The role of remote sensing in flood mapping

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Abstract

Floods frequently occur around the world, causing a great impact on life and economies at large. Mitigation and response mechanisms in flood-prone areas are in high demand due to the disasterously impactful and unexpected character floods hold. Attempts have been made in recent years to warn decision-makers to develop mechanisms that provide a good overview for mitigation, planning, response and recovery for areas at risk. Flood disaster management literature is observable that use earth observation techniques to understand risk and aftermath damages of flood occurrence. Considering the magnitude of impact floods can impose on areas, this review discusses applications of remote sensing used in flood observation and delineation, damage assessment and vulnerability. Different stakeholders involved in monitoring, evaluation and management of flood disasters include meteorological authorities, disaster management parties, as well as relief organisations. This essay provides an in-depth description of satellite, data and classification methodologies applied in flood mapping. It highlights the cartographic products derived from critical studies, as well as accuracy assessments executed in order to validate results. In conclusion, a critical analysis was conducted to develop a dialogue between selected studies discussed in this essay.

Keywords: floods, remote sensing, mapping, spatial analysis

1 Introduction

As the world faces some of the most overwhelming climate change facets, flood phenomena continue to increase with the measure of impact varying from one scenario to another (Alahacoon et al., 2018). Today, several settlements and communities living on coastland and inland have found themselves underwater (Islam et al., 2000; Klemas, 2015), with most of the standing elements of the environment washed away, making floods one of the most severe natural disasters (Sanyal et al., 2003). It has been said that global warming has been the cause of the continuous increase in sea level and extreme weather conditions like storm surge and heavy or prolonged rainfall. These, together with surface-altering human activities and increased urbanization in flood plain regions, have triggered a higher occurrence of floods, though most flooding hazards have been linked to climate change (Centre for Research on the Epidemiology of Disasters, 2019). There are three common types of floods: surge, fluvial and flash flooding. Surge floods can occur in coastal areas of the sea or ocean or by storms, which are triggered by strong winds from hurricanes that push water onshore. The second type of flood is fluvial, or river line flooding, usually caused by heavy-prolonged rainfall that considerably raises the river level and allows for shore cross. The third type is the flash flooding, which is caused by sudden heavy rainfall and failure of the ground to absorb the water quickly.

Southern-Asian countries, central European countries and north-eastern states of the USA have experienced significant socio-economic impacts as a result of natural flood disasters. The International Disaster Database reveals that floods are the most frequent and impacting hazards both to human and natural phenomena. Many studies have been conducted to understand the behaviour of floods. Environmental scientists and geographic information experts have also put attention on understanding rivers and oceans, as well as their inundation. This has built the knowledge capacity to model flood behaviour, while developing technologies to exploit available earth observation measurements and ancillary data (Guy et al., 2019). The field of remote sensing represents an essential source of observations and information, facilitating research and disaster management procedures related to flood phenomena and other natural hazards.

Remote sensing has played an essential role in understanding and analyzing flood events, providing a variety of ways to record flood occurrences, even in remote areas and developing countries (Domeneghetti et al., 2019). Imagery measured by earth observation satellites provide broad, detailed and multi-temporal coverage of affected areas. Currently, some earth observation satellites facilitate real-time data for flood events, which allows for more efficient means of acquisition, processing, analysis and visualization (Domeneghetti et al., 2019). This has aided decision-makers in their effort to plan and coordinate emergency relief and response activities. The integration of Geographical Information Systems (GIS) and remote sensing technologies have provided structural solutions to developing flood management programs that include models for flood prediction and vulnerability. GIS is a software tool utilized to manipulate remotely sensed data in order to undertake acceptable flood hazard and risk mapping, damage assessment, modelling and forecasting. This essay reviews a selection of papers on remote sensing methodologies and processes providing solutions to challenges faced with handling flood occurrences and mapping.

2 Materials and methodology

Flood maps are usually created depending on the estimated depth of inundation. This estimation is created from various hydrological and remotely sensed data. Satellite data required for flooding depends on the phase of the disaster, type of disaster and the extent or severity of the disaster, which also translates to the scale of the assessment or level of detail required. Most times during flooding, especially those caused by rainstorms, cloud cover is pronounced, causing satellite imagery to capture such a phenomenon that affects the level of investigation, analysis, and response that can be carried out in such location.

2.1 Optical remote sensing

The first use of remote sensing to study flood-prone areas was with the Landsat Multispectral Scanner (MSS), a high-resolution image (80m). The Landsat MSS was utilized to investigate areas susceptible to flood in the US. Landsat MSS data were used to deal with the flood-affected areas in Iowa (Hallberg et al., 1973), Arizona (Morrison et al., 1973), and Mississippi River basin (Deutsch et al., 1973). This assessment was achieved by using band 7 (0.8 – 1.1µm) of the Landsat MSS, which was able to distinguish between water and moisture from dry surfaces. It was used majorly for the reason of obtaining location-specific information of the states in the US that were susceptible to flooding.

During the 1980s, the Landsat Thematic Mapper (TM) characterized as a multispectral scanning radiometer that was on board Landsats 4 and 5 and with 30m resolution was launched. The TM was also able to distinguish between the bare soil and water using NIR (band 4), but a specific limitation also arose which was that the Landsat TM could not distinguish between water and elements of asphalt which was used for infrastructure as they both appeared black (displayed similar spectral signature).how to determine the distinction between the inundated areas and moist areas. In order to solve this challenge, Wang et al. (2002) incorporated the use of Landsat TM band 7 (2.08 - 2.35 micrometers) to build a better means to distinguish and extract the inundated areas.

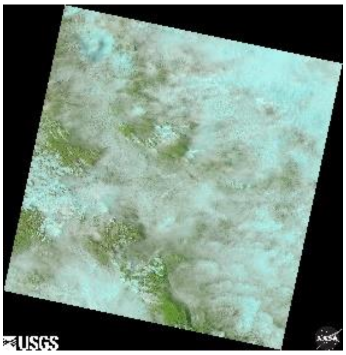

Figure 1. Clouded Landsat 8 image of Flooded Kogi State in Nigeria for 14th September 2017.

Another satellite SPOT has been used to investigate flood delineation. SPOT imageries, for example, were used along with a DEM for delineation of monsoon flood in Bangladesh (Brouder, 1994; Sado et al., 1997). Also, cases of regional flooding as occurred, which required near real-time assessment to investigate the flooding occurrence. This is the case in Romania as well as in many other European countries, where prevention and monitoring floods are activities of national interest, taking into account the frequency of occurrence and the degree of the effects. In the case of Romania, Irimescu, Craciunescu, Stancalie, & Nertan (2010), describes the methodology used to map the flood extent using MODIS (medium spatial resolution) data during the Danube flood in 2006 and to estimate the affected land cover/ land use categories, in near-real-time for decision-makers. MODIS TERRA and AQUA provides temporal resolution (daily coverage), spectral resolution (36 bands, for visible and infrared spectrum), the radiometric resolution of 12 bits. To improve the spatial resolution, SPOT 4 (20m in multispectral) and FORMOSAT 2 (8 m in multispectral) were used for hi-precision flood mapping and validation of water mask extracted from MODIS data. Also, coarse-resolution satellite data such as Advanced Very High-Resolution Radiometer (AVHRR), which is used for meteorological purposes, have been found useful for floods. Although the AVHRR imageries are majorly affected by cloud cover, its advantage other satellites are its very high temporal resolution, which allows for real-time flood assessment. AVHRR utilizes near-infrared band more effectively to detect undulated areas in Normalized Difference Vegetation Index (NDVI) since water has a unique spectral signature in near infra region. With the launching of the very high-resolution satellite, imageries such as IKONOS and SPOT 5 can also be used for location-specific flood management information. The limitation of this is that there is a very limited swath, and it is associated with a high price.

2.2 Microwave remote sensing

Optical imagery is usually of less or no use during flood disaster response in near real-time. In mitigating this challenge, microwave radiation can be utilized, particularly radar imageries. Microwave represents the EM spectrum, which ranges from 1mm to 1m. This wavelength, unlike the optical used for flooding, is beyond what humans can sense. The microwave is composed of several nine bands, which range from P band to Ka-band. The wavelength increases from Ka to P, with a decrease in frequency. For the microwave, remote sensing (MRS) can be classified into passive and active remote sensing. The passive MRS is directly independent of the sun. It refers to a method of sensing naturally emitted energy from the earth's surface captured in the microwave region. This emitted energy is usually related to the temperature and moisture property of the surface of interest. They are referred to as radiometers.

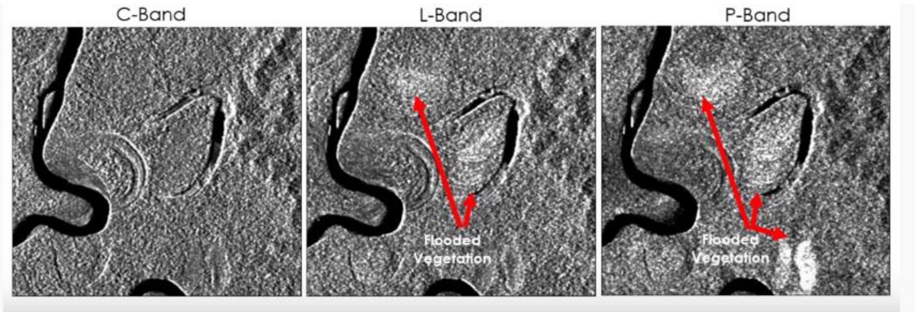

Figure 2. Description of the signal penetration for delineating flooded and non-flooded areas using multifrequency C-Band, L-Band, and P-Band obtained from ELSAR for Peru 1993.

Active MRS has the same function as the passive MRS except for the fact that it generates its energy and transmits its electromagnetic energy. The most widely known imaging active microwave remote sensor (AMRS) is RAdio Detection And Ranging (RADAR). The Radar imageries have the advantage of penetrating cloud cover and distinguish between land and water to a higher degree. The most utilized radar imagery is the Synthetic aperture radar (SAR). SAR, because of its comparative advantage, is used for meteorological phenomena such as a flood. It represents this data based on the backscatter received, i.e., the amount of backscatter emission, which is dependent on the emissivity of the undulated and non-undulated surfaces. The emissivity is a comparison of the emission based on the blackbody material. Hence, the emissivity for all surfaces is between 0 and 1. SAR captures the backscatter data as decibel (dB), which are functions of the angle of incidence of the sensor and the digital number. The threshold values of the backscatter are dependent on the processes utilized for the study area and the overall spectral signature of the features or surfaces. The SAR imagery is dependent on the interaction of the signal wavelength with the surfaces or feature, the surface variations (roughness or topography of the surface), electrical characteristics (dielectric constant of the surface, moisture content, and conductivity) and the radar frequency (incident and incoming polarization pattern).

Just as SAR depends on various parameters, these parameters also tend to cause several difficulties in flood delineation based on the nature of the study area. Specular scattering occurs when a smooth surface such as a calm water surface and the signal scatters away from the satellite, hence open water appears appearing as dark in the image. For a rough surface, the signal scatters in different direction but mostly away from the satellite, an example of this is, is a water surface that has some level of roughness caused by either short floating vegetation, wind and heavy rain hence it will appear dark but not as dark as a water surface completely smooth. For instance, in the case of forest cover obstruction (Kundus et al., 2001) proposes that identifying the inundated areas under forest cover lies in the fact that flooded forests produce a bright radar backscatter in contrast to non-flooded forests due to a double bounce effect whereas the flooded areas without a forest canopy will appear dark in SAR imageries as usual. However, depicting flooded areas still requires more understanding of the terrain. Finally, the right combination of the incident angle of the sensor, wavelength, and polarization will help in the determination of flood-affected areas. The ratio of flooded areas to non-flooded areas is higher in horizontal polarization than in vertical polarization, if the wavelength and incidence angle are the same. Furthermore, if the polarization parameters and wavelength are constant, the ratio of flooded areas to non-flooded is more significant at a smaller incident angle than at a larger incident angle (Wang et al., 1995).

Table 1. Wavelength and SAR Signal Response over Flooded Vegetation (*wavelengths most frequently used in SAR are in parenthesis).

Band Designation*	Wavelength (λ), (cm)	Frequency (v) GHz (10^9 cycles.sec^{-1})
Ka (0.86cm)	0.8 – 1.1	40.0 – 26.5
K	1.1 – 1.7	26.5 -18.0
Ku	1.7 – 2.4	18.0 – 12.5
X (3.0cm, 3.2cm)	2.4 – 3.8	12.5 – 8.0
C (6.0)	3.8 – 7.5	8.0 – 4.0
S	7.5 – 15.0	4.0 – 2.0
L (23.5 – 25 cm)	15.0 – 30.0	2.0 – 1.0
P	30.0 – 100.0	1.0 – 0.3

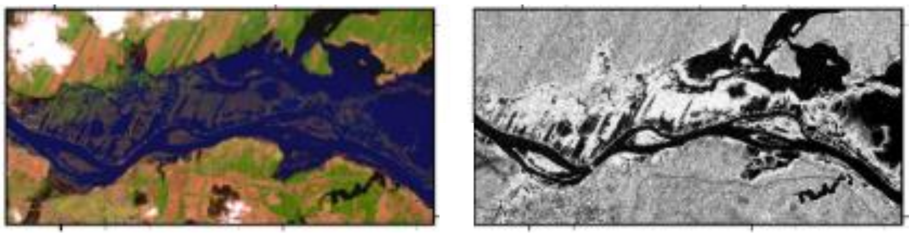

Figure 3. Landsat 5 and RADARSAT 2 of the central portion of the Saint John River floodplain east of Maugerville.

2.3 Classification

The binary model used by Rejesk (1993), is a simple method used to determine flooded areas by decided If raster cell represents water (flooded) or not (land area). Various methods were also utilized, the most common of them was by ranking different locations of an area depending on the intensity of the water in each pixel, in most cases the flood depth is the most important factor used to identify the intensity of the water. Depending on the flood depth, the study area will be classified into different levels of flood risk.

1. Wetness Index (Beven et al., 1979; Moore et al., 1991; Wolock et al., 1995), to calculate the depth of flood.
2. Islam in 2001 used a supervised classification method to identify the depth of flood. This method uses the background of the flooded area to estimate the depth of flood by giving weight for each land use and geology in the study area.

In general, both unsupervised and supervised classification can be used to identify flooded areas (inundated areas). These methods share similar classification processes; the first thing is that the image is classified into different classes, then further subdivisions are usually done to reduce these classes. In the end, the final output is in two categories: water (inundated) and non-water (non-inundated) after the interpretation of the pixel covered by the cloud. The algorithm usually does these classifications in such a way that the images are classified into a flooded area, normal water like existing water bodies such as rivers and lakes in the normal situation and non-water areas. After this process, the analyst uses the landcover, NDVI, and elevation data to compute flood hazard areas.

In Flood hazard assessment in Bangladesh using NOAA AVHRR data with the geographical information system (GIS), Islam and Sado (2000) used the images taken during the flood and dry season, then compared the pixel value in the two images, and finally integrated it with GIS. The pixel that represents water area during the flood but non-water area during the dry season was classified as an inundated area. They utilized the ISO-DATA clustering method, which is an unsupervised classification, as well as Parallelepiped, Maximum likelihood, Mahalanobis distance, and Minimum distance, which are all Supervised classification method. Comparison between these methods allowed for cross-validation and accuracy assessment. The Satellite images were used to create a final thematic map like flood depth and landcover. This was partly achieved by the integration of the result of data with data from GIS databases like the digital physiographic maps, geology maps, digital elevation data, and drainage maps.

Optical Remote Sensing of Flood Extent can also be done by combining different bands. This method was used to map flooded areas around the Mississippi river in 1993 by combining infrared, near-infrared, and green wavelengths of light observed by Thematic Mapper (TM) onboard the Landsat 5 satellite (bands 5, 4, and 2). Wang, Colby, and Mulcahy (2002) developed an approach for flood mapping extent in a coastal floodplain by comparing the reflectance of water with land area and finally using the digital elevation model (DEM) data to detect flooded area beneath the forest canopy.

Other researchers also used other forms of band computation, which are promising and majorly involves the use of raster algebra to separate the image into inundated and non-inundated areas. The single-band method is one of this method, it depends on choosing one band from the multispectral image, and then an appropriate threshold of the index will be applied on the image to classify the image into two classes - flooded area and non-flooded area.

Also, a multi-band method exists, which primarily focuses on the band-ratio approach. In 1996, Gao used the Normalized Difference Water Index (NDWI) to extract information about vegetation liquid. Then McFeeters (1996) used the NDWI to extract information about water body from satellite images, and he used the green band and near-infrared band to extract the information as follows:

$$NDWI = \frac{(\text{Green} - \text{MNIR})}{(\text{Green} + \text{MNIR})} \quad (1)$$

As a result of this formula, the water body will have a positive value, soil and vegetation will have zero or negative values, and that is because their reflectance of NIR is high. In 2006, another method represented by Hanqiu Xu, he used Modified Normalized Difference Water Index (MNDWI), this method was used because of built-up areas have the same reflectance pattern as the green and NIR band. Hence, using MNDWI reduces the noise coming from the land and buildings as it can distinguish to a great extent, the spectral reflectance of floods and built-up areas better (Klemas, 2015). MNDWI used Middle Infrared Band (MIR) instead of NIR band as shown in equation 1, and this will guarantee that the water features will have a high positive value, land-up, building, vegetation and soil will have zero or negative values, the formula of MNDWI represented as following:

$$MNDWI = \frac{(\text{Green} - \text{NIR})}{(\text{Green} + \text{NIR})} \quad (2)$$

Active microwave remote sensing (ARMS) for Flood mapping is better than using optical images to detect flooded area because radar (microwave) are not affected by the sun and the clouds or other atmospheric obstacles. The most utilized AMRS is Synthetic Aperture Radar (SAR). Different techniques can be used for flood mapping using radar data such as the threshold for the backscatter, and depending on this threshold, the study area can be divided into water area (flooded) and land surfaces (non-flooded). This is usually done by segmentation technique-by setting an optimal threshold to classify the image into two classes flooded area and no flooded area. The threshold determines base on a frequency histogram of the areas corresponding to dark grey tones in the SAR image and too flooded areas in the aerial photographs. It is one of the most frequently used techniques in AMRS to segregate flooded areas from non-flooded areas in a radar image (Liu et al., 1999; Townsend et al., 1998). Commonly, a threshold value of radar backscatter is set in decibel (dB), and a binary algorithm is followed to determine whether a given raster cell is 'flooded' or not. Radar backscatter is computed as a function of the incidence angle of the sensor and the digital number (DN) (Chen et al., 1999). The threshold values are determined by several processes depending on the study area and the overall spectral signature of the imagery.

Another widely used technique applied to SAR images is the coherence mapping algorithm depending on the backscatter intensity. The coherence over water pixel (flooded area) with the surrounded area (non-flooded area) is used to classify the image, i.e. the value of the coherence or correlation of radar backscatters from before and after flood imagery is determined and used to assign flooded or non-flooded.

Another approach used for mapping flood accurately is by creating the 'least accumulative cost–distance' matrix, which represents the distance that water must spend to get to an area (pixel) from the mainstream of the river. Flooded cells from the SAR image will be used to act as the border limits of the inundation event, and a combination with a continuous surface (raster) for the area represents the cost-distance matrix will give us flooded area. Random forest algorithm classification can also be used in radar image to detect flooded areas depending on backscatter intensity from the features, it is a supervised method, and requires the excellent knowledge of the study area to train it before applying it.

3 Accuracy assessment

Flood maps assist various disaster response and recovery efforts. However, some maps have been produced without undergoing any validation process or stating timelines of use (Guy et al., 2019). Accuracy assessment should an essential procedure in flood mapping in that it provides accountability that the flood maps being produced have accurate information for decision makers in disaster management.

In addition to densified urban areas, rugged terrain and low spatial resolutions, significant challenges in mapping flood extents are due to cloud coveror cloud shadow (in case of optical), and flooded vegetation or wind roughening of water surfaces (in case of radar). This has caused significant variation in classification accuracies of satellite flood maps mingled with challenges of mixed pixels. Attempts to cross-validate accuracies with ground truth data have yielded 90% accuracies (Guy et al., 2019). High accuracy with flood innundation maps can be achieved through using a high-resolution image, high-accuracy terrain data and high-quality hydraulic boundary conditions. But, these are expensive to acquire quickly in the event of a flood. Currently, finnundation mapping calibration in various studies is usually done by using field data during flood events. This somewhat improved accuracies of maps and models as well. Calibration aims at delivering accurate map outputs for flood affected areas.

Dr. Jagath Rajapaksa, in his study “Field Data Collection Program for Accuracy Assessment of Flood Mapping of Microwave Remote Sensing,” underwent an accuracy assessment of flood maps generated with SAR (Synthetic Aperture Radar) as an initiative to facilitate post-flood disaster activities and response planning. Accuracy assessment of flood mapping has been greatly assisted by conducting field data collection in order to assess accuracy of the satellite data being analyzed. However, water detection algorithms have been frustrated by different land cover and land use types making the accuracy of flood mapping a challenge. Thus, an assessment of results from a classification algorithm can be done, while comparing mapped classes in a given minimum mapping unit (MMU) with referenced sampled data classification in the spatial unit of analysis. Usually, samples are randomly selected from flood-affected areas; this is done by either going to the field for ground-truthing or using visual interpretation from aerial orthophotos (Malinowski et al., 2015). As a result, overall accuracy (OA) of flood classes and allocation disagreement of classes are calculated as accurate measures of the generated maps. Overall accuracy refers to the ratio of rightly classified samples from all classes to overall number of classes. Allocation disagreement expresses the amount of misplaced categories from the classified map relative to the spatial allocation in the reference dataset.

3.1 Cartographic products

Various stakeholders use flood maps. The map serves three functions; (i) prevent the build-up of new risks (planning and construction), (ii) reduce existing risks, and (iii) adapt to changing risk factors. Invariably, based on its use, stakeholders usually specify its content, scale, accuracy, or readability of the map. Hence, its applications are innumerable as they can be used in flood risk and disaster strategy, land-use planning and management, emergency planning, public awareness-raising, the private sector, and in particular the insurance sector. According to various literature reviewed, several cartographic products were obtained, such as the flood hazard map, near real-time flood inundation mapping, flood danger and damage assessment map. The hazard zone mapping is the product of analysis of flood over a while to propose areas usually susceptible to flood for planning processes and awareness campaigns (Islam et al., 2000).

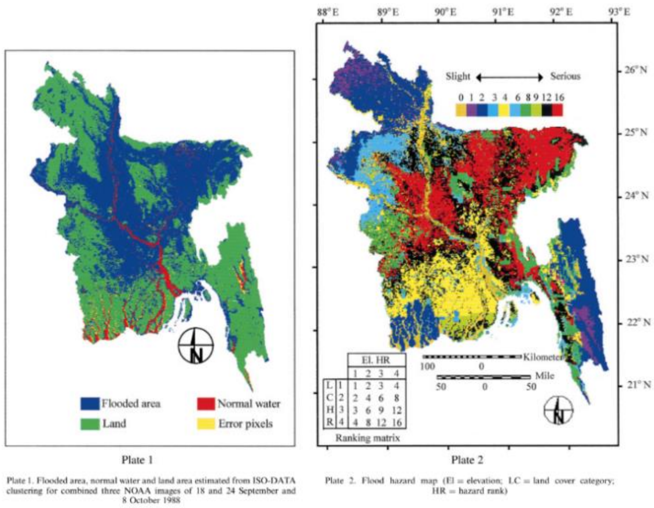

Figure 4. The map to the right represents the flooded area, regular water, and land area estimated from ISO-DATA clustering of Bangladesh for combined three NOAA images of 18 and 24 September and 8 October 1988. The map to the left Flood hazard map (El elevation; LC land cover category; HR hazard rank)

Whenever an area has been flooded in real-time, and the information is required about the inundated areas, the extent of the flood, and the affected and non-affected areas, then the cartographic product is the near real-time flood inundation map (see Figure 5). In achieving this product, the information of the satellite passing overhead the study area are utilized else the interpreter must wait for the incoming satellite. Hence, the reason for near-real-time. It can be modelled for an extended period. The flood damage assessment and danger map combines various flood parameters to form a level (degree) of danger (depth, velocity, debris often combined with recurrence interval). The information can be of qualitative or quantitative. They are usually utilized by emergency responders to determine where to focus rescue efforts, access water level, help determine the extent of the damage, and then identify areas that could potentially be affected by the flood. It is the mapping of damaged land use, agricultural farmland, and structures within the study area.

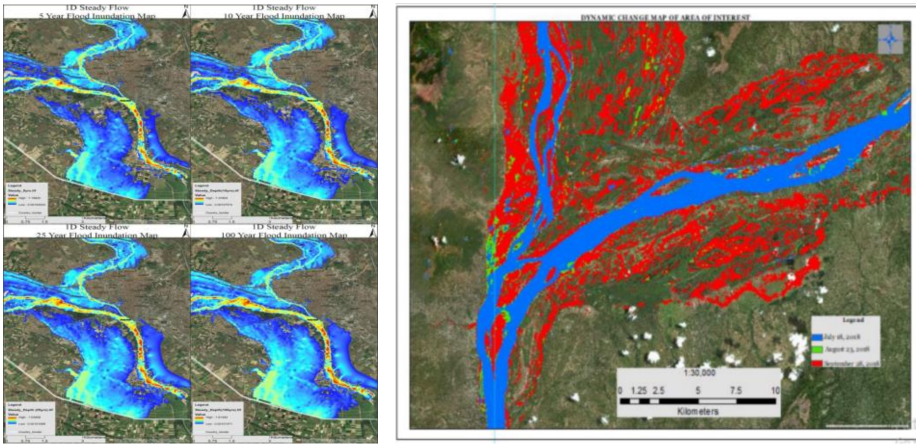

Figure 5. D Steady Flow Inundation Maps of Floods with Different Return Periods Case of Edirne, Turkey [left], and the map of Flooded area of Lokoja, Kogi State from 23rd August to 28th September 2018 overlaid on satellite imagery. The results revealed that about 211 buildings (including shops, supermarkets, hotels, churches, and mosques), three major roads, and 317sqkm of farmlands were adversely affected during the three months, especially September [right].

4 Critical analysis

Flooding remains the most destructive and frequent natural hazard. During Flood events, high precise information is required by decision-makers to improve response activities. This information is needed in real-time so that they can manage the resources they have to manage the population. In this context, satellite earth observatory can play a crucial role in other to provide the information. Radar and optical remote sensing systems, whether through aircraft or satellite, are used for the observation and delineation of floods, damage assessment and to provide information for models that allow researchers to understand an area's flood vulnerability (Klemas, 2015). For assessing floods, various literature states that many researchers prefer using multidate radar imagery in addition to image processing techniques to overcome any remotely sensed data limitations (Sanyal et al., 2004). For many flood studies, multi-temporal data is used; however, researchers agree that a challenge with multi-temporal data is that it does not always capture peak flood, especially for visual interpretation cases. Typically, floodwaters have already receded by the time satellites capture an image (Brivio et al., 2002; Sanyal et al., 2004).

In a study, researchers attempted to delineate floodwaters using synthetic aperture radar (SAR) with a statistical active contour model, a method used for segmentation. When comparing the accuracy of radar versus optical, they found that 75 percent of the SAR segmentation fell within 20m of the shoreline traced using aerial photography. The researchers also reported that SAR misclassified water and some forms of vegetation (Horritt et al., 2001). Although using optical remote sensing systems can produce more accurate results in ideal atmospheric conditions, Klemas argues that nonideal conditions are usually present, thus using different types of sensors and methodologies can be required. A reason SAR is a preferred method for flood observation is due to its effectiveness in penetrating cloud cover. However, SAR has its limitations when used alone (Horritt et al., 2001; Klemas, 2015). Another study used SAR alongside ancillary data, then validated their results with a study on a 1994 flood in northern Italy, which produced 96 percent accuracy (Brivio et al., 2002). Other researchers also mention flood delineation and observation with SAR can be improved with the use of airborne LiDAR to record water depth, high-resolution visible/infrared for visual interpretation, near-infrared to classify water and vegetation, as well as field measurements (Brivio et al., 2002; Klemas, 2015; Horritt et al., 2001).

Many authors believe that by mapping flood hazards, communities will be able to prepare and plan for disaster and prevent damage (Islam et al., 2000; Klemas, 2015). Flood damage assessment from remote sensing can be good at both medium resolution (20 – 250 m) and high resolution (0.5 – 0.4 m) depending on the use (Klemas, 2015). Other studies support this by mentioning their use of medium-resolution data from meteorological satellites or high-resolution radar satellites (Islam et al., 2000; Klemas, 2015; Sanyal et al., 2004). Flood vulnerability prediction systems help mitigate flood-induced hazards by allowing communities to plan flood defenses. Also, spatial mapping extent of flooding through remote sensors can help calibrate and evaluate hydrologic models, helping prediction and flood management strategies as well (Klemas, 2015). Another study argues that higher safety can derive from planning flood defenses based on the flood hazard map that can be created using flood depth. However, the study suggests for a complete assessment, flood frequency, and flood depth should both be used to estimate risk zones (Islam et al., 2000).

Many variables can influence flood hazard of a particular area, including elevation and land cover/land use; however, another study suggests that the essential components for flood hazard assessment are flood frequency and water depth (Islam et al., 2000). The types of data used to assess flood hazards include DEMs, drainage networks, physiographic, geological, and administrative boundaries (Islam et al., 2000). In a 2004 literature review discussing applications of remote sensing in flood management, authors argue that a high dependence is put on utilizing DEMs with high-resolution or else accuracy of results is jeopardized. Two reviews both agree that radar, the data that DEMs derive from, can be very expensive relative to using optical remote sensing systems and image processing techniques (Sanyal et al., 2004; Klemas, 2015). Since flooding damage tends to be more intense in developing nations than in developed, the high budget methods noted in the literature review do not make sense for areas where financial resources are less available. The methodologies are not inclusive to the areas that need inexpensive ways to manage floods. The authors suggest developing a hydro-geomorphic map for tracing previous floods to allow low-budget communities an opportunity to assess flood hazards (Sanyal et al., 2004).

4.1 Advantages and disadvantages

With remote sensing techniques, the required steps for monitoring, mitigating and preventing an emergency are optimum. It can be used to measure and monitor the areal extent of the flooded areas with a very reasonable degree of accuracy (SAR HH polarized signal), to efficiently relay proper information for target rescue efforts and to gain the insight necessary for providing the extent and the estimates of land and infrastructure affected (quantifiably). Using remotely sensed data into a GIS allows for quick computation and assessments of water levels, damage, and areas facing potential flood danger. With SAR, the advantages of remote sensing for flooding has become somewhat limitless as it provides information irrespective of the meteorological conditions during acquisitions, as well as the possibility of acquiring independently of illumination from the sun. Flood maps are usually used by flood forecast agencies, hydropower companies, conservation authorities, city planning, and emergency response departments, and insurance companies (for flood compensation). Satellite observation facilitates the regular monitoring of the extent of floods and mapping of flood risk zones (Brakenridge et al., 2001).

Disadvantages that exists in remote sensing is a result of imagery as well as a natural phenomenon. As discussed earlier, both optical and microwave remote sensing can be used. With optical remote sensing, the challenges are either related to spatial resolution, temporal resolution, cloud cover, or all the above. Also, considering the microwave remote sensing (RADAR) signals are capable of penetrating clouds and other robust features, the analyst often faces difficulties relating to interpreting the amount of RADAR penetration and interpreting specific images. The data processing is somewhat complicated, time-consuming (depending on the speed and power of computers), and involves subjective interpretation, i.e., based on the experience and knowledge of the interpreter. Hence, as a result, a hybrid method is being adopted to facilitate better analysis and presentation.

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