NICOLAUS COPERNICUS UNIVERSITY IN TORUŃ

Bulletin of Geography. Physical Geography Series, No. 26 (2024): 5–18
http://doi.org/10.12775/bgeo-2024-0001

Assessment of flood disaster and management strategies in the lower Brahmaputra valley of Assam

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Abstract. Floods are common in every rainy season in the Brahmaputra valley. Several districts in Assam experience flooding every year. One of the flood-prone districts in Assam is Bongaigaon, which is situated in the lower reach of Brahmaputra River. The present work aims to examine the threats associated with floods and the role of government in management strategies. For the study, primary and secondary data have been gathered from different sources, including the District DC office (DDMA branch), Assam Secretariat office (ASDMA Branch), Sentinel 1, ICIMOD and field surveys and have been analyzed with the help of different tools. In this study, 2015, 2017, 2019, 2021 and 2022 flood hazard scenarios of the district have been considered for the case evaluation. The result shows that flooding in this area has a wide range of negative impacts. Furthermore, different efforts have notably been made by the district and state administration to reduce the impact and promote sustainable management.

Key words:
Lower Brahmaputra valley,
Bongaigaon,
floods,
threats,
management strategies

Introduction

Throughout the globe, occurrences of floods have been intensifying threats and have become one of the most common hazardous phenomena in recent times (Gupta and Dixit 2022). In the monsoon period, floods become a cause of intense fatalities in both natural as well as human-environmental aspects (Pradhan et al. 2021). Floods become more of a risk factor when they harm natural as well as human-induced property (Maranzoni et al. 2023). From 2000 to 2019, 44% of the disasters around the globe comprised only flood events, of which, 41% of the total flood events were experienced in Asian countries (CRED 2019). Floods are a very regular phenomenon in India, and their characteristics differ due to a wide variety of geo-environmental settings (Singh and Kumar 2017). Assam is one of the most flood-prone states among all the north-eastern states of India (Saikia 2022) because all rivers in this region can generate floods. Therefore, the region has been predominantly experiencing recurrent floods every year. Flooding in the Brahmaputra basin is a chronic phenomenon and affects a large area within the boundary (Kumar et al. 2022). Floodplain zones of Brahmaputra valley are rich in fertile soils throughout the entire valley (Shrivastava and Heinen 2005), which is a pull factor for human settlement even in such sensitive areas of the region, and hence people are more inclined to dwell with the floods. Therefore, the impact of flooding in the region is an ongoing phenomenon and can be seen mostly in urbanized, densely populated, and other developed areas prone to flooding (Samu and Kentel 2018). Assam Valley has long experienced small and large flood events

across the entire region, and reports indicate that Assam witnessed major floods in the years 1954, 1962, 1972, 1977, 1984, 1988, 2002, 2004 and 2012 (Debbarma and Deen 2020). With the increasing rate of rainfall in the Brahmaputra basin, the occurrence of floods is very regular in the basin. The emerging land use transformation and human growth in the lower Brahmaputra valley pose a high risk of flooding (Kumar et al. 2022). Various national and international instructions have been made for flood management, but the intensity of floods and the rate at which they devastate nature have still not been significantly reduced (Katyal and Petrisor 2011). However, structural and non-structural management strategies have been introduced in different river basins and vary from one to another (Talukdar and Kalita 2005; Watson and Biedenharn 2010). To reduce the flood-induced risks and effects, a suitable sustainable management plan along with a disaster framework and proper execution are of utmost concern (Taupo 2019). Though flooding is responsible for devastation, the degree of devastation can be reduced with the proper implication of mitigation measures (Samu and Kentel 2018). The main objective of the study is to analyze the flood-induced threats and explore different initiatives taken by government authorities to manage flood risks within the district.

The district is one of the most flood-prone regions of Assam and is situated near the right

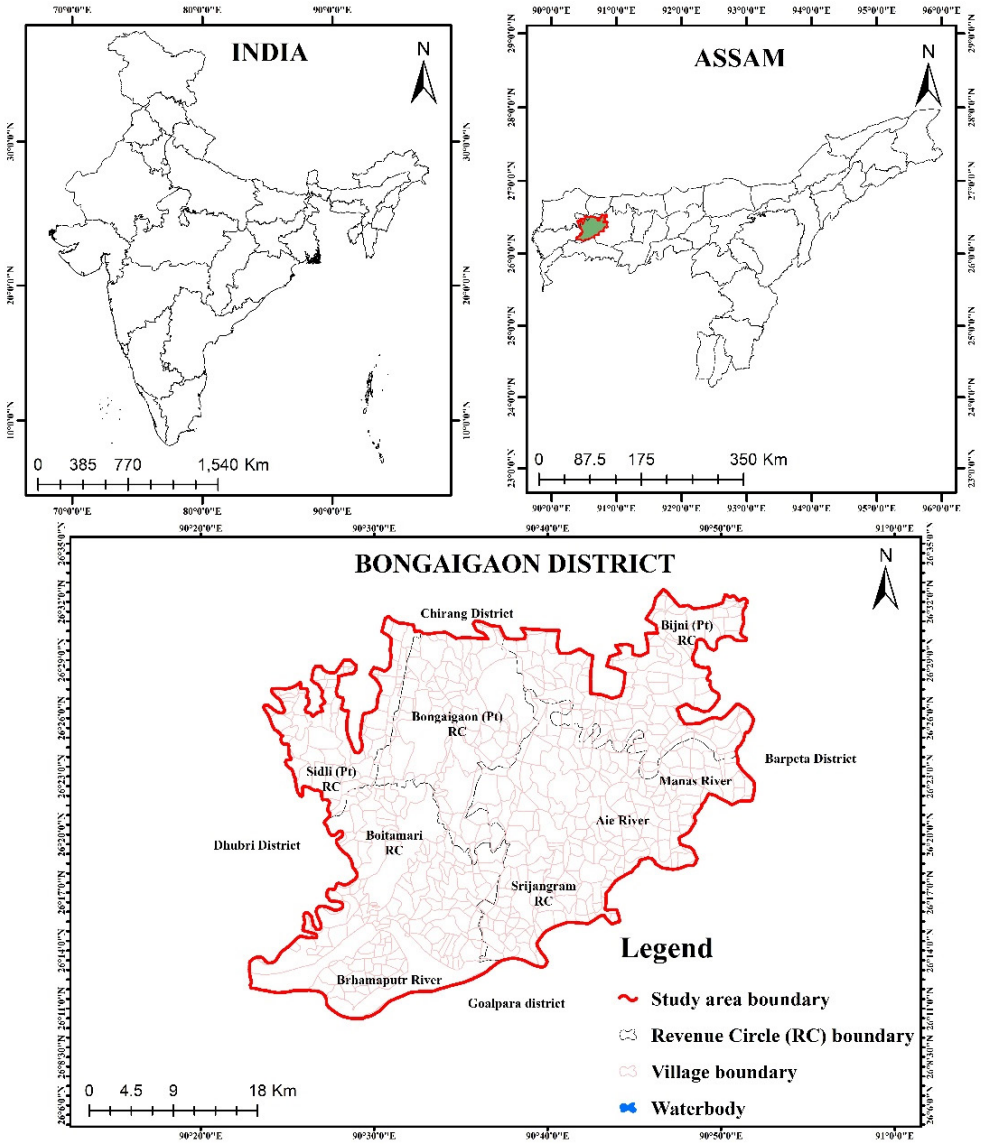

Fig. 1. Location of study area

Citation: Bulletin of Geography. Physical Geography Series 2024, 26, http://doi.org/10.12775/bgeo-2024-0001

bank of the river Brahmaputra. The study area is a part of the lower Brahmaputra valley, which is characterized by the river Brahmaputra and its tributaries. The geographical extension of the area ranges from 26°09'52"N to 26°30'03"N latitudes and 89°28'E to 92°22'47"E (Fig. 1). The area experiences flood hazards every year and creates associated flood risks among different aspects of the social life of the people residing in the area.

Materials and methods

The study area of the present research work has been selected as the Bongaigaon district of Assam. In the present study, data have been mostly taken from secondary sources, which have been gathered from the ASDMA and DDMA offices. Moreover, the Google Earth Engine platform has been used to identify the flooded area within the district for the years 2015, 2017, 2019 and 2021 using the Sentinel 1 SAR (GRD) dataset retrieved from (https://developers.google.com/earth-engine/datasets/catalog/sentinel). We have utilized an open-source ICIMOD dataset retrieved from (https://www.icimod.org) for preparing an inundation map for the year 2022 in GIS platform. However, in this study, flood shelter locations have been identified by the researcher through direct observation or interaction with flood-prone dwellers. In the process of flood shelter identification, researchers took some information from the governmental offices. The study also incorporates Google Earth Pro for the calculation of the distance and elevation of the respective flood shelters. Data have been represented with graphs and charts using MS Excel.

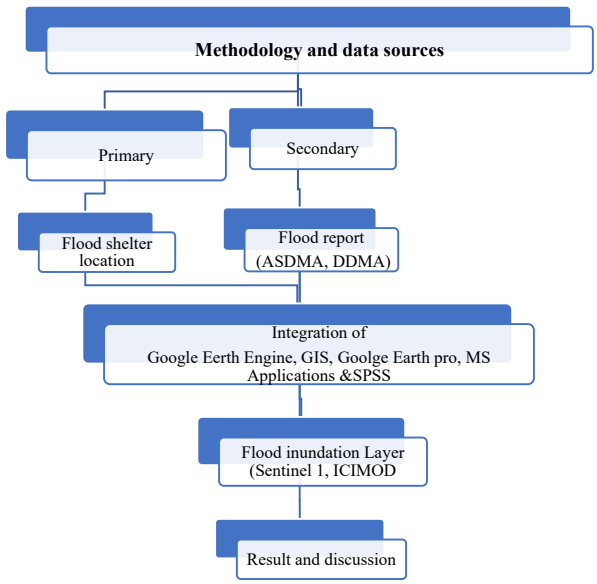

Fig. 2. Detailed methodology of the study

Results

Flood hazards and threats

The 2015 flood scenario

At the onset of the 2015 flood, the district experienced five waves of flooding. This devastating flood directly affected Bongaigaon (Pt), Boitamari, Bijni (Pt), Sidli (Pt) and the Srijangram revenue circle (i.e., local administrative unit of a district of an Indian state), with multifold impacts. During this flood period, a total of 300 revenue villages were affected (Fig. 3a), of which the Srijangram circle accounted for the villages affected most heavily. It has been observed that cropland, the human population and animals were tremendously affected by this flood (Table 1).

This flood also led to damage to various types of houses, some of which collapsed entirely and some of which were partially damaged. Figure 4a shows the flooded area of the district for the year 2015. With the advent of the first flood wave, it was found that one human life was lost. The 2015 flood started in the second half of May and lasted until September. This long flooding period also impacted livestock (Fig. 3d). It is found that a total of 53 animals were washed away, of which 18 were large animals and the remaining 35 were small. Furthermore, flooding also ruined many infrastructural facilities across the district, such as roads, embankments, educational institutions, etc. It was found that that year saw the highest number of houses damaged, as shown in Figure 3e. A total of 31 roads were damaged due to this flood event; likewise, Huramara-Barghala embankment, Dumerguri-Sontoshpur embankment, Sontoshpur pt-II M.V. school, and Sontoshpur L.P. school, and Dumerguri MEM school were completely devastated during the flood.

Table 1. Flood-induced threats on different aspects in Bongaigaon district

RC	Bongaigaon			Boitamari			Sidli (Pt)			Bijni (Pt)			Srijangram		
Year	Village affected [N°]	Crop area affected [Ha]	People affected [N°]	Village affected [N°]	Crop area affected [Ha]	Population affected [N°]	Village affected [N°]	Crop area affected [Ha]	Population affected [N°]	Village affected [N°]	Crop area affected [Ha]	Population affected N°]	Village affected [N°]	Crop area [Ha]	Population affected [N°]
2015	3	313	573	61	2,056	69,704	23	800	19,500	58	4,275	104,107	155	5,792	207,774
2017	2	70	200	55	641	46,471	18	411	7,430	44	5,759	68,616	143	8,163	219,163
2019	6	**NA**	27,000	65	1,002	73,912	12	**NA**	8,700	44	3,997	88,407	89	7,861	127,378
2021	NA	NA	NA	20	21	335	NA	NA	NA	48	579	46,835	161	812	17,056
2022	15	197	925	79	638	66,972	36	271	1,657	81	2,712	103,609	140	2,445	166,318

Note: NA = Not Available ; RC = Revenue Circle; N° = in number; Ha = in hectares)

The 2017 flood scenario

The occurrence of the flood in this district tends to continue at a rage every year; most parts of the district were also inundated due to floods in the year 2017 (Fig. 4b), which accounted for huge damages and losses. It has been assessed that a total of 262 villages were directly affected (Fig. 3a), with the highest number of affected villages being from the Srijangram Revenue Circle (Table I). The havoc nature of the flood in this area also demolished agricultural sectors, from the lives of livestock to crop area damages. The result shows that 15,044 hectares of crops were damaged within the district during the flood season (Fig. 3b). It is estimated that eight humans lost their lives, and 341,880 people were affected by the flood (Fig. 3c). Along with the flood, severe bank erosion in some parts of the district also damaged infrastructure. It was found that 50% of the Jaraguri embankment had been breached as a result of riverbank erosion problems.

The 2019 flood scenario

The hazardous flood of 2019 affected 216 villages (Fig. 3a) in the Bongaigaon district. It has been calculated that the highest number of villages affected in the Srijangram Revenue Circle is 89 (Table 1). A total of 12,860 hectares of crops were damaged, and the total number of affected persons was 325,397 throughout the flood season (Fig. 3b, c). Moreover, one human life was lost in the Srijangram circle, and 21 animals were washed away by flood waves. The flood of the year 2019 also destroyed some infrastructure, consisting of embankment breaches, road damage (full and partial), educational and health institution facilities, and others. The tremendous pressure of flood water damaged four embankments and ten roads which were mostly constructed under PMGSY (Pradhan Mantri Gram Sadak Yojana). Out of the total destroyed roads, five were fully damaged and five were partially affected. Moreover, it has been counted that 31 bridges collapsed badly. According to the ASDMA report, a total of 62 educational institutions and 29 health centers were damaged in 2019. The inundated area of the district is shown in Figure 4c.

Other infrastructural structures under the APDCL (Assam Power Distribution Company Limited), such as the LT line, Amp line, and K.V. lines were also destroyed in different parts of the district. LT line connections were damaged at ~18 places and KV lines at ~14 places within the district.

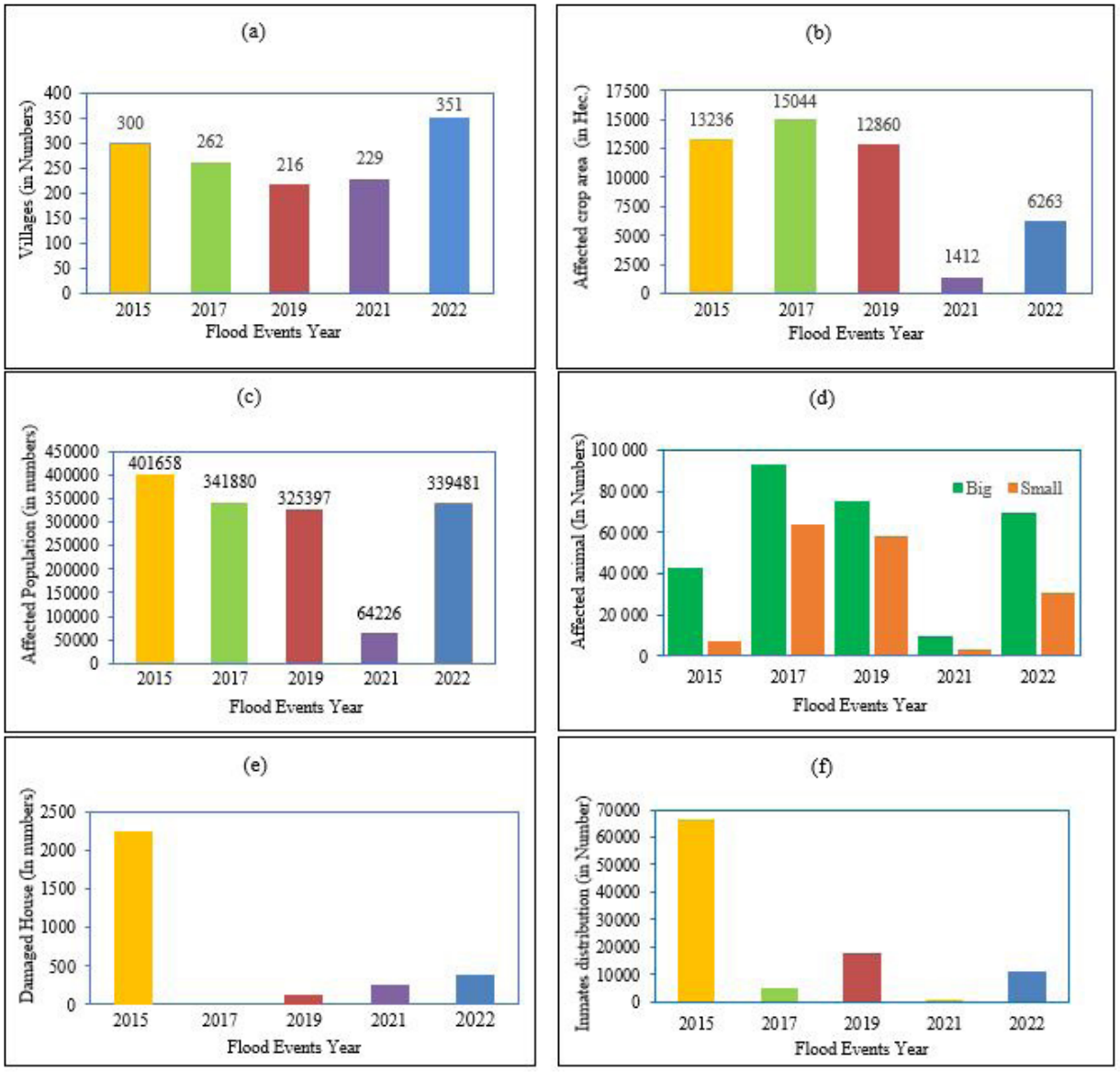

Fig. 3. (a) Flood-affected village in different flood years; (b) Flood-affected crop area in different flood years; (c) Flood-affected population in different flood years; (d) Flood-affected livestock in different flood years; (e) Flood-affected homes in different flood years; (f) Distribution of inmates in relief camps on different flood years
Source: ASDMA report

The 2021 flood scenario

Figure 4d depicts the area of the Bongaigaon district flooded during 2021. In this year, out of a total of five revenue circles, three were affected, and the remaining two were spared by the flood (Table 1). Out of the total affected villages, 20, 48 and 161 have been estimated within Boitamari, Bijni (Pt) and Srijangram circles, respectively. The total population that was affected directly or indirectly was 64,226 (Fig. 3c) and the total crop area spoiled was 1,412 hectares in the district (Fig. 3b). Due to the 2021 flood wave, a total of nine embankments were completely breached, 148 roads were destroyed, and 14 bridges collapsed.

The 2022 flood scenario

However, in the very recent flood of 2022, the district went through a tough situation with remarkable effects on socio-economic and other parameters of

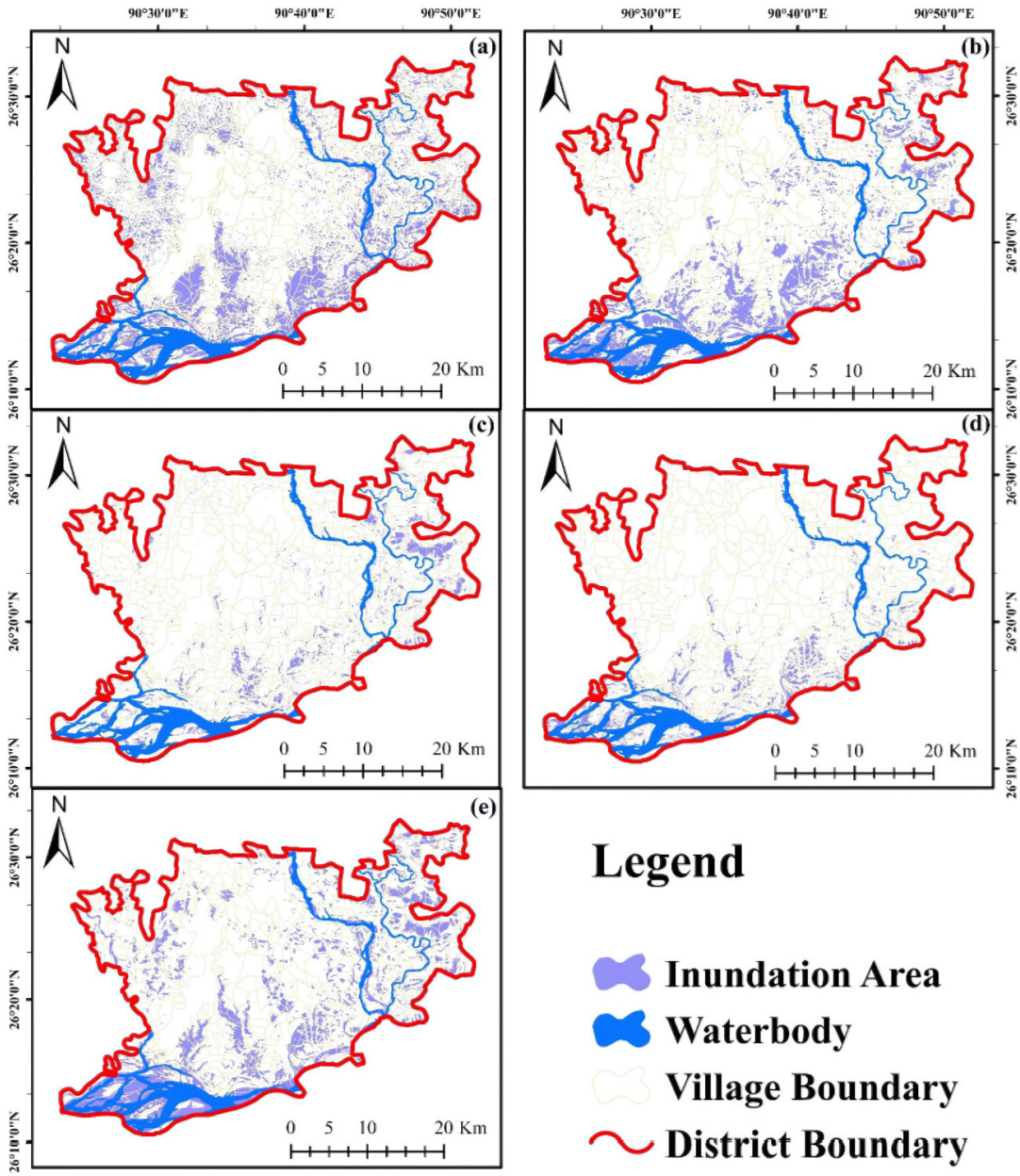

Fig. 4. Inundation map of the Bongaigaon district for diiferent temporal contexts: (a) 2015; (b) 2017; (c) 2019; (d) 2021; (e) 2022

the district. The inundated map of the district for the year 2022 is shown in Figure 4e.

Due to the flood in the region, 351 villages were directly affected (Fig. 3a) and 140 villages under the Srijangram circle can be seen as largely damaged (Table I). The result in (Fig. 3b) shows that 6,263 hectares of crops were destroyed this year, and 339,481 people were directly affected in the district in the 2022 flood (Fig. 3c). It can be seen that infrastructural assets such as three embankments were damaged and breached totally and 82 roads were destroyed, of which some were damaged fully and some partially due to flooding.

Citation: Bulletin of Geography. Physical Geography Series 2024, 26, http://doi.org/10.12775/bgeo-2024-0001

Execution measures and applications in the study area

Emergency response and evacuation process

Implementing immediate responses with adequate facilities during any natural disaster is the first and foremost step for minimizing the impact and fatalities (Feng and Cui 2021), where individual, community and governmental efforts contribute to establishing a proper execution measure. In the district, governmental efforts and the local public are involved in the emergency period, especially during the flood. The process of the evacuation system consists of first searching for trapped people and then sending them to a certain location (Lu et al. 2016). Distributing inmates (rescued persons or self-evacuated people) by effective means to certain flood shelter locations is another important step to reduce the flood stigma. Figure 3f shows the distribution of inmates at the circle level for the years 2015, 2017, 2019, 2021 and 2022.

Throughout the flood years, the Srijangram revenue circle recorded the highest numbers of inmate distributions as compared to other circles (Table 2). Moreover, different governmental agencies, armed forces and police forces did a tremendous job during the harsh times faced by the people of the district. It has been assessed from the ASDMA report that 628 people were successfully rescued in 2015, and 12 boats were deployed in the process. Similarly, in 2017, 2,042 people were rescued and 24 boats were deployed; 2,607 people were evacuated with 36 boats deployed in the year 2019; 764 people and 166 animals were rescued successfully during the emergency time of 2021; and 747 persons and 678 animals were rescued during 2022 with the deployment of 33 boats.

Relief centers and materials

Distribution of relief supplies to flood-affected people is an essential operational strategy to ensure they are not deprived of the minimum level of basic food for sustaining life (Yan et al. 2021). Relief distribution, especially after shocks, upholds the moral and equitable principles of the flood victims (De la Torre et al. 2012). Efforts that are made by the government authority, especially from the district disaster management authority (DDMA) of the Bongaigaon district, regularly operate the relief centers and relief distribution in the context of a disaster mitigation approach. Sufficient numbers of relief centers were opened across the district to supply food and other logistics. It can be seen that a total of 90 relief distribution centers were established in the year 2015, whereas 121, 100, 69 and 177 relief distribution centers were created in the years 2017, 2019, 2021 and 2022, respectively. Flood distribution centers are designed to store and allocate food and allied items for flood victims in the district. It can be seen in Table 3 that food items like rice, dal, salt and other items were distributed accordingly for considerable years.

Flood shelter (Identification & typology)

The location of an ideal flood shelter with adequate facilities for disaster victims is one of the crucial factors in disaster response and management criteria (Akgün et al. 2015; Ekaputra et al. 2022).

Table 2. Distribution pattern of shelter occupants in different flood periods in Bongaigaon district

RC	Bongaigaon	Boitamari	Sidli (Pt)	Bijni (Pt)	Srijangram
Year	Shelter occupant distribution [N°]	Shelter occupant distribution [N°]	Shelter occupant distribution [N°]	Shelter occupant distribution [N°]	Shelter occupant distribution [N°]
2015	573	1,035	NA	4,370	60,500
2017	200	1,351	1,850	-	1,351
2019	1,785	4,831	1,320	8,711	1,290
2021	NA	NA	NA	232	446
2022	153	656	1,657	1,306	7,144

Note: NA = Not Available; RC = Revenue Circle

Table 3. Distribution of relief materials during different years in Bongaigaon district

RC	Bongaigaon				Boitamari				Sidli (Pt)				Bijni (Pt)				Srijangram			
Year	R [Q]	D [Q]	S [Q]	MO [L]	R [Q]	D [Q]	S [Q]	MO [L]	R [Q]	D [Q]	S [Q]	MO [L]	R [Q]	D [Q]	S [Q]	MO [L]	R [Q]	D [Q]	S [Q]	MO [L]
2015	8.9	1.7	1.3	42	2127.3	407.9	120.7	NA	NA	NA	NA	NA	477.8	89.6	24.5	NA	2483.5	527.5	77.6	195.4
2017	1.0	0.2	0.06	0.02	1703.8	370.9	100.6	NA	89.5	16.7	5.01	501.06	2276.06	433.7	130.1	7006.5	3726.8	729.6	132.5	NA
2019	10.8	2.1	0.6	63.66	4827.04	944.11	283.46	NA	109.1	20.76	6.23	623.04	2737.4	456.1	136.9	13684	3285	645.2	99.1	NA
2021	NA	NA	NA	NA	4.24	1.01	0.3	30.15	NA	NA	NA	NA	904.1	172.1	15.7	237	701	130	38.88	3887.4
2022	9.8	1.8	0.56	55.5	1391.0	265	79.5	172	18.2	3.3	0.9	99.4	1719.7	314.1	94.2	2657.3	2052.7	387.03	115.4	11543.4

Note: Note: NA= Not available; R = Rice; D = Dal; S = Salt; MO = Mustard oil; O = Other items, (-) = Data not found; RC = Revenue Circle; [Q] = in quintals; [L] = in liters

Establishing flood shelters depends on many factors, of which accessibility, elevation, space, etc. play a decisive role (Rahman et al. 2015).

Figure 5 shows the variety of flood shelters in the study area, some of which are identified and created by government authorities (ideally, permanent flood shelters), and others of which are spontaneously prepared by the victims themselves for temporary protection during an emergency.

Table 4 shows the locations of all the flood shelters in the region, in addition to their names and typologies. The study also grouped the shelter's locations into various clusters according to some associated factors such as proximity to river (distance in km), proximity to road (distance in km) and elevation (in meters). The result shows that 11, 14 and 6 flood shelters are found near Brahmaputra, Aie and Manas Rivers, respectively. However, 7, 1 and 29 flood shelters are found near national highways NH-31 C, NH 31 and major roads other than NHs, respectively (Table 5).

Moreover, the study further estimated different classes of shelter altitudes. It has been found that ten shelters are situated at an altitude of less than 60.96 m from MSL (Mean Sea Level) whereas 31 and 9 shelters are situated at a height of 60.95 to 76.2 m and more than 76.2 m from MSL, respectively (Table 6).

Discussion

Under different circumstances and factors, the negative consequences of flood phenomena have been growing globally over time (Mai et al. 2020). Owing to this inevitable phenomenon in the Brahmaputra valley of Assam, several districts have been dealing with property damages and social instability, which in the regions have been causing economic growth and development that cannot be sustained (Rai and Mehra 2019; Das and Deka 2021). Bongaigaon district is one of the worst flood-affected regions in the westernmost part of Assam, where flooding has irreversible effects on people and other properties. The years in which the region was predominantly affected by floods and witnessed major events were 1954, 1962, 1972, 1977, 1984, 1988, 2002, 2004 and 2012 (Debbarma and Deen 2020). The Brahmaputra River, along with

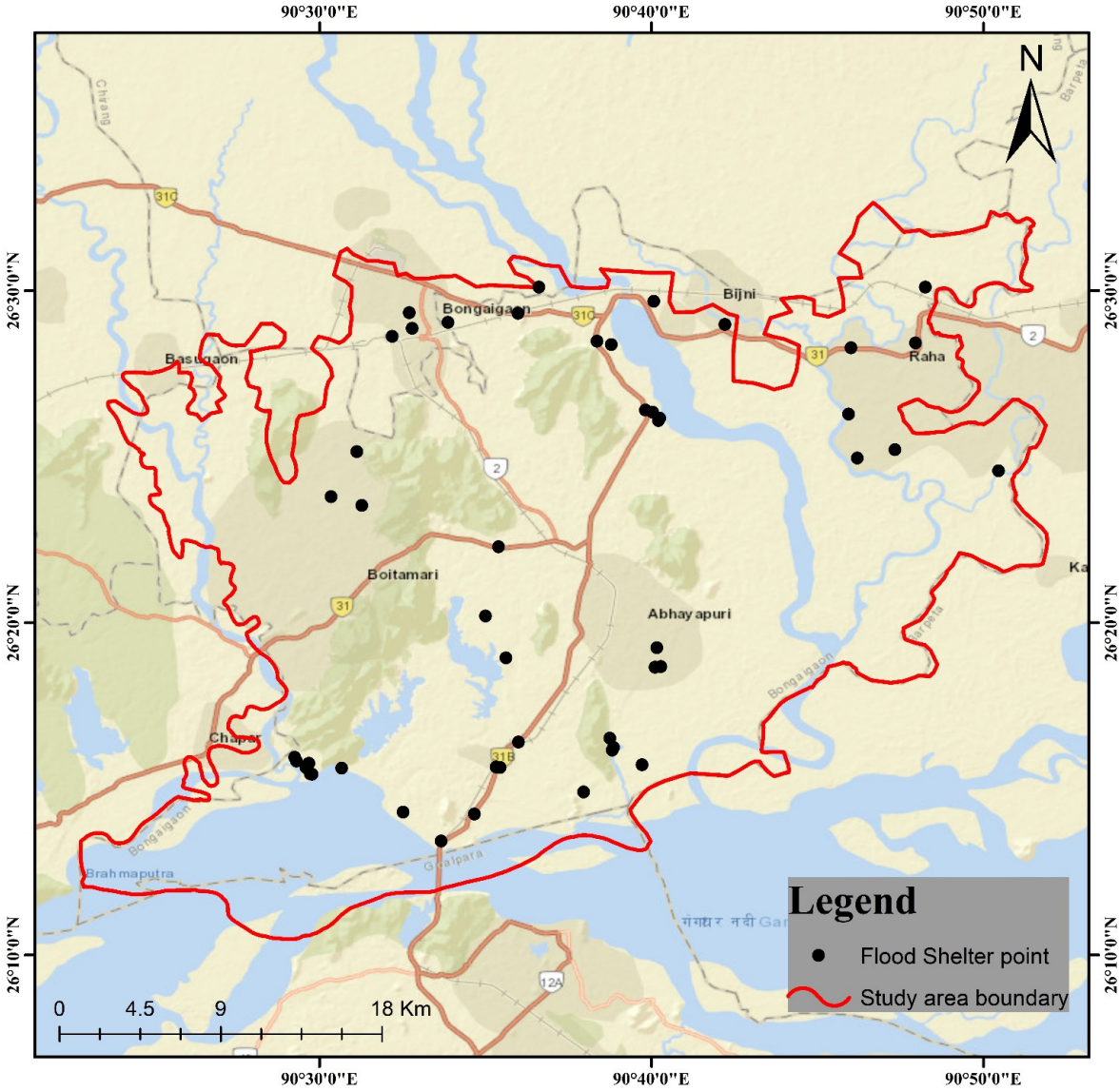

Fig. 5. Flood shelter map of Bongaigaon district

its tributaries, drains a huge amount of water in the monsoon season, creating flooding in this entire region (Singh and Kumar 2017). Monsoonal rainfall between June and September ranges from 1,750 mm to 6,400 mm within the entire Brahmaputra basin in Indian territory (Bhattachaiyya and Bora 1977). Every year, flooding does terrible harm to society as a result of extreme rainfall. The study area falls under the lower Brahmaputra floodplain zone, which is attributed to the river Brahmaputra and its major tributaries like the rivers Manas and Aie, which carry a high flux of water discharge from the upper reach of the Himalayan region, leading to flooding in and around the area after rising water levels. The water level of the rivers Brahmaputra, Manas and Aie fluctuates annually and exceeds the danger level. The result is the havoc of flooding in the entire Bongaigaon district. Therefore, understanding and evaluation of existing flood mitigation measures in the region can reveal significant pros and cons to the strategies and provide more room to develop relevant, efficient, integrated approaches for flood management systems (Glago 2021). The result indicates that the Srijangram circle is the most damaged circle of the district. Out of all the considered years, 2022 proved to be the greatest flood year, with the highest number of villages affected, whereas the number of

Table 4. Location of flood shelters for emergency purpose in the study area

Shelter ID	Latitude	Longitude	Shelter	Typology of Shelter
1	26°15′27.29"	90°29′43.45"	Bhairav Pahar L.P School	P
2	26°15′26.49"	90°29′46.57"	Bhairav Pahar Culvert	T
3	26°15′37.67"	90°30′40"	Pub Majeralga GP	P
4	26°15′38.67"	90°29′35.53"	Kochudola Primary Health center	P
5	26°15′46.17"	90°29′40.75"	Kochudola High School	P
6	26°15′50.41"	90°29′18.51"	Oudubi GP	P
7	26°15′56.92"	90°29′15.20"	Oudubi M.V School	P
8	26°14′18.05"	90°32′31.03"	Chatpara-Koreya Pt -2 Pool	T
9	26°13′25.91"	90°33′39.91"	Jogighopa Vatipara Street	P
10	26°14′14.67"	90°34′39.98"	kabaitari Part-3 Road	P
11	26°15′39.58"	90°35′19.18"	Chalantapara HS School	P
12	26°15′38.65"	90°35′26.44"	Chalantapara M.V School	P
13	26°16′24.55"	90°35′59.58"	Bechimari Railway track	T
14	26°16′10.01"	90°38′49.19"	Malegarh Foothill track no-1	T
15	26°16′14.69"	90°38′51.52"	Malegarh Foothill track no-2	T
16	26°16′31.52"	90°38′44.82"	999 No. Jitkibari L.P School	P
17	26°14′54.51"	90°37′57.43"	Malegarh HS School	P
18	26°15′43.74"	90°39′43.06"	Borjona street	T
19	26°18′39.71"	90°40′06.61"	Haripur Community temple house	T
20	26°18′41.10"	90°40′17.12"	Haripur-Amguri Bridge	T
21	26°19′15.03"	90°40′09.79"	533 No Bowalipara L.P School	P
22	26°26′5.21"	90°40′12.57"	Jaraiguri Nabanur Pre-senior madrasa M.E School	P
23	26°26′09.66"	90°40′14.85"	8 no Hapachara GP	P
24	26°26′20.54"	90°40′02.09"	Sesapani-Jaraiguri Embankment	T
25	26°26′24.19"	90°39′49.08"	Sidalsuti HS School	P
26	26°28′58.88"	90°42′12.80"	Gerukabari High School	P
27	26°47′37.78"	90°79′92.44"	Manikpur Anchalik College	P
28	26°47′12.98"	90°76′68.69"	Bhatipara market place	T
29	24°44′20.59"	90°73′63.85"	Bhandara market place	T
30	26°43′80.25"	90°76′56.23"	Salabila High School	P
31	26°47′46.38"	90°63′93.11"	Hapachara L.P School	P
32	26°47′29.35"	90°64′65.33"	Balajani L.P School	P
33	26°41′59.96"	90°77′35.62"	Bashbari Market place	T
34	26°40′95.82"	90°84′09.19"	Nowagaon L.P. School	P
35	26°42′01.94"	90°78′89.44"	Awlaguri L.P. School	P
36	26.50′17.29"	90°80′41.57"	Patiladoha High School	P
37	26°48′40.42"	90°56′45.13"	Netaji Bidyan Nekatan	P
38	26°48′10.74"	90°54′65.28"	Kalibari Community Club	P
39	26°48′89.10"	90°54′50.36"	North Bongaigaon High School	P
40	26°47′70.85"	90°53′64.85"	Dolaigaon GP	P
41	26°50′17.85"	90°61′01.81"	Popragaon LP School	P
42	26°48′86.00"	90°59′96.96"	Chaprakata MV School	P
43	26°51′79.26"	90°59′18.61"	Daukhanagar ME Madrassa	P
44	26°39′65.69"	90°50′58.39"	Dhalagaon MV School	P
45	26°39′22.79"	90°52′12.26"	Dewangaon Sutradharpar L.P. School	P
46	26°37′15.03"	90°58′98.57"	Bashbari GP	P
47	26°41′92.27"	90°51′87.44"	JaladhishSangha Library	P
48	26°31′57.12"	90°59′36.28"	Ghilaguri Pt-III L.P. School	P
49	26°33′67.13"	90°58′33.66"	Binapani High School	P
50	26°29′40.72"	90°40'4.3212"	Chowraguri High School	P

Note: P = Permanent flood shelter; T = Temporary flood shelter

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Table 5. Distances of flood shelter from different riverbanks, NH roads & other major roads

Near to Brahmaputra river bank		Near to Manas River bank		Near to Aie River bank		Near to NH 31-B		Near to NH 31-C		Near to NH 31		Near to other roads	
Sh. Id	Dist. [km]	Sh. Id	Dist. [km]	Sh. Id	Dist. [km]	Sh. Id	Dist. [km]	Sh. Id	Dist. [km]	Sh. Id	Dist. [km]	Sh. Id	Dist. [km]
1	0.17	27	1.15	14	3.80	10	0.03	26 27	0.36	46	0.04	8	2.60
2	0.14	36	2.06	15	3.96	11	0.06	36 41	0.15			3	0.47
3	0.80	30	0.12	16	5.23	12	0.10	42 43	1.43			2	0.59
4	0.55	33	0.57	18	1.7	13	0.09	50	1.05			1	0.57
5	0.76	35	1.53	19	8.63	25	0.02		0.04			4	0.26
6	0.26	28	1.23	20	8.42	31	0.04		3.22			5	0.01
7	0.32			21	6.75	32	0.68		0.49			6	0.03
8	0.1			22	0.37							7	0.05
9	0.66			23	0.25							44	0.79
10	1.68			24	0.47							45	0.83
17	1.42			32	0.42							47	0.02
				41	1.08							40	1.44
				43	1.84							38	0.82
				50	1.23							37	1.10
												39	0.63
												49	0.02
												48	0.02
												17	0.01
												18	1.46
												14	0.01
												15	0.01
												16	0.01
												19	0.75
												20	1.22
												21	0.61
												34	2.80
												35	0.97
												33	2.68
												30	1.43

Note: Sh. = Flood Shelter; Dist. = Distance

villages affected was lowest in 2019. Similarly, the affected number of people is highest in the year 2015 and lowest in 2021. The greatest crop areas and livestock numbers (big and small animals) were impacted in 2017. To minimize flood fatalities for long-term effects, understanding flood risk along with the integration of different structural and non-structural assets is of utmost importance (Sayers et al. 2013). During the flood emergency, the district's authority deployed different execution measures

Table 6. Locational pattern of flood shelters based on elevation in the district

Particular	Shelter placed at respective elevation [in meters] from MSL (Mean Sea Level)		
Elevation Ranges	<70	70–76	>76
Shelter ID	1, 2, 3, 4 ,7, 9, 10, 13, 20, 29	5, 6, 8, 11, 12, 14, 15, 16, 17, 18, 19, 21, 22, 23, 24, 25, 26, 27, 28, 30, 32, 33, 34, 35, 36, 44, 45, 46, 48, 49, 50	31, 37, 38, 39, 40, 41, 42, 43, 47
Total	**10**	**31**	**9**

to reduce the flood impact in the region. In the above-mentioned years, several boats were deployed in the submerged area of the district and rescued a large number of humans and domestic animals during the harsh times. The result shows that the distribution of self-evacuees and rescued persons in the various revenue circles is regulated as a prime mitigation measure during the flood season. Apart from that, relief center establishments also play an important role in the distribution of relief items like food for people and other domestic animals that have become victims of floods. The study also finds flood shelters have good road network connectivity and are well placed at definite elevations, which help in the distribution of people and goods with a quick response. In the context of minimizing threats and managing purposes, rescue operations, the allocation of people to flood shelters, the distribution of shelter occupants, food, and other necessary supplies were implemented. Moreover, local-level monitoring and assessment are of utmost importance to the reduction of flood damages.

Conclusion

Flooding in the region is a common phenomenon. The region's general growth and development are comprehensively hampered by floods. The study's findings show that the Srijangram revenue circle experienced the highest flood impact among all the revenue circles of the district over time. This particular revenue circle is highly sensitive to the rivers Aie and Manas with respect to flood risk. Moreover, the study finds that, in 2022, flood impact was quite high in the district. Since flooding occurs frequently in the district, proper mitigation measures will lessen the potential impact of flooding. The results implied the need for strategic facilities such as the provision and monitoring of flood shelters for flood victims, rescue operations in times of emergency, the provision of relief items, and so forth to be carried out using governmental aid and support in order to mitigate flood impacts. Furthermore, embankment breaching is another important issue that leads to more havoc in certain riverine tracks during flood periods. Thus, a holistic approach that includes a detailed identification of flood-prone zones, zones suitable for flood shelters, zoning of embankment breaching points and embankment suitability analysis, and the preparation of a community-based flood management model, etc., may be extremely important to improve the execution measures for a sustainable flood management system in the district.

Acknowledgements

The corresponding author P. Dutta kindly thanks the Head, Department of Geography, Gauhati University for providing all the necessary facilities to carry out this study. We further would like to acknowledge data sources e.g., offices and websites like ASDMA Guwahati, DDMA Bongaigaon, Assam; AWRMI, Beltola, Guwahati, Assam; Unite States Geological Survey (USGS); ICIMOD; and Copernicus Open Access Hub. The author P. Dutta also would like to thank Prof. Bimal Kumar Kar, Dept. of Geography, (GU); Dr Jatan Debnath (Post Doc. fellow, GU) for their kind help and suggestions. The corresponding author further acknowledges Mr Ananta Samanta (District Project Officer, Bongaigaon, ASDMA) for his continuous help and support in the data-gathering process. Last not the least, we extent our heartfelt thanks to each and every anonymous reviewer.

Disclosure statement

No potential conflict of interest was reported by the authors.

Author contributions

Study design: PD; data collection: PD; statistical analysis: PD; result interpretation: PD; manuscript preparation: PD, SD; literature review: SD.

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Received 5 June 2023
Accepted 15 January 2024