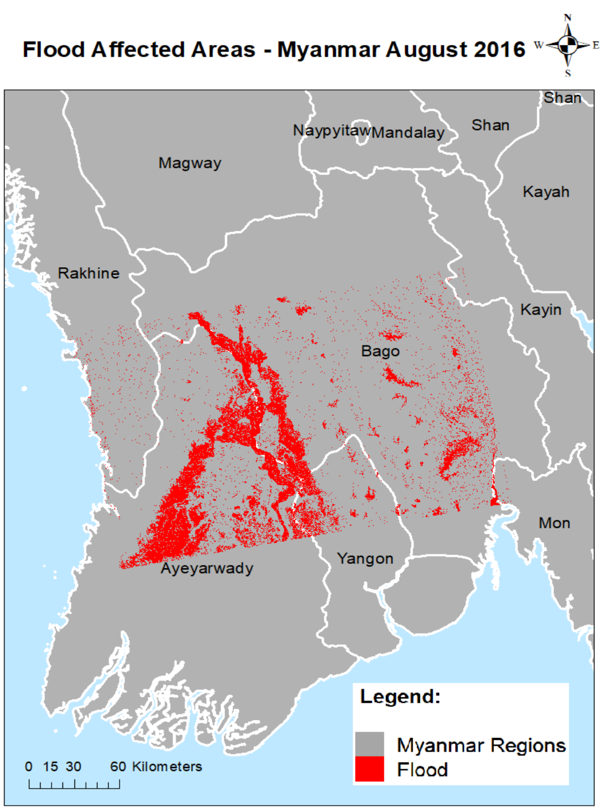

Fig. 8 Flood Affected Areas – Myanmar August 2016

Fig. 8 shows the flood mapping results of 2016:

Moreover, in Fig. 8, it can be determined that the main regions affected at that date in the study area were three: Ayeyarwady, Bago and Yangon. Besides, it has been calculated that a total area of 3,248 Km2 was affected by the flood in August 2016.

4. Conclusion

The technological advance of the Sentinel 1 Satellite and SNAP Platform has been observed, allowing us to use image processing techniques to process SAR images to collect many different types of information, in this case, the flood affectation of Myanmar in 2015 and 2016.

SAR datasets were used to identify and map two consecutive flood events in Myanmar. The threshold method was used to determine the flooded areas; the threshold values of 0.066 and 0.05 were calculated in 2015 and 2016, respectively.

The case of this flood was chosen because it is a two-year consecutive and progressive flood over Myanmar. Unfortunately, in July 2015, this country was also affected by Cyclone Komen, which contributed to the subsequent impact of the analyzed flood events.

After developing the proposed image analysis, it was possible to determine that a total area of 1,924 Km2 was affected by the flood in July 2015, representing 2.58% of the total area of the two regions affected.

Moreover, the flood affected a total area of 3,248 Km2 in August 2016, representing 4.32% of the total area of the three regions affected.

These processing tools and methods are essential for developing countries lacking natural disaster management state departments.

However, universities or research laboratories can use these free tools, such as the SNAP platform, and could obtain SAR images from the Copernicus program that are equally available for users.

These described elements could be used to develop flood mapping for the general public and local and national decision-makers.

Since this information obtained helps make fast decisions, for example, which area is more affected and which regions need immediate help.

Conflict of Interest:

The authors declare that they have no conflict of interest.

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