



Assessment of the water inundation area due to the tropical cyclone Bulbul (2019) in the selected districts of West Bengal, India with the application of RS and GIS tools

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Abstract

Flood is one of the most commonly occurring natural disasters affecting lives and properties. One of the major causes of flood in low-lying areas or coastal areas is cyclones. The paper aims to assess the effect of cyclone Bulbul that occurred on 9th November 2019 and water inundation caused in South 24 Parganas, East Medinipur, and North 24 Parganas districts of West Bengal. Sentinel 1 data of 10 m spatial resolution for pre and post-event was used for the study. Remote sensing (RS) and geographic information system (GIS) tools were utilized to process and analyse the SAR data. The output of the study was prepared in the form of an illustrative water inundation map. The analysis result showed that out of the three districts, South 24 Parganas showed the maximum changes in the water inundation after the event. The changes in the water inundated area from pre-event to post-event were 99.922 km² to 149.22 km²; 196.36 km² to 195.93 km² and 497.27 km² to 505.14 km² for South 24 Pargana, East Medinipur, and North 24 Pargana districts, respectively. From the study, it was concluded that RS and GIS applications are convenient, effective, and fast techniques for the assessment of water inundation caused due to natural disasters.

Keywords Flood · Cyclone · Remote sensing · Geographic information system · Inundation

Introduction

India has a large coastline (~7500 km), making the coastal areas along the North Indian Ocean basin more prone to the tropical cyclones consisting of the Bay of Bengal (BoB) and the Arabian Sea (Rahman and Salehin 2013). Approximately 7% of global tropical cyclones originate in the BoB and the Arabian Sea, where most cyclones occur in BoB compared to the Arabian Sea with an approximate 4:1 ratio (Kumar et al. 2020). The effect will be exacerbated in coastal cities due to the dense population, which is highly prone to sea-level rise (Sanyal and Lu 2005; Temmerman et al. 2013). Because of its high-speed winds, contribution to storm surge

flooding, excessive rainfall, and inland flood, the cyclones are capable of massive destruction, which leads to property loss and lives across the adjacent coastal area (Chittibabu et al. 2004; Jha et al. 2011). Shallow bathymetry, flat coastal terrain, low-lying areas, and increasing sea surface temperatures before the onset of monsoon are the key factors contributing to cyclogenesis in BoB (Islam and Peterson 2009; Islam and Dharanirajan 2017).

In the context of West Bengal, in its low-lying coastal areas, people are affected by strong and frequent cyclone events and floods (Samanta 1997; Singh and Kumar 2017). Coastal and rainwater flooding is another threat in the low-lying coastal areas of South Parganas, East Medinipur, and North Parganas districts (Samanta 1997; Dube et al. 2006). The foothills of West Bengal are a component of the vast Eastern Himalayas, renowned for being a flood-prone area due to their geographic position (Dube et al. 2006; Dhara and Paul 2016). The area is also well known for frequent and heavy rainstorms and climate-induced catastrophic events, such as floods due to the unprecedented rains in the Himalayas of Bhutan (Ghosh and Ghosal 2020). Losses (human and animal, human accidents, and death), property destruction

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(crops, agricultural land, and houses), and communications (bridge, roads, and railways) are major after-effects of floods (Kumar et al. 2020). Bulbul cyclone was accompanied by torrential rains and high-velocity winds to the tune of 110–120 km/h gusting up to 130 km/h. The coastal areas of West Bengal such as Digha, Howrah, Hooghly, North and South 24 Parganas, Purba Medinipur witnessed wind over 100 km/h during the storm was tracking West Bengal (Das 2019).

Remote sensing is the best tool to assess the damage caused by natural disasters such as cyclones, floods, hurricanes, earthquakes, etc. Many satellite-borne sensors operate in polar-orbiting satellite or geostationary satellites to observe disasters such as cyclones and hurricanes (Wang and Shuzhu 2020a, b). One such sensor is Synthetic Aperture Radar (SAR) carried in the low earth orbiting satellite, which operates in the microwave region of the electromagnetic spectrum (Limlahapun and Fukui 2017). SAR is an active sensor that captures images with a high spatial resolution (10 m) and can penetrate clouds, making it a vital tool to monitor real-time disasters (Wang et al. 2020a, b). It is known that tropical cyclones are accompanied by torrential rain and thick cloud cover, making real-time monitoring of the situation using optical satellite imaging impossible as they cannot penetrate the cloud. This challenge is met by SAR imagery which captures imagery of inaccessible areas, irrespective of cloud cover, quickly during disasters (Manavalan 2017). Sentinel-1 SAR image was used for the scope of this study which has a high temporal resolution of 12 days (Gao et al. 2017). It operates in C-band with a frequency of 5.404 GHz acquiring dual-polarization data of VV and VH (Rüetschi and Schaepman 2018). The Sentinel-1 temporal backscatter signature was used for mapping of water and land features. The objective of the present study is to identify the inundated areas due to cyclones, so dark tone pixels depicting water features were identified. In the case of water features, low or null values of the VV band appear in a dark tone due to the absence of roughness. In other words, the water features in the absence of waves show a negative backscatter, usually below -20 dB, making its delineation from the land feature very accurate (Conde and Muñoz 2019). The SAR images were processed using freely available Sentinel Application Platform (SNAP 7.0) software developed by the European Space Agency (ESA).

Objectives of the present study

Cyclone Bulbul, which streaked in the Indian state of West Bengal as well as in Bangladesh on 9th November 2019, was a powerful tropical cyclone, causing heavy rainfall and flash floods across the area (Hoque et al. 2020) leading to flooding situations in the South 24 Parganas, East Medinipur,

and North 24 Parganas district of West Bengal. The major objectives of the study were:

- (1) Processing of the satellite data for both pre and post-Bulbul to be used for the water inundation mapping.
- (2) Analysis of the districts for inundation caused due to the cyclone.

Study area

The study area is confined to South 24 Parganas, East Medinipur, and North 24 Parganas districts of West Bengal. Figure 1 shows the map of the study area.

South 24 Parganas is a district in the Indian state of West Bengal, headquartered in Alipore. It is the largest district in West Bengal regarding the land area and the second largest in population. It is India's sixth-most populous district. The district mostly has agricultural land and is the main source of livelihood for the people of the district. The northern part of the district has the urban outskirts of Kolkata, while the southern portion contains the tiny islands divided by river channels created by the Bay of Bengal. The Sundarbans Forest, one of the major mangrove forests in the world, also lies in the southeast part of the district (Bagchi 2017).

The district of East Medinipur is an administrative unit in the state of West Bengal, India. The state of Odisha is on the south-western border; the Bay of Bengal is on the south; the Hooghly River and the South 24 Parganas district on the east; and the Howrah district on the north-east. The district is surrounded by Paschim Medinipur district in the west and the Bay of Bengal in the South. Hooghly River, in the east, acts as the boundary between the South 24 Parganas and East Medinipur (Mondal et al. 2015).

North 24 Parganas is a district in Southern West Bengal, Eastern India. It borders Nadia by the north, Bangladesh (Khulna Division) by the north and east, South 24 Parganas and Kolkata by the south, and Kolkata, Howrah, and Hooghly by the west. Barasat is the headquarters of the North Parganas district. North 24 Parganas is the most populous district in West Bengal and the second most populous district in India. It is the tenth-largest district by area in the state (Dhali et al. 2019).

The extent and details of the districts and the images used in the study are shown in Table 1.

Materials and methodology

At the outset, an intense literature review was done to understand the cyclone Bulbul and its effect. As the in-situ measurements of different parameters during the cyclonic phase are very difficult to conduct, the present study is conducted with the help of remotely sensed satellite data. This work



Fig. 1 Map of the study area showing all the three districts falling in the coastal region of West Bengal

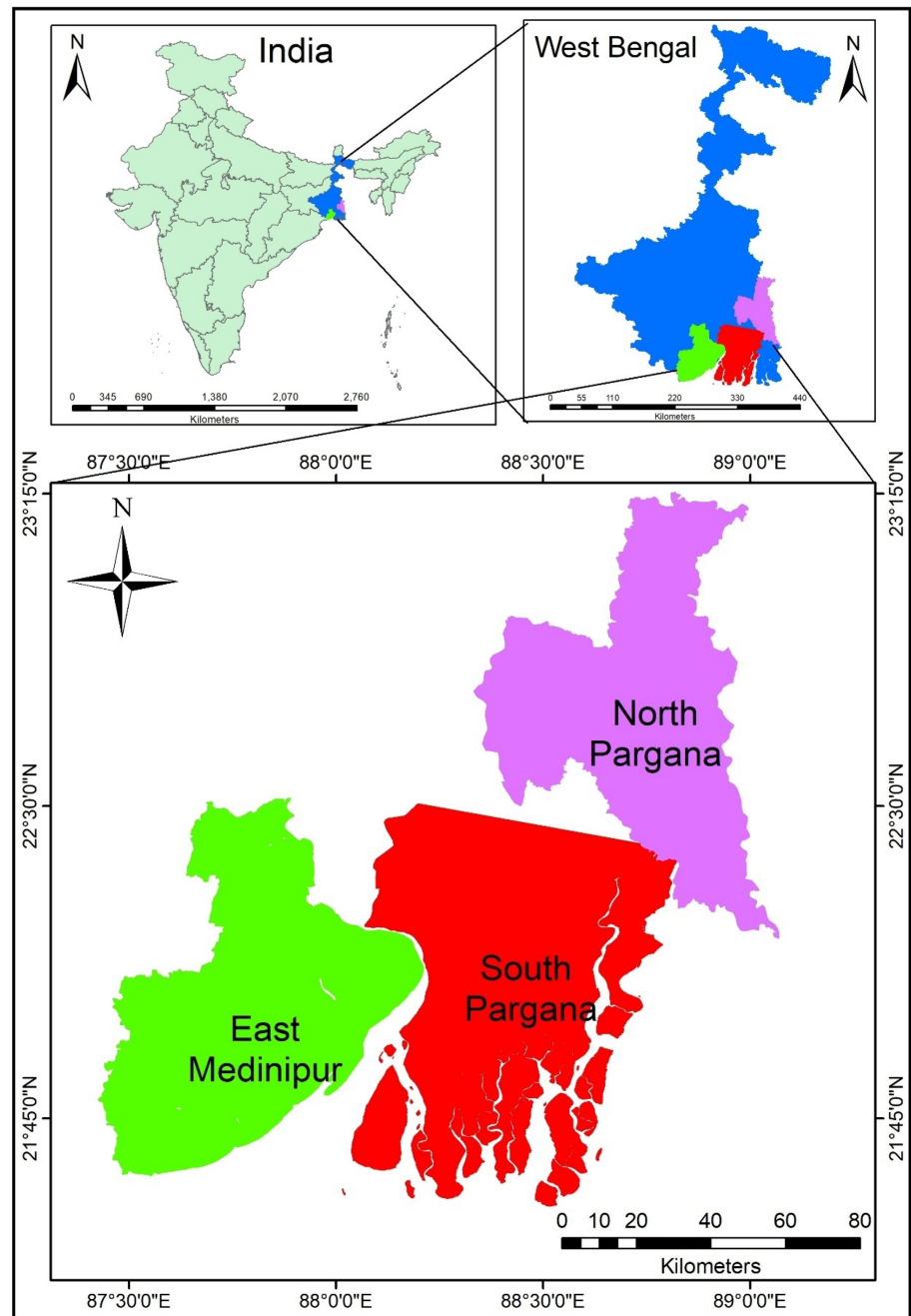


Table 1 Details of the district and Sentinel-1 satellite imagery dataset

District	Lat/long	Area [in sq.km.]	Pre-event dates	Post-event dates	Resolution and polarisation
East Medinipur	21.9373°N, 87.7763°E	4102	31-10-2019	12-11-2019	10 m, VV& VH
North 24 Pargana	22.6168°N, 88.4029°E	3844	28-10-2019	12-11-2019	10 m, VV& VH
South 24 Pargana	22.1352°N, 88.4016°E	5056	31-10-2019	12-11-2019	10 m, VV& VH

was performed with the Sentinel-1 Synthetic Aperture Radar (SAR) Ground Range Detected (GRD) data and has dual-polarization namely VV and VH. The data was collected from Copernicus open access hub (<https://scihub.copernicus.eu/dhus/#/home>). Both the pre-event and the post-event data were downloaded as mentioned in Table 1 for all three districts. As cyclone Bulbul occurred on 9th November 2019, the dates of sensing for the raw data were quite justifiable as it was very close to the pre-event and post-event for after effect analysis.

Satellite data downloaded has some noise and obstruction, which needs to be cleaned or processed before going for the actual mapping of the area (Srivastava et al. 2020). The platform used for the data processing and water inundation mapping was open-access software SNAP 7.0 and ArcGIS 10.7 software. A total of 6 images, for both the pre and the post, raw data were downloaded, and seven-fold processing was done on each image before they could be used for the water inundation mapping (Filipponi 2019). The steps for the pre-processing of SAR data are as follows:

1. Sub-setting of the large raw data: As the satellite data downloaded covers a very large area, sub-setting the data to confine into the study is very important. It was done in the SNAP platform using the subset tool. The values of the geographic coordinates of the study area were used to create a subset of the whole image. Also, sub-setting the data helps reduce the processing time. In the SNAP platform, sub-setting is performed under the Raster operation.
2. Apply orbital filter: Defines the relationship between ground and image coordinates, improves the accuracy of later orbit-based calibration steps. In the SNAP platform, orbital filter is done under the Radar operation.
3. Thermal noise reduction: Reduces the noise induced by the thermal parameters. Additive thermal noise distorts the image intensity of Sentinel-1, especially in the cross-polarization channel (Park et al., 2017). Thermal noise reduction decreases noise effects in the inter-sub-swath texture by normalising the backscatter signal throughout the whole Sentinel-1 scene, resulting in fewer discontinuities between sub-swaths for scenes acquired in multi-swath acquisition modes (Filipponi 2019). Thermal noise reduction is performed in the SNAP platform under Radar operation followed by Radiometric and Thermal Noise Removal.
4. Calibration: Converts the image pixel values from digital number (DN) to a standard geophysical measurement unit of radar backscatter. The calibration reverses the scaling factor used during level-1 product generation and adds a constant offset and a range-dependent gain, as well as the absolute calibration constant (Filipponi 2019). Like Thermal Noise Removal, Calibration is performed in SNAP platformed under Radar operation followed by Radiometric and Calibration.
5. Speckle filtering: Speckle, which appears as granular noise in SAR images, is caused by the interference of waves reflected from many elementary scatterers (Lee et al. 1994). Speckle filtering is a technique for decreasing speckle and thereby improving image quality. The SNAP programme incorporates numerous filters, all of which are statistical, to mitigate this issue (Conde and Muñoz 2019). Radar operation from the tool section is selected to perform this operation in the SNAP platform, and Speckle Filtering is selected, followed by Speckle-Filter.
6. Terrain Correction uses a DEM to remove geometry-dependent radiometric distortions; normalizes measured backscatter concerning terrain slope. Geocoding uses a DEM to remove geometric distortions such as foreshortening, layover, and shadow; it connects the image to a geographic coordinate system. In the SNAP platform we go to Radar operation followed by Geometric → Terrain Correction → Range-Doppler Terrain Correction for the terrain correction.
7. Conversion to dB: The last pre-processing step converts the unitless backscatter values to a dB unit. This is generally done using a logarithmic equation ($\text{dB} = 10 * \log[\text{DN}]$) for much better visualization, also to have the better rectification in the histogram. In the SNAP platform this operation is performed under the Product Explorer with the command Linear to dB.

After the pre-processing, the raw data was ready for further analysis of the image for water inundation. For mapping the water inundated part of the study area, the dark pixels were initially identified. The first step in binarizing images to separate water from non-water areas is to calculate and select an appropriate threshold for each image. For this calculation, the histogram of the filtered backscatter coefficient was examined on a logarithmic scale to aid in the threshold selection process (Fig. 2). Typically, histograms exhibit two peaks (pixel value frequencies) with varying degrees of backscattering (Perrou et al. 2018). Low backscatter values corresponded to water areas which is visualized in dark pixels, whereas high values corresponded to non-water areas. The specular reflection over the smooth water surface causes a low or null backscatter coefficient. The signal gets reflected away from the sensor; as a result, a dark pixel is obtained (Brivio et al. 2002; Malnes et al. 2002; Solbø and Solheim 2005; Perrou and Parcharidis 2018; Denis 2019). VV band of the image was used for further processing as water bodies are easily identified using this band (Twele 2016). Using SAR image and Google imagery as a reference, training datasets were prepared further to classify the water and non-water feature in the image. Based on these calculations, all



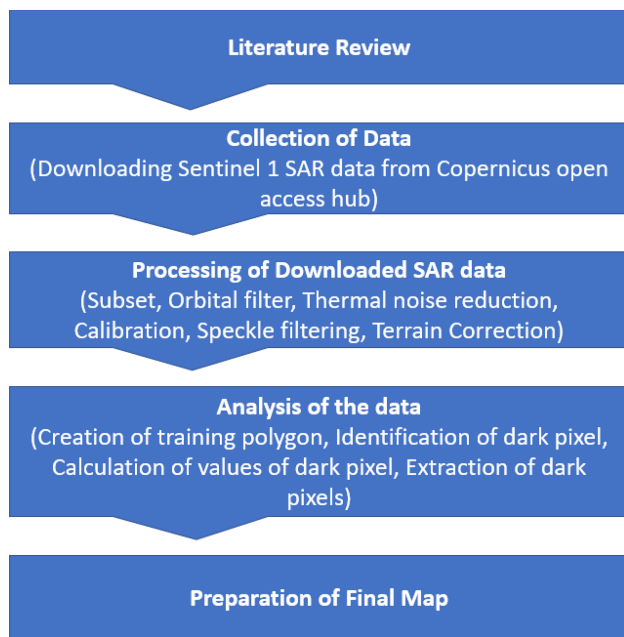


Fig. 2 Methodology flow chart for the study

regions flooded with water were marked for consideration for analysis. The maximum and lowest values of the dark pixels were also computed (Mohan 2014). In the present study the maximum value of the dark pixel is 0.0783 and the minimum value of dark pixel is $1.066\text{E-}6$ (Fig. 3). This procedure was carried out on both the pre-event and post-event data sets, respectively. The portion of the map that has been flooded is exported in GeoTIFF format from the SNAP. The data in GeoTIFF format was exported and processed on the ArcGIS software platform to create the final map. After processing the data in the ArcGIS platform, the final result was produced in the jpeg map format for distribution. The

methodology used in the present study is shown in the flow chart below.

Results and discussion

The raw satellite SAR data downloaded from the Copernicus hub needs to be pre-processed as it has some noise and obstacles which need to be removed. Two time periods Sentinel 1 data were taken for each district to study the water inundation area in the study area. For the pre-event Sentinel 1 data of 31/10/2019 & 28-10-2019 was taken for study, and for the post-event study Sentinel 1 data of 12/11/2019 was taken for study.

The Sentinel 1 data of both the Pre and the Post Event before and after the pre-processing for all the three districts is shown in Fig. 4.

After the pre-processing, water inundated area masking was done in the SNAP software. The water containing dark pixel was identified and taken in the polygon as training datasets. Minimum and maximum values of the dark pixels for VV band were considered to extract the water inundated part in the study area. 40 polygons for each map were taken as the training set. After that, all the water covered part in the study area was classified using the Band math operation in the SNAP and using the values of the maximum and the minimum of water pixels (Townsend 2001). This classified area was then exported from the SNAP in the Geotiff format for further operation in the ArcGIS. The images of water inundated areas of both the pre and post-events for all three districts are shown in Fig. 5.

The water inundation map of both the pre and the post-event was then processed in the ArcGIS platform, and the final output in the form of the map was prepared. The pixel count of the water inundated part used for the calculation of

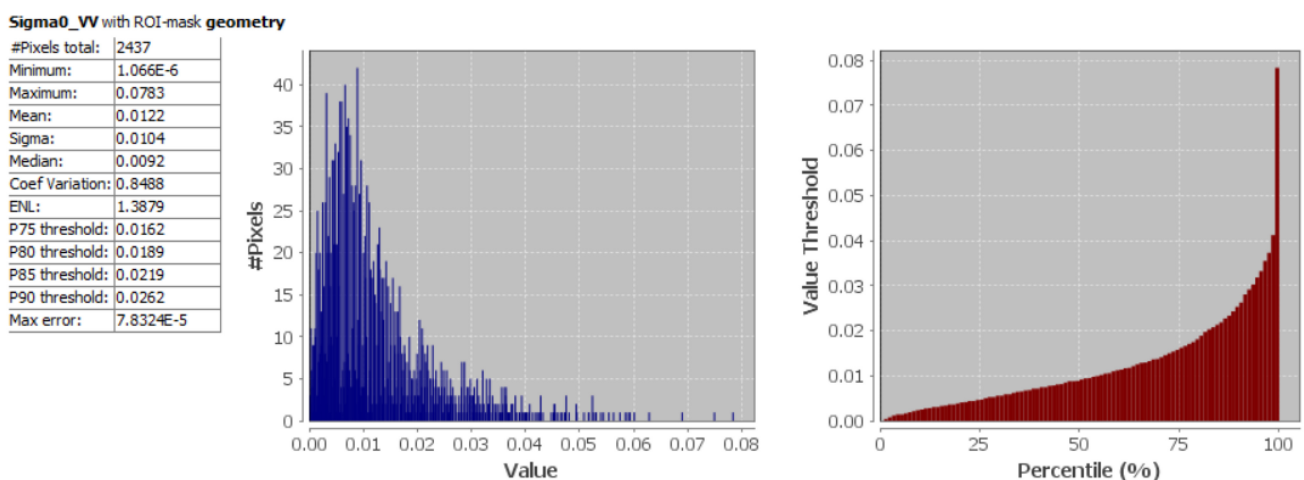
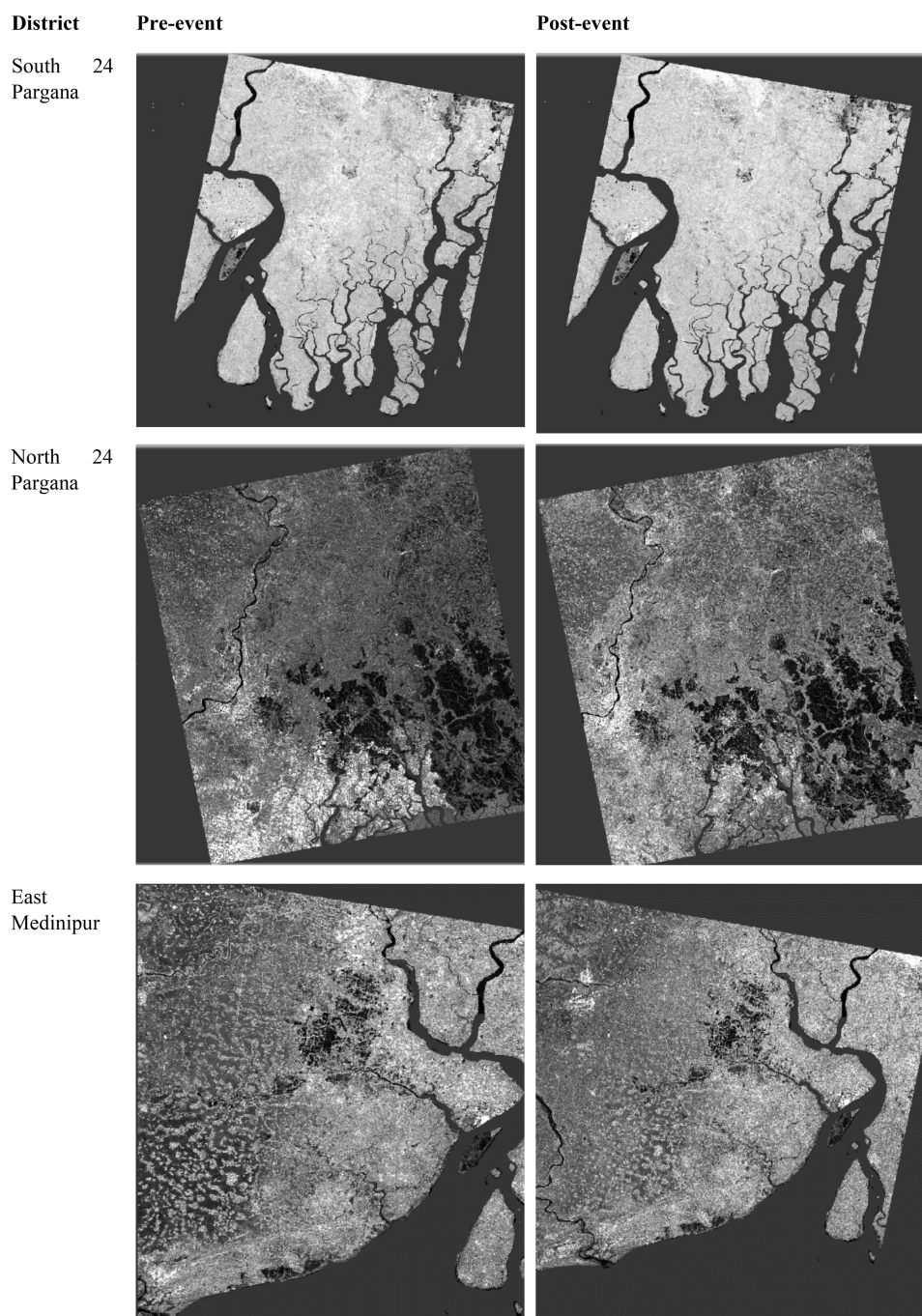


Fig. 3 Histogram showing the pixel values

Fig. 4 Pre and Post-event satellite data after the pre-processing of Sentinel-1 images



the water inundated area for the pre and post-event are as shown in Table 2 for each district. The water inundated area was converted to a feature file (polygon) using the conversion tool in the ArcMap for the calculation of the area in km^2 , as shown in Table 2.

There was no major damage in agricultural land or settlement due to the water inundation after the Bulbul cyclone. The major effect was in the already existing water body where the water inundation area was increased. For the districts South Pargana and North Pargana, the trend in the

water inundation area is increasing in the post-event compared to the pre-event. This is also quite natural. Whenever flooding occurs due to precipitation or cyclonic events, there is an increase in the inundated area after the event.

Nevertheless, a slight decrease was observed in the East Medinipur district for the water inundated area. The decrease in terms of area (in sq.km.) was insignificant. The analysis found that the southwestern part of the area, which was inundated more in the pre-event, has shown a decreasing trend in the post-event. In the East Medinipur district, the area where

Fig. 5 Water inundated area of both the pre and post events for all the three districts extracted using band math operation in the SNAP 7.0 software

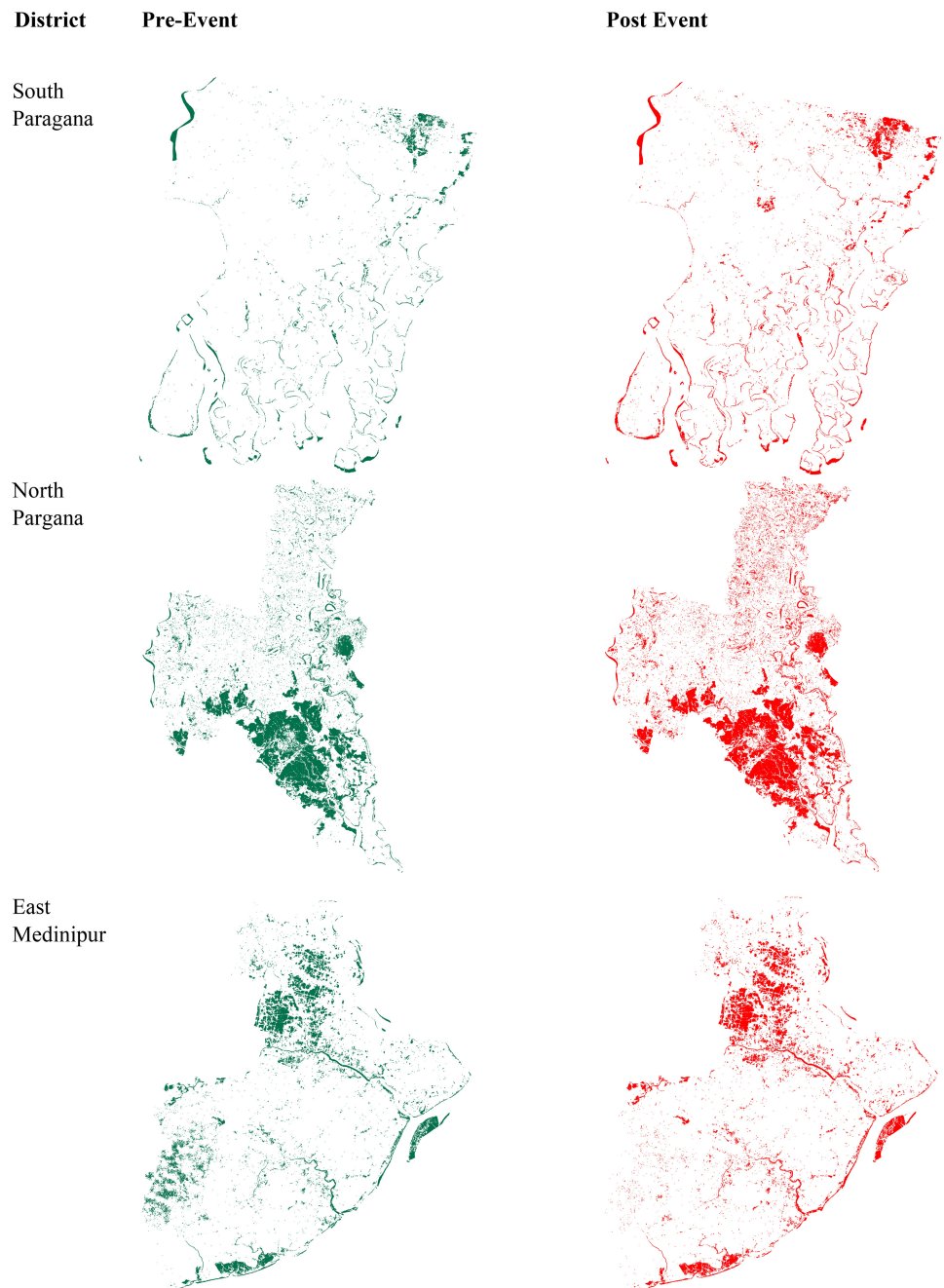


Table 2 Area inundated by water for both pre and the post-Bulbul event

District	Time	Pixel count of water inundated area	Water Inundation Area (km ²)
South Pargana	Pre-Bulbul	10,88,631	99.922
	Post-Bulbul	16,25,026	149.22
East Medinipur	Pre-Bulbul	21,39,867	196.36
	Post-Bulbul	21,33,544	195.93
North Pargana	Pre-Bulbul	52,40,482	497.27
	Post-Bulbul	55,12,030	505.14

the anomaly is shown falls in the Erga sub-division area, the settlement and built-up area. Since this is falling in the settlement area, there is a high possibility that the water has been drained out. And perhaps that is the reason that this part of the area was not inundated even after the cyclone event took place. Another key reason for this unusual tendency could be that the pre-event area inundated in the southwest was shallow. That water may have mixed with the permanent water body in the aftermath of the cyclonic event. As a result, the inundated area has shrunk in the aftermath of the incident. Nonetheless, more investigation is needed to figure out why

this anomaly occurred in the East Medinipur district. However, due to the proximity to the coastal line, South Pargana suffers the most from increasing water inundation during the pre- and post-event periods. Table 2 shows the inundated area in square kilometres.

The final output map of all the three districts were prepared in ArcGIS. The final output of North Pargana is explained in Fig. 6. The water inundation area has increased from 99.922 to 149.22 km² after the cyclone Bulbul. For the East Medinipur, the trend in the water inundation is different

(Fig. 7). Here the water inundation area has decreased from 196.36 to 195.93 km² after the cyclone.

Moreover, again, for the North Pargana, the trend is increasing in the water inundation area from 497.27 to 505.14 km² after the cyclone (Fig. 8). In these figures, it is very illustratively shown that the blue colour represents the inundated area before the cyclone. In the red colour, the water inundation area is demarcated after the cyclone Bulbul. The inset map in these figures helps to understand which part of India these districts lie.

Fig. 6 Comparison of water inundation pre and post-event (South 24 Parganas)

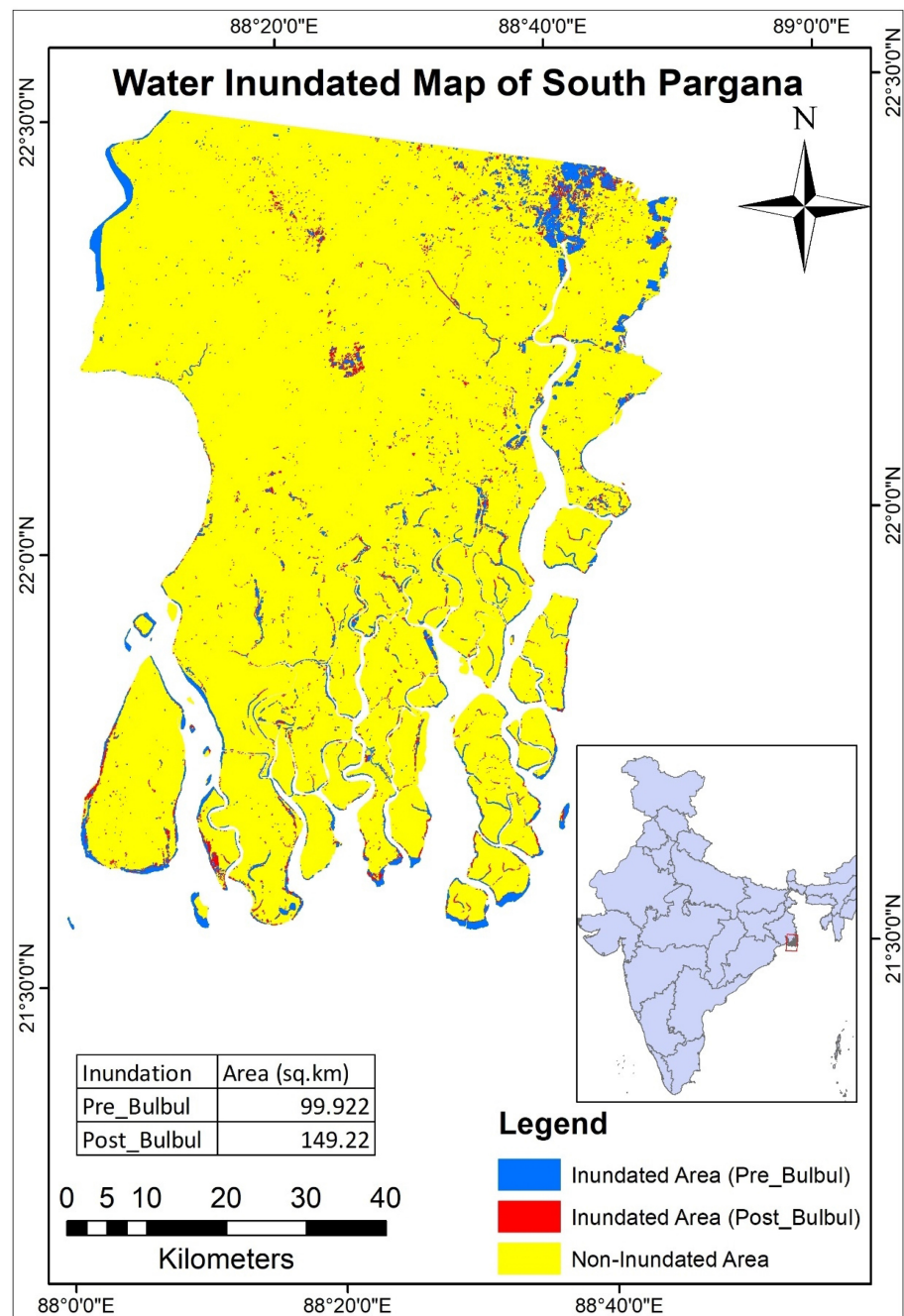
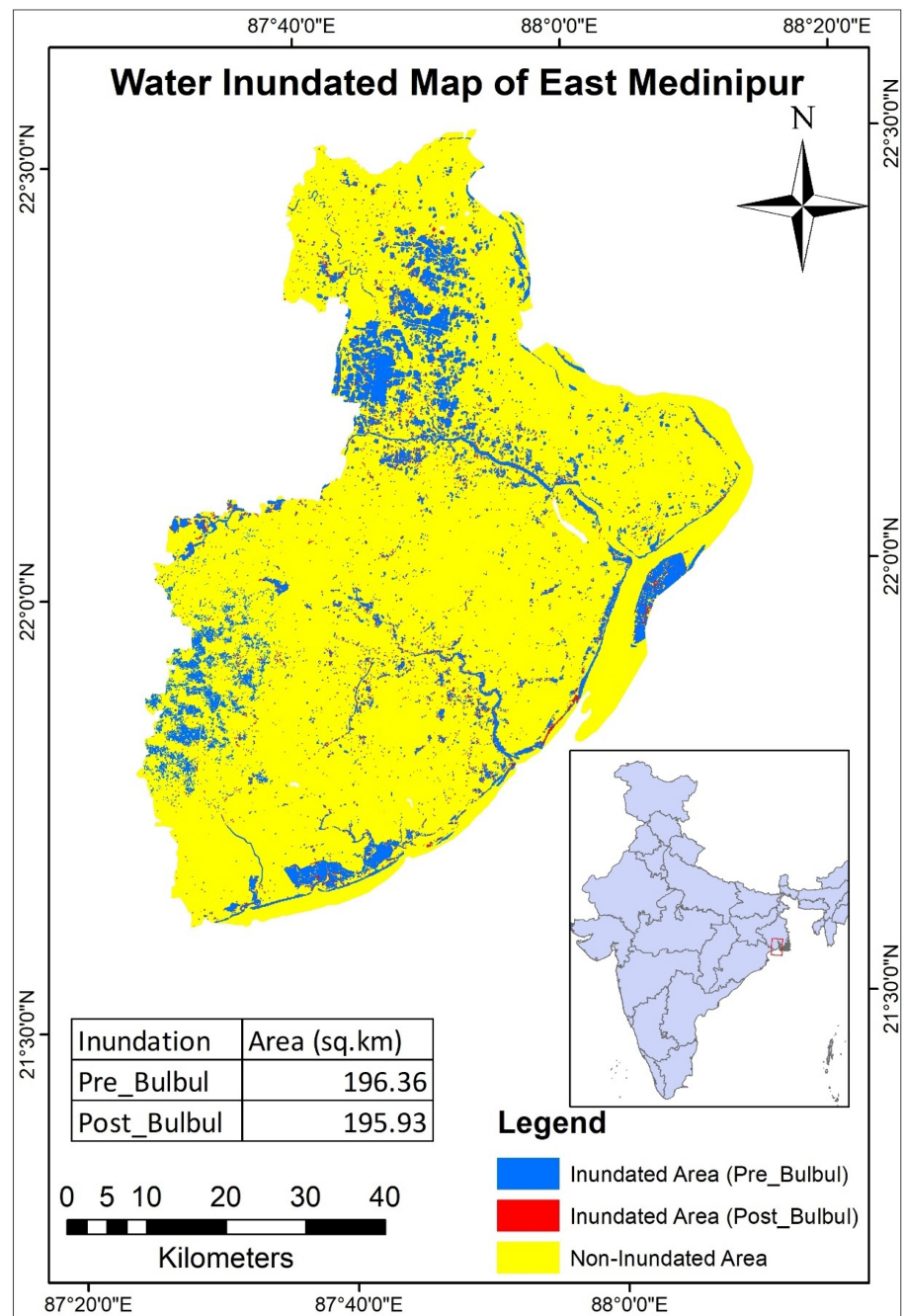


Fig. 7 Comparison of water inundation pre and post-event (East Medinipur)



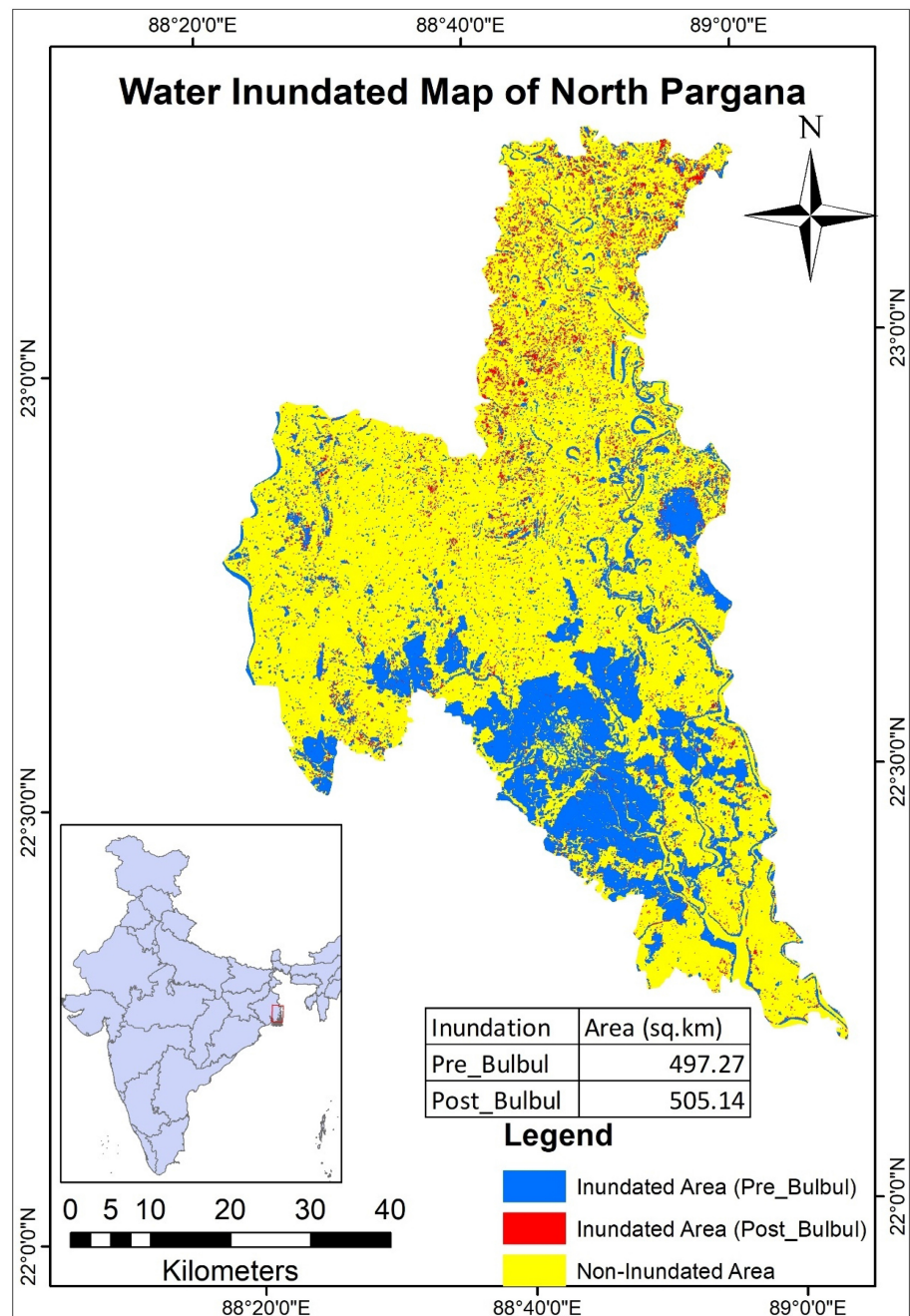
Conclusions

In coastal areas, cyclones are a frequently occurring phenomenon, resulting in flooding events. Subsequently, such flooding events cause loss of lives and properties (Paul and Routray 2011; Woodruff et al. 2013). Bulbul cyclone triggered in the Bay of Bengal on November 2019 had resulted in water inundation problem in some coastal areas of Bengal, as can be concluded by the study of SAR images of 12-11-2019. As it is impossible to map the area physically in a short period, geospatial tools and techniques were used to

map the water inundated area due to the effect of cyclone Bulbul. Sentinel 1 data in the SNAP software was found to be an easy and accurate technique for mapping. Following major conclusions can be drawn from the study:

1. The study shows a cost-efficient and effective way to build a spatial database to assess the region of water inundation due to cyclonic events.
2. This kind of initiative would significantly boost our ability to predict flood risk and measure the vulnerability of individuals.

Fig. 8 Comparison of water inundation pre and post-event (North 24 Parganas)



An area of 149.22 km² was inundated after the cyclone Bulbul took place compared to 99.922 km² of the inundated area in the pre cyclone event for the South Pargana district, the difference of which is highest among the three districts in the study area. For the East Medinipur district, the changes in the water inundation from pre to post-event were 196.36 km² to 195.93 km², which is a negative change. Furthermore, for the North Pargana district, the changes in the water inundation area from pre to post-event were 497.27 km² to 505.14 km².

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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