9-2022

Delineating Flood Zones Upon Employing Synthetic Aperture Data for the 2020 Flood in Bangladesh

Saleh Ahmed
Boise State University

Publication Information

Aziz, Md. Abdullah; Moniruzzaman, Md.; Tripathi, Akshar; Hossain, Md. Ismail; Ahmed, Saleh; Rahaman, Khan Rubayet; . . . and Ahmed, Rokib. (2022). "Delineating Flood Zones Upon Employing Synthetic Aperture Data for the 2020 Flood in Bangladesh". *Earth Systems and Environment, 6*(3), 733-743. https://doi.org/10.1007/s41748-022-00295-0

Delineating Flood Zones Upon Employing Synthetic Aperture Data for the 2020 Flood in Bangladesh

Md. Abdullah Aziz
Agricultural Statistics Division
Bangladesh Rice Research Institute
Bangladesh

Md Moniruzzaman*
Spatial Business Integration GmbH (SBI)
Darmstadt, Germany
m.monir@spatial-business-integration.com
ORCID: 0000-0002-5139-6434

Akshar Tripathi
Department of Civil Engineering
Indian Institute of Technology (IIT) Ropar
Rupnagar, Punjab, India.

Md. Ismail Hossain
Agricultural Statistics Division
Bangladesh Rice Research Institute
Bangladesh

Saleh Ahmed
School of Public Service
Boise State University
Boise, ID, USA

Khan Rubayet Rahaman
Department of Geography and Environmental Studies
Saint Mary's University
Halifax, NS, Canada

Farhana Rahman
University of Technology
Ultimo, Sydney, Australia.

Rokib Ahmed
Agricultural Statistics Division
Bangladesh Rice Research Institute
Bangladesh

Abstract

Delineating a flood map is critical in order to perceive the potential risks of the event at diverse communities living both in urban and rural settings in Bangladesh. A timely generated flood map can help determine the losses of properties, calculate payment options from insurances, and set up mitigation measures when required. Application of satellite remote sensing (RS) and geographic information systems (GIS) are common these days to determine inundated areas, and to calculate possible losses of economies at scale. However, challenges remain while considering the available options for collecting satellite imageries obtained during the monsoon season with more than 70% cloud coverages found in the data. As a result, active synthetic aperture radar (SAR) sensors are a better choice to utilize the data in delineating the inundated areas. In doing so, this scientific paper sets up a few objectives to (i) prepare a flood map of Bangladesh using SAR remote sensing data available from Sentinel-1 satellite; and (ii) generate the inundated maps using cloud-based product, i.e., Google Earth Engine (GEE) in categorizing flood-affected districts of Bangladesh in 2020. Results have demonstrated that approximately 11% area of Bangladesh has been affected by the 2020 flood mainly located in the north-central and north-eastern part of the country. Moreover, the old Brahmaputra floodplain, Tista floodplain, lower Ganges-River floodplain, and Karataya-Bangali floodplain have been severely affected by the flood. Note that, the GEE-based automated processing systems adopted in this study have enhanced the computational time while obtaining freely available satellite data to generate mitigation strategies for the betterment of the communities suffered by the flood event.

Keywords: inundation, SAR sensors, Sentinel-1, Google Earth Engine, physiography, geographic information system

Introduction

The temporary overflow of water that inundates typical drylands in any location is generally termed a flooding event. Flood takes place due to heavy and continuous rains during the monsoon season, surges from storms that strike the inland areas from the ocean, rapid melting of snow, or damaging the dams, embankments, or levees during the high rainfall season (NOAA, 2021). Recently, the frequency of global flooding events has been increasing significantly due to deforestation, abrupt changes in landuse and landscapes, increasing number of coastal storms, inadequate management of urban stormwater runoffs, and climate change (Asinya & Alam, 2021;

Baky et al., 2020; Dung et al., 2021; Haque et al., 2021; Hirabayashi et al., 2013; Jothimani et al., 2021; Khosravi et al., 2016, 2018; Manawi et al., 2020; Mubialiwo et al., 2022; Nsangou et al., 2021). Flooding is considered as one of the major natural disasters globally that poses enormous damage to life, economy, environment, and nonliving objects (e.g., infrastructures, transportation networks, houses, urban centers, crops, etc.) (Ahmed et al., 2017; Dung et al., 2021; Hirabayashi et al., 2013; Messner & Meyer, 2006). Flooding is responsible for approximately 40% of the devastating impacts of natural disasters throughout the world (Bich et al., 2011). Scientists have reported that the damages are done in agricultural productions, disrupted human settlements, polluted natural and built environment, and claimed lives (Chapi et al., 2017; Messner & Meyer, 2006; Sarhadi et al., 2012; Yu et al., 2013). Approximately one billion people are living close to the vulnerable river basins that are subjected to flood risk each year (UNU, 2018). These areas are expected to experience a potential increase in excessive rainfall and precipitation in the coming years. Furthermore, the increasing number of populations living close to the vulnerable areas to flooding may increase the loss of human lives and properties. The figures are expected to become almost doubled by the year 2050 (Ahmed et al., 2017; Taherkhani et al., 2020). Developing countries are considered as the most vulnerable areas to experience the havoc done by floods in this particular time frame. Bangladesh is one of the critical countries to get inundated by floods due to the fact of the unique geographical setting and excessive river flow during the monsoon season. Scientific evidence has suggested that one-third area of the country may experience the flood as an annual event in the face of unprecedented climate change (Haque et al., 2021; Khosravi et al., 2018; Rahman et al., 2019; Singha et al., 2020). Moreover, the potential scenarios have demonstrated that Bangladesh may experience food insecurity due to loss of rice production (i.e., the staple food for the people of Bangladesh) mostly damaged by an increasing number of floods (Singha et al., 2020).

It is worth noting that Bangladesh is situated in a low-lying flat location that is going through extensive and frequent flooding almost every year in flood-prone regions (Ara & Ostendorf, 2017; Baky et al., 2020; Rahman et al., 2019). Additionally, it is also one of the most densely populated and disaster-prone countries in the world (Ahmed et al., 2017; Moniruzzaman & Chattoraj, 2021). Typically, the flooding in Bangladesh depends on the intensity, magnitude, and duration of rainfall across the three major river basins such as the Ganges, the Brahmaputra, and Meghna (Hanlon, 2020; Singha et al., 2020). These three rivers also fabricate the country as one of the world's largest deltaic countries (Hanlon, 2020). From the Himalayan Mountain region, these three rivers carry a huge volume of water along with 1 billion tons of silt every year (Ali, 2007). It has been found that the delta gradually sinks during the sediment deposition and compaction stage each year because of floods. The water with a high current transports sands and sediments that cause riverbank erosion till it slows down. After that, it causes sediment deposition along the riverbank and therefore develops natural levees, helping in compaction within sands, as it gets slower. Almost 70% of land areas of Bangladesh are currently used for agricultural crop production, where paddy is the main crop as it is cultivated up to three times annually (Singha et al., 2020). The occurrence of extensive flooding every year is typically responsible for damaging the standing paddy fields throughout the country, which eventually triggers food insecurity (Singha et al., 2020).

Interestingly, there are some noticeable variations of landuse and patterns of flooding in the northern and southern areas of Bangladesh. In the case of the northern part of the delta, it has been observed that sediments are carried out by the river usually help in developing the floodplain, particularly during the monsoon season (Brammer, 2012; Hanlon et al., 2016). On the other hand, a different scenario is found in the coastal areas in the south. In the southern coastal areas, sediments are carried and discharged out to the sea by the rivers flowing with high currents and speeds during the monsoon period when it rains heavily sometimes 100 mm in a day. However, the sediments are thrown back to the inland areas by the tidal waves during the dry season. This happens in the summer season when the tidal wave enters almost 300 km upstream of the coastal zone. Furthermore, when the flow of water current gets slower, the formation of silt takes place in the inland areas. Also, the water finds its way when all high tides are calmed down and water current enhanced, consequently clear out channels and keep the area free and navigable.

In order to perceive the risks and potential inundation areas of flooding for the whole country, it is required to have access to a comprehensive and reliable flood map. Consequently, flood maps can help to understand the associated risks at communities at the local level (e.g., municipalities), manage floodplains accordingly, and introduce appropriate monitoring and mapping schemes to respond to the potential disaster management strategies. The frequency of flooding can be detected from the nature of inundation (i.e., water level) during the specific period and at the specific areas that are known as flooding hotspots. The three major river basins of the Ganges, Brahmaputra, and Meghna are usually inundated by their tributaries that discharge huge volumes of water (190,000 m^3s^{-1}) during the monsoon into the river basins (Ali, 2007). These flooded hotspots are usually inundated approximately five times every year from 2014 to 2018, covering an area of about 28,586 km^2 (Singha et al., 2020). Riverine floods vary widely depending on source mechanism, global location, geology, and physiography

(O'Connor et al., 2002). Furthermore, highly accurate flood mapping provides key information in strategic planning for the authorities responsible for estimating potential damages to ensure sustainability at the regional and community level (Papila et al., 2020).

Satellite-borne remote sensing and geographic information systems (GIS) technologies are widely used in the recent time as a prominent tool for mapping, monitoring, analyzing, managing, modeling geospatial data, and scientifically generating spatio-temporal scenarios (Gupta et al., 2020; Moniruzzaman et al., 2018, 2021; Rousta et al., 2020b, 2020a, 2020c; Sanyal & Lu, 2004; Tripathi & Tiwari, 2020, 2021). Satellite imageries can determine the extent of flooding over large geographical areas, providing an advantage over in situ data sources where the information can have limited spatial and temporal resolution whilst being costly to acquire (Clement et al., 2018). Additionally, satellite imageries enable fast, reliable and cost-effective results for monitoring large geographical coverages, thus providing geospatial information to support disaster monitoring and management effectively and efficiently (Papila et al., 2020). Over the past several decades, remote sensing and GIS are effective in handling large hydrological datasets to create more accurate flood hazard maps in terms of spatial and temporal resolution (Shahabi et al., 2020).

Flooding in Bangladesh normally occurs during the monsoon season from June to September (Ali, 2007). The convectional rainfall of the monsoon adds up to the relief rainfall caused due to existence of the Himalayas in the North (Bookhagen & Burbank, 2010). Also, atmospheric blockings affect the rainfall anomalies, climate variability, and land surface temperature significantly (Rousta et al., 2014, 2018) that may trigger inundation and waterlogging conditions. Optical satellite remote sensing technology usually fails to capture imageries of monsoon in Asia due to dense cloud cover and an overcast situation in the atmosphere (Qadir & Mondal, 2020). However, Sentinel-1 synthetic aperture radar (SAR) data can provide all-weather, day and night, global observation of the earth's surface consistently (ESA, 2021). Consequently, the SAR sensors can penetrate through clouds and can accurately identify the ground surface including the surface water. As a result, SAR-based data are effective for flood mapping and forecasting (Ouchi, 2013; Teshebaeva et al., 2015; Tripathi & Tiwari, 2019a, 2019b). SAR systems and the Sentinel-1 satellites are programmed with active sensors that emit a radar pulse and record the backscatter after interaction with the target (i.e., land surface in particular) at the satellite. They provide an advantage over optical sensors by enabling the collection of data through cloud cover and during the night (Clement et al., 2018). Hence, the study aims to prepare a flood inundation map of Bangladesh for July 2020 using Sentinel-1 SAR datasets upon employing Google Earth Engine (GEE) systems as a geospatial tool. The study shows the spatial extend of the July 2020 flood and its areal distribution for the whole country. Note that, the model employed in this study can generate accurate flood maps and can enhance the understanding of potential flood risks zonation in similar geographic settings during monsoon. In the following section, we illustrate the geographical settings of the study area, raster and vector data properties, comprehensive method of model building, results, and discussion, followed by concluding remarks.

Materials and Methods

Study Area

Bangladesh covers an area of 147,570 sq km (Rasel et al., 2013). It extends from 20'34N to 26'38N latitude and from 88'01E to 92'41E longitude (Figure 1) (Aziz et al., 2021). The Maximum extension of Bangladesh is about 440 km in the E-W direction and 760 km in the NW-SE direction, and predominantly characterized by rich fertile flat land. Most of the country is situated in less than 12 m (39 ft) above sea level, and it is estimated that around 10% of its land area would be flooded if the sea level were to rise by 1 m (3.3 ft) in the next 30 years (Karim & Mimura, 2008). Approximately, 17% of the country is covered by forests and 12% is covered by hill systems. The country's *Haor* wetlands (wetland ecosystem in local language) are of significance to global environmental science (Byomkesh et al., 2008).

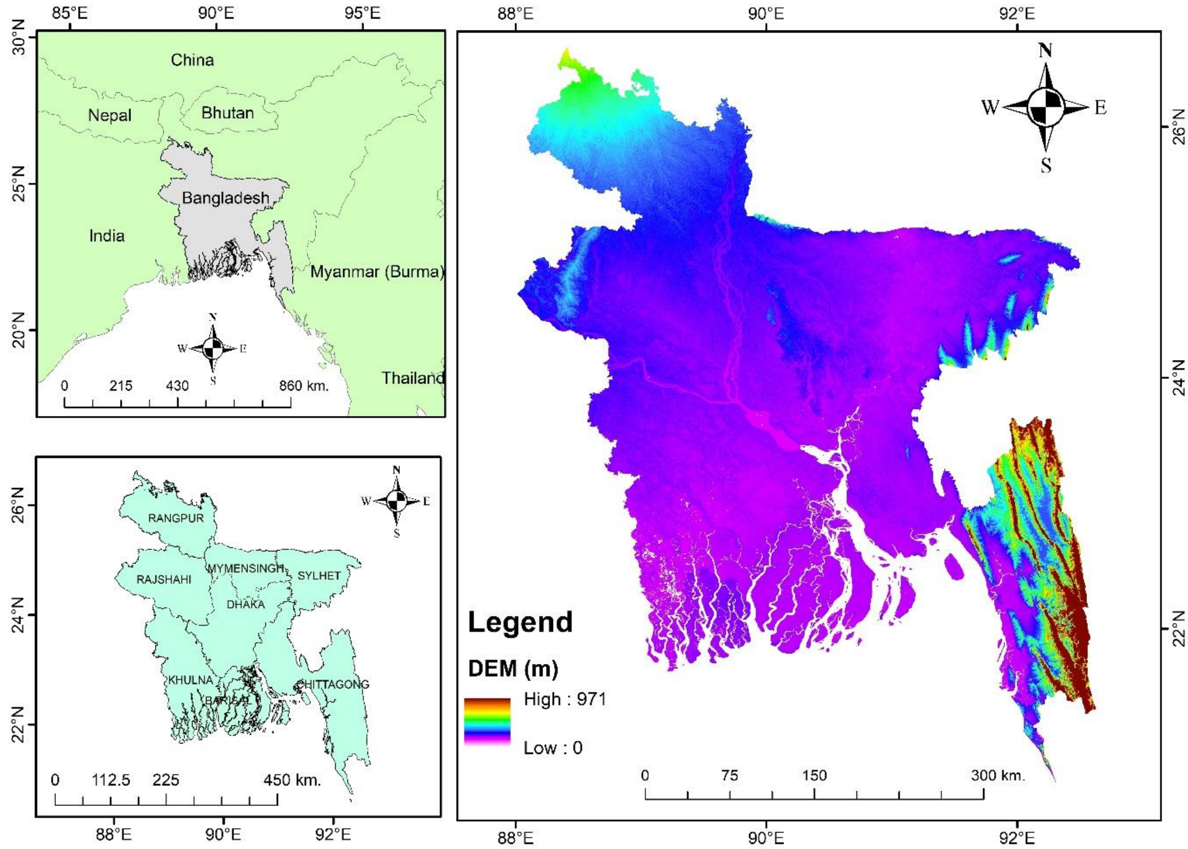

Figure 1: Map of the study area.

The population of the country has been estimated to 163 million, one of the most densely populated countries in the world (Singha et al., 2020). The Ganges, Brahmaputra, and Meghna are the major river systems in the country with 230 branches of small rivers and tributaries (Singha et al., 2020). The hydro meteorological characteristics of these three river basins are the same and are usually the reason for major flooding in the country.

The annual average precipitation varies from 200 mm to 2000 mm and almost 80% of precipitation has been observed during the monsoon season, which occurs usually between June and September (Singha et al., 2020). . In 1987, 1988 and 1998, Bangladesh has experienced three major floods, leaving trails of devastation and human misery (Mirza, 2003). In 2020 Bangladesh has again severely suffered from a monsoon flood where 102 Upazila (i.e., sub-district levels of government system) and 654 unions (i.e., bottom layer local government entity) have been inundated in flood, affecting 3.3 million people and leaving 7,31,958 people water logged (CARE, 2020).

Datasets Used

We have used Sentinel-1 SAR data to perform our analysis in this study. Note that, Sentinel-1 has been launched in April 2014 and is the first satellite constellation of the European Space Agency's (ESA) Copernicus Programme and comprises of two satellites that share the same orbital plane—Sentinel-1A and Sentinel-1B (Bousbih et al., 2019; Tripathi & Tiwari, 2020, 2021). They carry a C-band (i.e., 5.7 cm wavelength) synthetic aperture radar (SAR) instrument, which can collect data in all-weather conditions including day and night time consistently. Sentinel-1 SAR has a spatial resolution of 5m × 20m with 12 days temporal resolution (ESA, 2021). The SAR data has been accessed from freely available Sentinel Scientific Data Hub (scihub.Copernicus.EU). Details of the obtained SAR datasets are summarized in the table 1.

In 2020 there have been a total of six spells of floods occurred in Bangladesh. The flood has started in June and the 3rd spell has been the most severe one, which lasts between 20th July and 08th August 2020 (BWDB, 2020). As a result, we have selected the "Before flood" and "During flood" time window from 28th May to 04th June 2020 and 20th July to 25th July 2020 respectively for capturing the appropriate data.

Table 1: Characteristics of Sentinel 1 SAR data set and others spatial data used in this study.

RS data	**Date**	**Satellite Sensor**	**Format/mode**	**Polarization**	**Pass**
Before flood	28/05/2020 to 04/06/2020	Sentinel-1	GRD/IW	VV	Descending
During flood	20/07/2020 to 25/07/2020	Sentinel-1	GRD/IW		
Vector data	**Geographic co-ordinate system**	**Projected co-ordinate system**	**Source**		
District shapefile	WGS1984	UTM Zone 45&46	Bangladesh Agricultural Research Council (BARC) (http://barc.gov.bd/)		
Physiographic map	WGS1984	UTM Zone 45&46	Bangladesh Country of Alamance (BCA)		
Major river map	WGS1984	TM Zone 45&46			

Methods

Data Collection and Pre-Processing

The fundamental data collection and processing methods have been carried out in Google Earth Engine (GEE) platform. The steps are described in the following section (Figure 2):

Load the Sentinel-1 and Study Area Data in the GEE Code Editor

The study area shapefile and the Sentinel 1 SAR data have been loaded for analysis in the GEE code editor platform.

Mosaic and Clip Sentinel-1 SAR Data

The Sentinel-1 SAR data has been mosaiced and afterwards clipped by the pre-loaded study area shape file (i.e., vector data set) in the GEE code editor platform.

Export the Clipped Data in Google Drive for Further Analysis

The clipped image has been resampled to 30m spatial resolution and exported to Google drive in GeoTIFF format. Note that, Geo TIFF format is a commonly used processed satellite data that can be employed for analysis and scientific models.

This is an author-produced, peer-reviewed version of this article. The final, definitive version of this document can be found online at *Earth Systems and Environment*, published by Springer. Copyright restrictions may apply. https://doi.org/10.1007/s41748-022-00295-0.

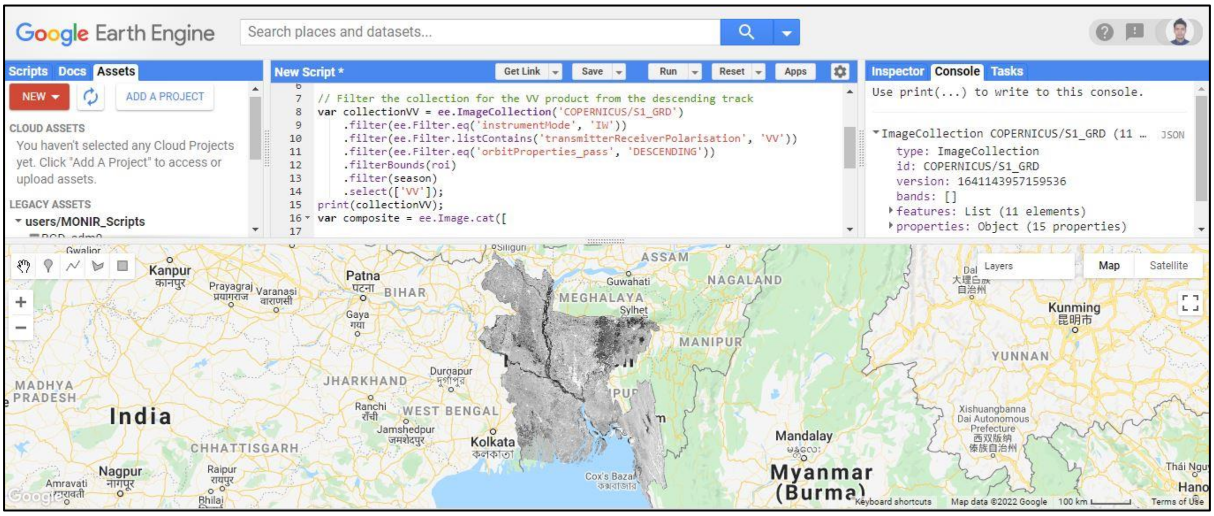

Figure 2: GEE data processing steps view

'Before Flood' and 'During Flood' Image Classification

We performed unsupervised classification technique to classify the water and non-water bodies for both 'before the flood' and 'during flood' images using ISO data Cluster Classifier. The unsupervised classification mainly used cluster analysis, while the cluster was to put pixels into several classes according to the similarity of the pixels. The aim was to ensure the distance between pixels in the same class such as: (i) as small as possible, and (ii) as large as possible, between the distances of two different classes. The core issues of unsupervised classification were the selection of the initial class parameters and required iteration adjustment (Haibo et al., 2011). Water bodies werea specular reflector of the radar pulse, resulting in the minimal signal returned to the satellite (Jung et al., 2010; Schlaffer et al., 2015). Thus, water bodies and non-water bodies were easily classified for both 'pre flood' and 'during flood' images by performing ISO cluster unsupervised classification options available in ArcGIS software.

Flooded Area Identification Removing Permanent Waterbodies

Before the flood water inundates a particular area, we have prepared the map of permanent waterbodies those have been demonstrating as river, ponds, canals, and swamps. Afterward, we have prepared the maps those have demonstrated permanent water bodies and flood inundation areas together. Upon subtracting the before flood images from the joint permanent and flood water images, we have obtained the actual flood map (details are shown in equation 1). Eventually the flood map represents the inundated areas due to flood on 25th July 2020 to represent the whole country.

$$\begin{matrix}\text{During flood image} \\ \text{(Flood water + permanent water)}\end{matrix} - \begin{matrix}\text{Before flood image} \\ \text{(Permanent water)}\end{matrix} = \begin{matrix}\text{Flood map} \\ \text{(Flood water only)}\end{matrix} \qquad \text{(i)}$$

Flood Area Calculation

District wise total flooded area were retrieved using district shape file (i.e., vector datasets) and zonal statistical tools in ArcGIS platform. After this, we analyzed the district wise flood inundation map to demonstrate approximate area under inundation.

Results and Discussion

Figure 3 (a) is showing the existing water bodies and major rivers of Bangladesh before the flood occurs. Eventually this map is representing the permanent water bodies of the country. Major permanent water bodies are mainly situated in the north-eastern side (i.e., Haor area of Bangladesh). Also, dominant permanent water bodies are found at the south-west part of Bangladesh (i.e., the Sundarbans mangrove forest in the coast of the country). Moreover, there are some major water bodies found in the south-eastern side of the country, which is representing the Kaptai lake area (i.e., one of the biggest lakes of the country for hydroelectricity production).

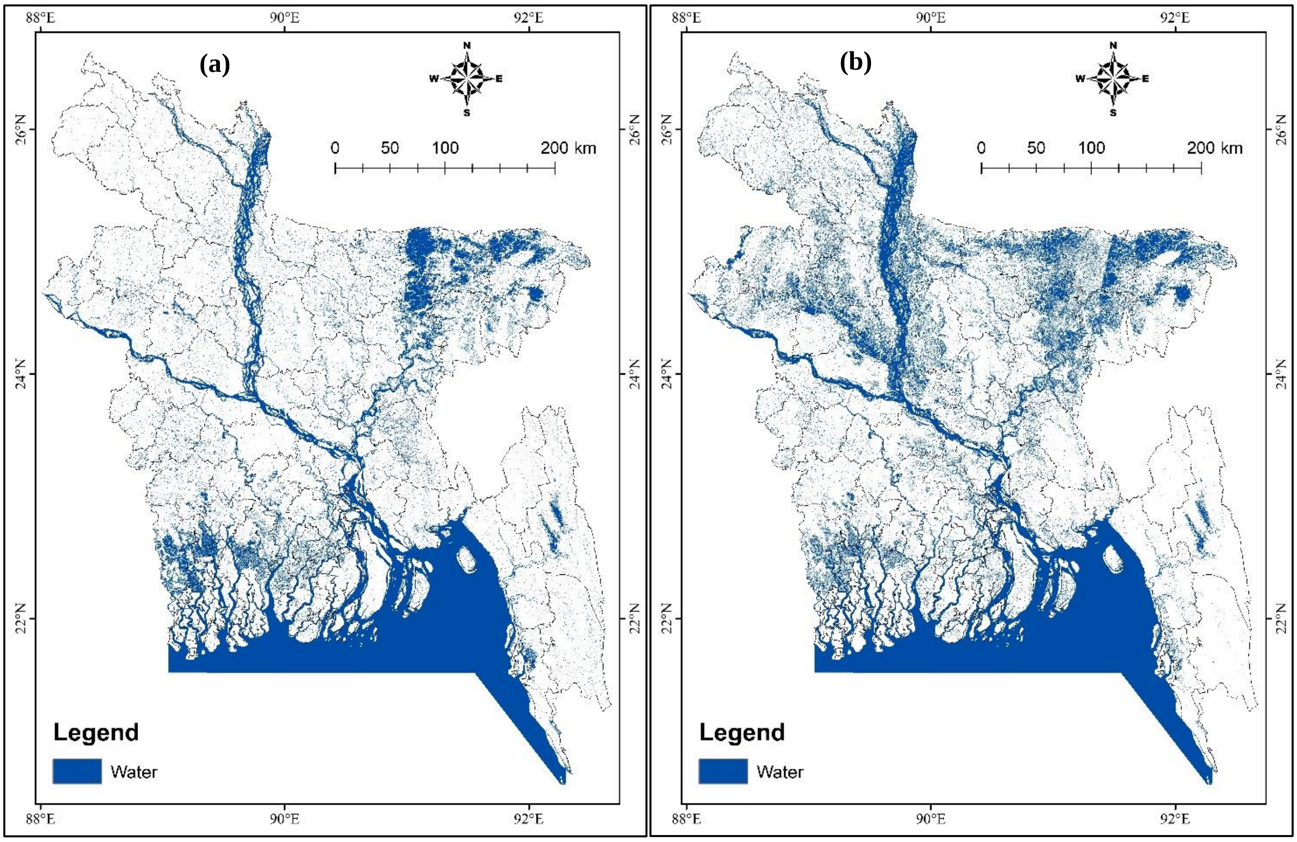

Figure 3: Flood maps of 2020; (a) before flood scenario and (b) during flood scenario.

Figure 3 (b) is demonstrating the water bodies and major rivers of Bangladesh during the flood situation. These water bodies are both permanent and inundated during the flood events. As mentioned earlier on, flood capturs almost one third of the areas in the country. Majority of the inundation occurs in the north-east and north-west zone of the country (see Fig. 3a for details). Consequently, Figure 4 exhibits only the inundated areas during the 2020 flood including major rivers of Bangladesh. Many areas in Bangladesh have been affected by flood, particularly in the north-central part of the country, which comprises both sides of the the Jamuna and Brahmaputra river. Additionally, the north-eastern part of Bangladesh has suffered inundation within the river catchment basin at a distance of approximately 20 km from the center of rivers. Comparing the flood map with the physiographic map of Bangladesh (see Figure 5 for details), it is evident that the old Brahmaputra floodplain, Tista floodplain, Low Ganges-River floodplain and Karataya-Bangali floodplains are severely affected by the recent 2020 flood.

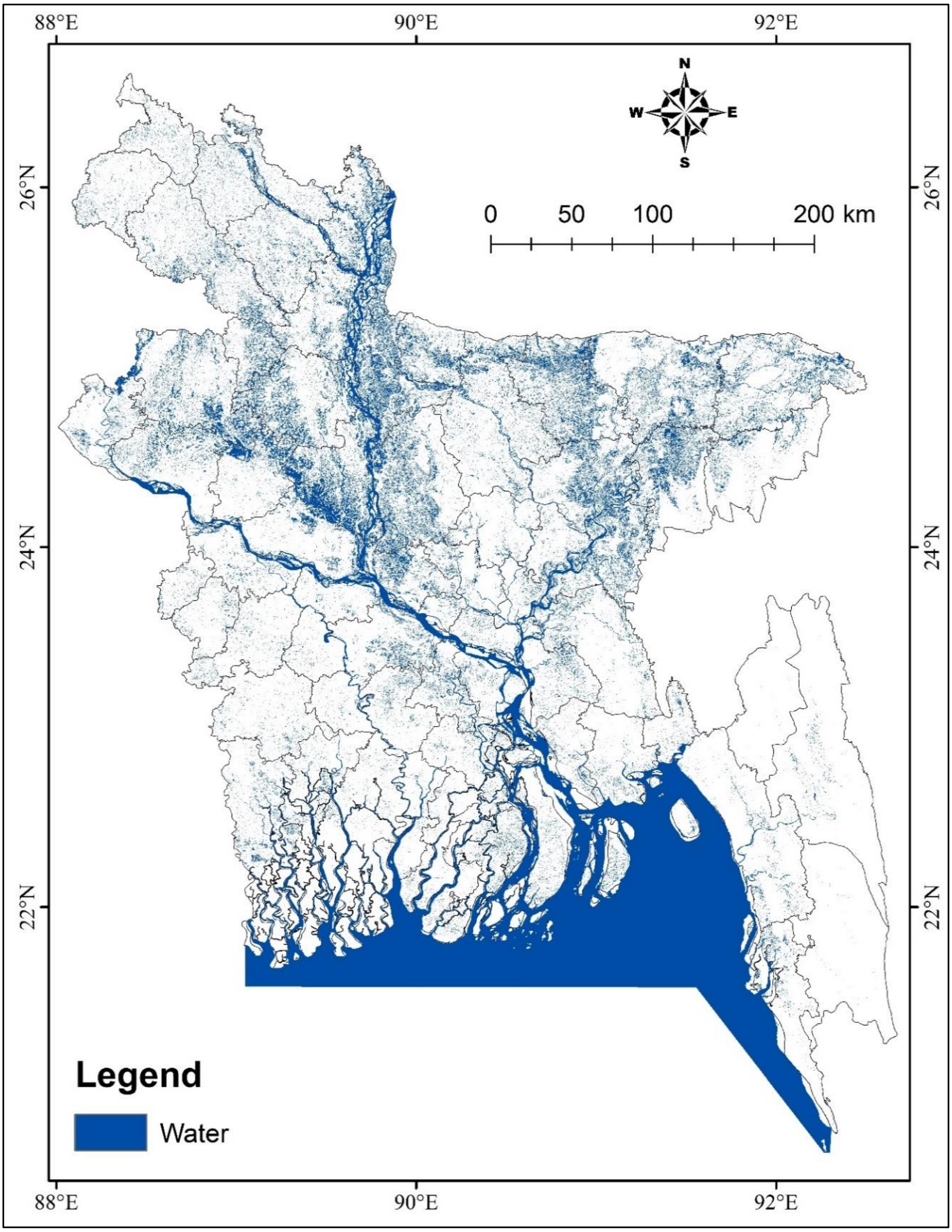

Figure 4: Flood inundation map of Bangladesh occurred in July 2020.

Table 3 exhibits the area of each district, flood-affected area, and percentages of flood affected regions in descending order where we have observed Jamalpur and Sirajganj districts are the worst affected districts. In fact, more than 30% of the total area in these two mentioned districts have been inundated.

This is an author-produced, peer-reviewed version of this article. The final, definitive version of this document can be found online at *Earth Systems and Environment*, published by Springer. Copyright restrictions may apply. https://doi.org/10.1007/s41748-022-00295-0.

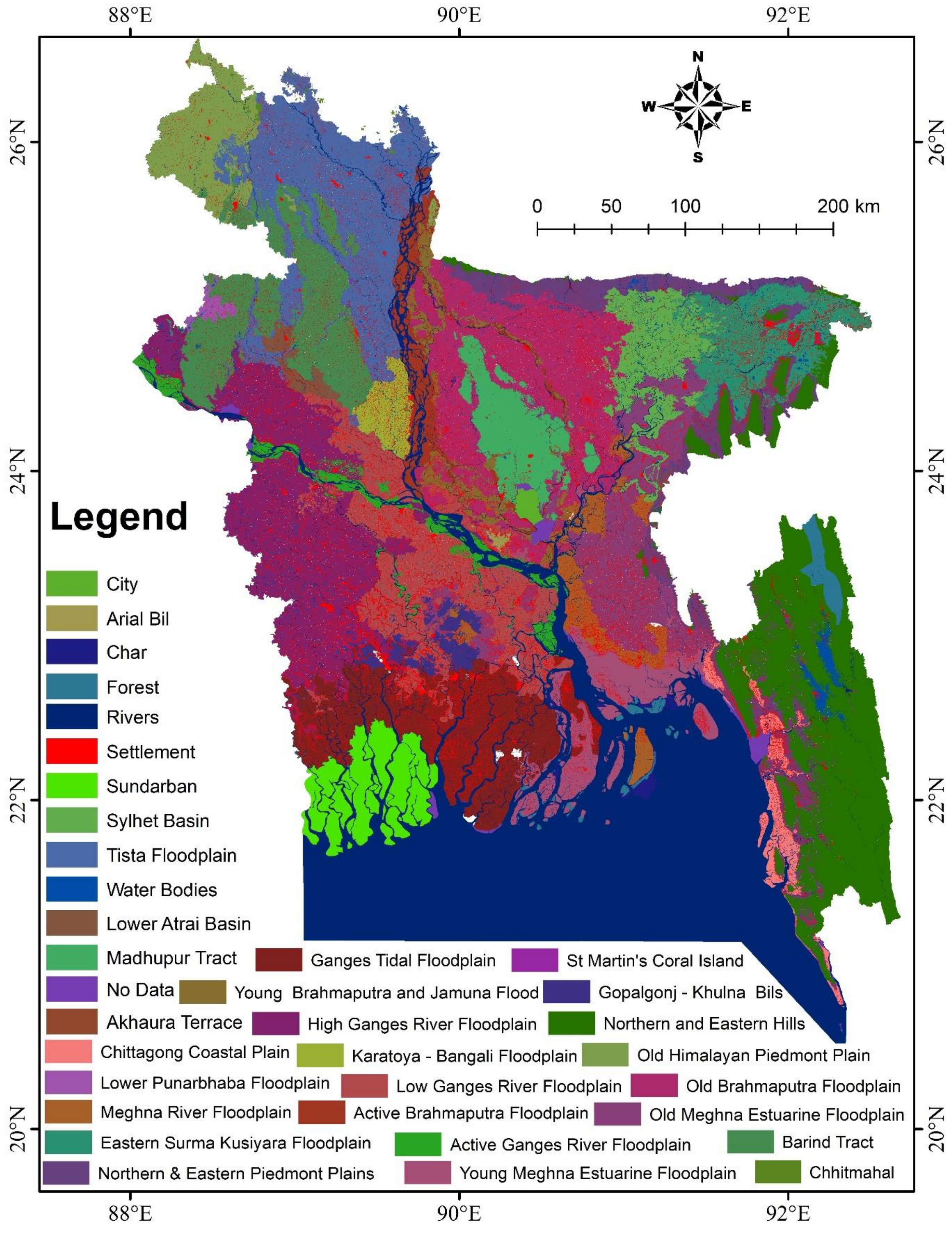

Figure 5: The physiography of Bangladesh (BARC, 2021)

Interestingly, Figure 6 illustrates the name of districts highly affected by flood with at least 40,000 ha of land areas has undergone in water. The geographic location of these districts is located mostly in the north-western part of the country. Moreover, few districts are existing in the north-eastern part such as Habiganj and Sylhet. It is worthwhile to note that approximately 11% area of the whole country has gone under water in this 2020 flood event.

Table 3: District wise flood inundation area of Bangladesh during July 2020.

DIST_NAME	Total Area (ha)	Flood Affected Area (ha)	Flood Affected%	DIST_NAME	Total Area (ha)	Flood Affected Area (ha)	Flood Affected%
JAMALPUR	206639.02	74422.89	36.02	NARAYANGANJ	77957.13	5407.38	6.94
SIRAJGANJ	243204.64	86860.98	35.72	MOULVI BAZAR	269960.69	16895.7	6.26
NETRAKONA	286100.52	78040.71	27.28	PANCHAGARH	138775.32	8634.33	6.22
KURIGRAM	226406.54	52379.1	23.13	PATUAKHALI	227625.18	13725.9	6.03
TANGAIL	344780.79	79210.26	22.97	MUNSHIGANJ	93204.19	5346.27	5.74
MANIKGANJ	137477.49	31569.75	22.96	GOPALGANJ	154443.86	8657.19	5.61
SHERPUR	132564.37	29848.41	22.52	SHARIATPUR	124854.35	6952.32	5.57
HABIGANJ	257034.82	57649.86	22.43	FENI	85915.40	4756.59	5.54
BOGURA	290795.23	64435.05	22.16	LAKSHMIPUR	132727.13	7347.69	5.54
KISHOREGANJ	251118.24	55098	21.94	GAZIPUR	167662.61	8956.08	5.34
JOYPURHAT	96330.31	20826.54	21.62	CUMILLA	313276.94	16541.91	5.28
BRAHMANBARIA	191503.52	40250.61	21.02	NOAKHALI	248258.20	13099.5	5.28
NAOGAON	344771.65	71282.7	20.68	BARISHAL	220494.60	11377.62	5.16
GAIBANDHA	217400.20	41402.88	19.04	THAKURGAON	181574.78	9241.47	5.09
PABNA	241071.92	45471.24	18.86	BHOLA	192269.44	8604.63	4.48
SUNAMGANJ	370253.17	65012.58	17.56	MEHERPUR	70925.40	3173.85	4.47
NATORE	191247.91	33175.17	17.35	CHUADANGA	112525.33	4707.45	4.18
SYLHET	345369.81	49587.39	14.36	SATKHIRA	343841.65	13321.62	3.87
RAJSHAHI	237589.91	32988.42	13.88	COX'S BAZAR	215669.94	8133.3	3.77
FARIDPUR	206649.44	25066.44	12.13	JHENAIDAH	194277.11	7252.02	3.73
MYMENSINGH	427911.38	49286.16	11.52	KHULNA	364500.22	11859.84	3.25
RANGPUR	232414.24	26630.01	11.46	JASHORE	252903.73	7402.77	2.93
DINAJPUR	346076.90	39623.04	11.45	JHALAKATI	72055.10	2025.18	2.81
NAWABGANJ	172965.28	19311.66	11.17	BARGUNA	130580.00	3577.32	2.74
MADARIPUR	111547.29	12178.53	10.92	MAGURA	104443.84	2825.91	2.71
NARSINGDI	116326.10	12165.93	10.46	CHATTOGRAM	418660.02	10252.8	2.45
KUSHTIA	168517.25	16535.43	9.81	NARAIL	96453.50	2149.83	2.23
LALMONIRHAT	123435.75	11354.49	9.20	PIROJPUR	116489.05	2091.15	1.80
NILPHAMARI	167371.62	14718.96	8.79	BAGERHAT	351591.39	4249.26	1.21
RAJBARI	112153.63	9069.3	8.09	RANGAMATI	531944.05	4836.96	0.91
DHAKA	152011.58	11226.33	7.39	BANDARBAN	431670.31	1094.76	0.25
CHANDPUR	169564.55	12072.69	7.12	KHAGRACHHARI	250108.14	170.73	0.07

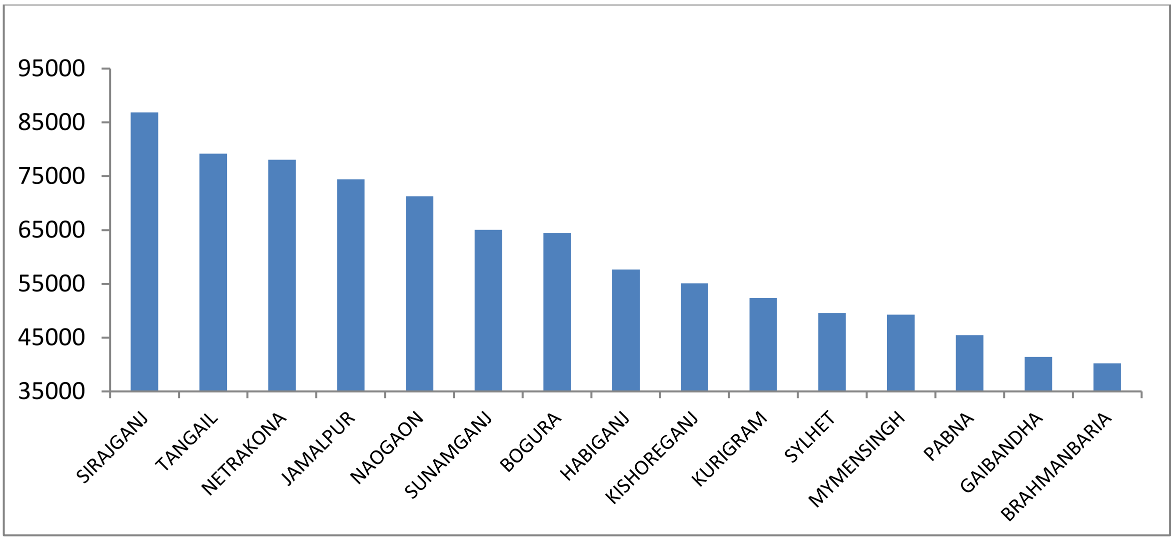

Figure 6: List of districts underwent flood water at least having 40,000 ha inundated area.

Majority of the recent body of literature have generated flood maps and vulnerable areas utilizing optical satellite senor data in GEE platforms (Lal et al., 2020). However, the problem with optical data is that it is opaque to cloud cover, which makes the use of SAR data inevitable for flood mapping (DeVries et al., 2020). Moreover, SAR data requires complicated pre-processing and data processing stages for generating comprehensive flood map (Tripathi et al., 2021). The present study has attempted to incorporate the advantage of using SAR data and GEE platform for generating higher resolution flood map in a quicker and cost-effective way. This study may solve several issues raised in the contemporary literature. However, the coding and models employed in this study enhance the methods by (i) overcoming the time required for data pre-processing stages, (ii) utilizing SAR data, which are available for free of cost, and (iii) requiring limited access to expensive software upon accessing to GEE platform. Consequently, all the data captured through the modeling techniques in this study can be easily saved in cloud while avoiding the expensive data storage devices.

Concluding Remarks

Sentinel-1 data processing and preparation required for generating flood maps have always been challenging for researchers worldwide. For natural hazards like floods when there is dense cloud cover in the atmosphere, the only sensor that can be utilized for studying such extraordinary situations is the active SAR sensor. However, owing to the large data size and need of high-end computing facilities often restrict even routine research to be carried out. In such situation, cloud computing methods are highly beneficial in terms of time and resources. GEE is one such cloud-based facility that is available for budding researchers and analysts in the field of satellite remote sensing. In 2020, Bangladesh has experienced severe flood event in various phases. Sirajganj, Tangail, Netrokona, Jamalpur, Naogaon, Sunamganj, Bogura, Habiganj, Kishorganj, Kurigram, Sylhet, Mymensingh, Pabna, Gaibandha, and Brahmanbaria districts are the most severely affected locations in the country. Approximately 11% area of the entire country has been affected by the destructive flood. The old Brahmaputra floodplain, Tista floodplain, Low Ganges-River floodplain and Karataya-Bangali floodplain have been severely affected by the 2020 flood. This study utilizes freely available satellite datasets and uses GEE for easing out the complicated and time-consuming data processing and preparation steps. The important novelties of this study are as follows:

- Cost-effective and time-saving approach for mapping of floods and flood-affected area calculation, which has immense potentials in developing countries;
- Timely mitigation and disaster management strategies can be executed with the availability of such empirical evidence available at any geographical setting; and
- The study paves the way for further research where flood modelling can be carried out using the GEE platform and satellite-based remotely sensed data, which will make the results available for policymakers in the least possible time.

Additionally, the current study extends several scopes and potentials of future research while integrating digital elevation model (DEM) to enhance flow of water from upstream to downstream that may leave few areas more vulnerable to other. Also, the authors are recommending that scientists interested to use our generated model shall review the appropriate codes in details before employing the method in different geographical setting.

Acknowledgement

The authors deeply acknowledge the Bangladesh Rice Research Institute, Gazipur-1701, Bangladesh and European Space Agency (ESA).

Author's Contributions: The authors, M.A.A., and M.M. proposed the topic, and contributed to the data processing and analysis. The authors, M.A.A., M.M. and K.R.R., contributed to the research design, analysis, interpretation, and wrote the manuscript; A.T., M.I.H., S.A., K.R.R., F.R. and R.A. contributed to enhancing the manuscript writing. The authors, M.M. and K.R.R. finalized the manuscript. All authors have read and agreed to the published version of the manuscript.

Conflict of Interest: On behalf of all authors, the corresponding author states that there is no conflict of interest

References

Ahmed, M. R., Rahaman, K. R., Kok, A., & Hassan, Q. K. (2017). Remote Sensing-Based Quantification of the Impact of Flash Flooding on the Rice Production: A Case Study over Northeastern Bangladesh. *Sensors*, *17*(10), 2347. https://doi.org/10.3390/s17102347

Ali, A. M. S. (2007). September 2004 Flood Event in Southwestern Bangladesh: A Study of its Nature, Causes, and Human Perception and Adjustments to a New Hazard. *Natural Hazards*, *40*(1), 89–111. https://doi.org/10.1007/s11069-006-0006-x

Ara, I., & Ostendorf, B. (2017). A Review of Food Security and the Potentials to Develop Spatially Informed Food Policies in Bangladesh. *Earth Systems and Environment*, *1*(2), 19. https://doi.org/10.1007/s41748-017-0021-y

Asinya, E. A., & Alam, M. J. B. (2021). Flood Risk in Rivers: Climate Driven or Morphological Adjustment. *Earth Systems and Environment*, *5*(4), 861–871. https://doi.org/10.1007/s41748-021-00257-y

Aziz, M. A., Hossain, A. Z., Moniruzzaman, M., Ahmed, R., Zahan, T., Azim, S., Qayum, M. A., Al Mamun, M. A., Kader, M. A., & Rahman, N. M. F. (2021). Mapping of Agricultural Drought in Bangladesh using Geographic Information System (GIS). *Earth Systems and Environment*, 1–11.

Baky, M. A. A., Islam, M., & Paul, S. (2020). Flood Hazard, Vulnerability and Risk Assessment for Different Land Use Classes Using a Flow Model. *Earth Systems and Environment*, *4*(1), 225–244. https://doi.org/10.1007/s41748-019-00141-w

BARC. (2021). *Bangladesh Agricultural Research Council (BARC)-Government of the People\'s Republic of Bangladesh*. http://barc.gov.bd/

Bich, T. H., Quang, L. N., Thanh Ha, L. T., Duc Hanh, T. T., & Guha-Sapir, D. (2011). Impacts of flood on health: Epidemiologic evidence from Hanoi, Vietnam. *Global Health Action*, *4*(1), 6356.

Bookhagen, B., & Burbank, D. W. (2010). Toward a complete Himalayan hydrological budget: Spatiotemporal distribution of snowmelt and rainfall and their impact on river discharge. *Journal of Geophysical Research: Earth Surface*, *115*(F3). https://doi.org/10.1029/2009JF001426

Bousbih, S., Zribi, M., Pelletier, C., Gorrab, A., Lili-Chabaane, Z., Baghdadi, N., Ben Aissa, N., & Mougenot, B. (2019). Soil texture estimation using radar and optical data from Sentinel-1 and Sentinel-2. *Remote Sensing*, *11*(13), 1520.

Brammer, H. (2012). *Physical geography of Bangladesh*. The University Press Ltd.

BWDB. (2020). *Bangladesh Water Development Board*. https://www.bwdb.gov.bd/

Byomkesh, T., Nakagoshi, N., & Md. Shahedur, R. (2008). State and management of wetlands in Bangladesh. *Landscape and Ecological Engineering*, *5*(1), 81. https://doi.org/10.1007/s11355-008-0052-5

CARE, B. (2020). *Monsoon Floods 2020 Coordinated Preliminary Impact and Needs Assessment—Needs Assessment Working Group*. https://reliefweb.int/report/bangladesh/bangladesh-monsoon-floods-2020-coordinated- preliminary-impact-and-needs-assessment.

Chapi, K., Singh, V. P., Shirzadi, A., Shahabi, H., Bui, D. T., Pham, B. T., & Khosravi, K. (2017). A novel hybrid artificial intelligence approach for flood susceptibility assessment. *Environmental Modelling & Software*, *95*, 229–245.

Clement, M. A., Kilsby, C. G., & Moore, P. (2018). Multi-temporal synthetic aperture radar flood mapping using change detection. *Journal of Flood Risk Management*, *11*(2), 152–168.

DeVries, B., Huang, C., Armston, J., Huang, W., Jones, J. W., & Lang, M. W. (2020). Rapid and robust monitoring of flood events using Sentinel-1 and Landsat data on the Google Earth Engine. *Remote Sensing of Environment*, *240*, 111664.

Dung, N. B., Long, N. Q., Goyal, R., An, D. T., & Minh, D. T. (2021). The Role of Factors Affecting Flood Hazard Zoning Using Analytical Hierarchy Process: A Review. *Earth Systems and Environment*. https://doi.org/10.1007/s41748-021-00235-4

ESA. (2021). *User Guides—Sentinel-1 SAR - Definitions—Sentinel Online—Sentinel Online*. https://sentinel.esa.int/web/sentinel/user-guides/sentinel-1-sar/definitions

Gupta, A., Moniruzzaman, M., Hande, A., Rousta, I., Olafsson, H., & Mondal, K. K. (2020). Estimation of particulate matter (PM 2.5, PM 10) concentration and its variation over urban sites in Bangladesh. *SN Applied Sciences*, *2*(12), 1–15.

Hanlon, J. (2020). Bangladesh farmers push for temporary flooding to correct Dutch polder failure. *Journal of International Development*, *32*(1), 29–43.

Hanlon, J., Roy, M., & Hulme, D. (2016). *Bangladesh confronts climate change: Keeping our heads above water*. Anthem press.

Haque, Md. N., Siddika, S., Sresto, M. A., Saroar, Md. M., & Shabab, K. R. (2021). Geo-spatial Analysis for Flash Flood Susceptibility Mapping in the North-East Haor (Wetland) Region in Bangladesh. *Earth Systems and Environment*, *5*(2), 365–384. https://doi.org/10.1007/s41748-021-00221-w

Hirabayashi, Y., Mahendran, R., Koirala, S., Konoshima, L., Yamazaki, D., Watanabe, S., Kim, H., & Kanae, S. (2013). Global flood risk under climate change. *Nature Climate Change*, *3*(9), 816–821.

Jothimani, M., Dawit, Z., & Mulualem, W. (2021). Flood Susceptibility Modeling of Megech River Catchment, Lake Tana Basin, North Western Ethiopia, Using Morphometric Analysis. *Earth Systems and Environment*, *5*(2), 353–364. https://doi.org/10.1007/s41748-020-00173-7

Karim, M. F., & Mimura, N. (2008). Impacts of climate change and sea-level rise on cyclonic storm surge floods in Bangladesh. *Global Environmental Change*, *18*(3), 490–500. https://doi.org/10.1016/j.gloenvcha.2008.05.002

Khosravi, K., Nohani, E., Maroufinia, E., & Pourghasemi, H. R. (2016). A GIS-based flood susceptibility assessment and its mapping in Iran: A comparison between frequency ratio and weights-of-evidence bivariate statistical models with multi-criteria decision-making technique. *Natural Hazards*, *83*(2), 947–987.

Khosravi, K., Pham, B. T., Chapi, K., Shirzadi, A., Shahabi, H., Revhaug, I., Prakash, I., & Bui, D. T. (2018). A comparative assessment of decision trees algorithms for flash flood susceptibility modeling at Haraz watershed, northern Iran. *Science of the Total Environment*, *627*, 744–755.

Lal, P., Prakash, A., & Kumar, A. (2020). Google Earth Engine for concurrent flood monitoring in the lower basin of Indo-Gangetic-Brahmaputra plains. *Natural Hazards*, *104*(2), 1947–1952.

Manawi, S. M. A., Nasir, K. A. M., Shiru, M. S., Hotaki, S. F., & Sediqi, M. N. (2020). Urban Flooding in the Northern Part of Kabul City: Causes and Mitigation. *Earth Systems and Environment*, *4*(3), 599–610. https://doi.org/10.1007/s41748-020-00165-7

Messner, F., & Meyer, V. (2006). Flood damage, vulnerability and risk perception–challenges for flood damage research. In *Flood risk management: Hazards, vulnerability and mitigation measures* (pp. 149–167). Springer.

Mirza, M. M. Q. (2003). Three recent extreme floods in Bangladesh: A hydro-meteorological analysis. In *Flood problem and management in South Asia* (pp. 35–64). Springer.

Moniruzzaman, M., & Chattoraj, S. L. (2021). Coupling of Rainfall Triggered Debris Flow Simulation in Parts of Bandarban, Bangladesh: An Earth Observation Based Approach for Landslide Hazard Assessment. *Global Journal of Science Frontier Research*. https://journalofscience.org/index.php/GJSFR/article/view/2876

Moniruzzaman, M., Roy, A., Bhatt, C. M., Gupta, A., An, N. T. T., & Hassan, M. R. (2018). Impact analysis of urbanization on land use land cover change for Khulna City, Bangladesh using temporal landsat imagery. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *42*(5).

Moniruzzaman, M., Thakur, P. K., Kumar, P., Alam, A., Garg, V., Rousta, I., & Olafsson, H. (2021). Decadal Urban Land Use/Land Cover Changes and Its Impact on Surface Runoff Potential for the Dhaka City and Surroundings Using Remote Sensing. *Remote Sensing*, *13*(1), 83.

Mubialiwo, A., Abebe, A., Kawo, N. S., Ekolu, J., Nadarajah, S., & Onyutha, C. (2022). Hydrodynamic Modelling of Floods and Estimating Socio-economic Impacts of Floods in Ugandan River Malaba Sub-catchment. *Earth Systems and Environment*. https://doi.org/10.1007/s41748-021-00283-w

NOAA. (2021). https://www.nssl.noaa.gov/education/svrwx101/floods/; Last Accessed: 06 Arpil 2021

Nsangou, D., Kpoumié, A., Mfonka, Z., Bateni, S. M., Ngouh, A. N., & Ndam Ngoupayou, J. R. (2021). The Mfoundi Watershed at Yaoundé in the Humid Tropical Zone of Cameroon: A Case Study of Urban Flood Susceptibility Mapping. *Earth Systems and Environment*. https://doi.org/10.1007/s41748-021-00276-9

O'Connor, J. E., Grant, G. E., & Costa, J. E. (2002). The geology and geography of floods. *Ancient Floods, Modern Hazards and Applications of Paleoflood Hydrology. Water Science and Application. American Geophysical Union*, *5*, 359–395.

Ouchi, K. (2013). Recent trend and advance of synthetic aperture radar with selected topics. *Remote Sensing*, *5*(2), 716–807.

Papila, I., Alganci, U., & Sertel, E. (2020). SENTINEL-1 Based Flood Mapping Using Interferometric Coherence and Intensity Change Detection Approach. *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, *43*, 1697–1703.

Qadir, A., & Mondal, P. (2020). Synergistic Use of Radar and Optical Satellite Data for Improved Monsoon Cropland Mapping in India. *Remote Sensing*, *12*(3), 522.

Rahman, M., Ningsheng, C., Islam, M. M., Dewan, A., Iqbal, J., Washakh, R. M. A., & Shufeng, T. (2019). Flood Susceptibility Assessment in Bangladesh Using Machine Learning and Multi-criteria Decision Analysis. *Earth Systems and Environment*, *3*(3), 585–601. https://doi.org/10.1007/s41748-019-00123-y

Rasel, H. M., Hasan, M. R., Ahmed, B., & Miah, M. S. U. (2013). Investigation of soil and water salinity, its effect on crop production and adaptation strategy. *International Journal of Water Resources and Environmental Engineering*, *5*(8), 475–481. https://doi.org/10.5897/IJWREE2013.0400

Rousta, I., Javadizadeh, F., Dargahian, F., Olafsson, H., Shiri-Karimvandi, A., Vahedinejad, S. H., Doostkamian, M., Monroy Vargas, E. R., & Asadolahi, A. (2018). Investigation of vorticity during prevalent winter precipitation in Iran. *Advances in Meteorology*, *2018*.

Rousta, I., Khosh Akhlagh, F., Soltani, M., & Modir Taheri Sh, S. (2014). Assessment of blocking effects on rainfall in northwestern Iran. *Proceedings of COMECAP 2014*, 291.

Rousta, I., Olafsson, H., Moniruzzaman, M., Ardö, J., Zhang, H., Mushore, T. D., Shahin, S., & Azim, S. (2020a). The 2000–2017 drought risk assessment of the western and southwestern basins in Iran. *Modeling Earth Systems and Environment*, *6*(2), 1201–1221.

Rousta, I., Olafsson, H., Moniruzzaman, M., Zhang, H., Liou, Y.-A., Mushore, T. D., & Gupta, A. (2020b). Impacts of drought on vegetation assessed by vegetation indices and meteorological factors in Afghanistan. *Remote Sensing*, *12*(15), 2433.

Rousta, I., Olafsson, H., Zhang, H., Moniruzzaman, M., Krzyszczak, J., & Baranowski, P. (2020c). *Anthropogenic factors affecting the vegetation dynamics in the arid Middle East*.

Sanyal, J., & Lu, X. X. (2004). Application of remote sensing in flood management with special reference to monsoon Asia: A review. *Natural Hazards*, *33*(2), 283–301.

Sarhadi, A., Soltani, S., & Modarres, R. (2012). Probabilistic flood inundation mapping of ungauged rivers: Linking GIS techniques and frequency analysis. *Journal of Hydrology*, *458*, 68–86.

Shahabi, H., Shirzadi, A., Ghaderi, K., Omidvar, E., Al-Ansari, N., Clague, J. J., Geertsema, M., Khosravi, K., Amini, A., & Bahrami, S. (2020). Flood detection and susceptibility mapping using sentinel-1 remote sensing data and a machine learning approach: Hybrid intelligence of bagging ensemble based on k-nearest neighbor classifier. *Remote Sensing*, *12*(2), 266.

Singha, M., Dong, J., Sarmah, S., You, N., Zhou, Y., Zhang, G., Doughty, R., & Xiao, X. (2020). Identifying floods and flood-affected paddy rice fields in Bangladesh based on Sentinel-1 imagery and Google Earth Engine. *ISPRS Journal of Photogrammetry and Remote Sensing*, *166*, 278–293.

Taherkhani, M., Vitousek, S., Barnard, P. L., Frazer, N., Anderson, T. R., & Fletcher, C. H. (2020). Sea-level rise exponentially increases coastal flood frequency. *Scientific Reports*, *10*(1), 6466. https://doi.org/10.1038/s41598-020-62188-4

Teshebaeva, K., Roessner, S., Echtler, H., Motagh, M., Wetzel, H.-U., & Molodbekov, B. (2015). ALOS/PALSAR InSAR time-series analysis for detecting very slow-moving landslides in Southern Kyrgyzstan. *Remote Sensing*, *7*(7), 8973–8994.

Tripathi, A., Attri, L., & Tiwari, R. K. (2021). Spaceborne C-band SAR remote sensing–based flood mapping and runoff estimation for 2019 flood scenario in Rupnagar, Punjab, India. *Environmental Monitoring and Assessment*, *193*(3), 1–16.

Tripathi, A., & Tiwari, R. K. (2019a). Utilization of spaceborne C-band SAR data for analysis of flood impact on agriculture and its management. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *42*(3/W6).

Tripathi, A., & Tiwari, R. K. (2020). Synergetic utilization of sentinel-1 SAR and sentinel-2 optical remote sensing data for surface soil moisture estimation for Rupnagar, Punjab, India. *Geocarto International*, 1–22.

Tripathi, A., & Tiwari, R. K. (2021). Utilisation of Spaceborne C-band dual Pol Sentinel-1 SAR data for simplified Regression-based Soil Organic Carbon Estimation in Rupnagar, Punjab, India. *Advances in Space Research*.

Tripathi, A., & Tiwari, R. K. (2019b). C-band SAR Interferometry based flood inundation mapping for Gorakhpur and adjoining areas. *2019 International Conference on Computer, Electrical & Communication Engineering (ICCECE)*, 1–6.

UNU. (2018). *UNU Update: Two billion face flood danger soon*. https://archive.unu.edu/update/archive/issue32_2.htm

Yu, J. J., Qin, X. S., & Larsen, O. (2013). Joint Monte Carlo and possibilistic simulation for flood damage assessment. *Stochastic Environmental Research and Risk Assessment*, *27*(3), 725–735.