Satellite images for extraction of flood disaster footprints and assessing the disaster impact: Brahmaputra floods of June–July 2012, Assam, India

C. M. Bhatt*, G. Srinivasa Rao, Asiya Begum, P. Manjusree, S. V. S. P. Sharma, L. Prasanna and V. Bhanumurthy

RS Applications Area, Disaster Management Support Division, National Remote Sensing Centre, Indian Space Research Organisation, Balanagar, Hyderabad 500 037, India

Satellite images provide information on the flood disaster footprints, which is essential for assessing the disaster impact and taking up flood mitigation activities. The Brahmaputra floods that occurred during June–July 2012 devastated a large part of Assam. This article discusses the maximum spatial extent affected due to the flood event, villages marooned and population affected, with the aid of multi-temporal satellite images coupled with the hydrological observations and freely available gridded population data. The study shows that about 4.65 lakh ha area was submerged, 23 of the 27 districts in Assam had more than 5% of the total geographical area submerged, about 3829 villages marooned and 23.08 lakh people were affected. Identification of the spatial extent of areas most vulnerable to flooding, captured from the satellite images acquired during the peak flood period will be helpful for prioritizing appropriate flood control measures in the flood-affected regions.

Keywords: Disaster footprints, floods, GIS, inundation, population, remote sensing.

THE recurrent flood events at frequent intervals demand the need for identification of flood-prone areas for prioritizing appropriate flood control measures[1]. Identification of the spatial extent of the area most vulnerable to flooding is one of the most important non-structural measures for mitigation of floods[2]. Conventional method for identification of flood-prone areas and formulation of effective remedial measures requires extensive field surveys, information about flood plains, flood duration, river configuration, etc., which is a time-consuming, complex and expensive task, whereas hydrological modelling requires reliable historical, hydrological database from well-distributed hydrological stations and fine resolution digital elevation models (DEMs), which often are not available[3,4]. The ability of space technology to provide basic information in space, time and frequency domains has proved useful in providing permanent records by mapping, monitoring and managing flood dynamics[5]. Satellite images available from a variety of active and passive sensors, operating in the visible, thermal and microwave ranges, provide cost-effective, crucial information on flood-inundated areas for different flood magnitudes[4,6,7]. Satellite data on floods remain a rich source of information that can provide disaster footprints of higher accuracy useful for assessing the disaster impact and taking up flood mitigation activities[1,4,8–14]. During June–July 2012, Assam witnessed devastating floods due to high water levels in the Brahmaputra and its tributaries, causing huge loss of human lives, cattle and infrastructure. This article discusses the maximum spatial extent affected due to the flood event, villages marooned and population affected with the aid of multi-temporal satellite images coupled with the hydrological observations and freely available gridded population data.

Environmental setting of the study area

Assam has a total geographical area (TGA) of about 78,438 square kilometers. It is located between 90–96°E long. and 24–28°N lat. and forms a part of the Brahmaputra basin (Figure 1). The Brahmaputra basin is a tectono-sedimentary basin, 720 km long and 80–90 km wide, underlain by Recent alluvium approximately 200–300 thick[15]. The elevation in the area ranges from 120 m at Kobo in the extreme east through 50.5 m at Guwahati to 28.45 m at Dhubri in the extreme west[16]. The basin lies within the monsoon rainfall regime, receiving an annual rainfall of about 230 cm. Each year, the mighty Brahmaputra river traversing across the length of Assam causes huge destruction and irreparable loss to the state's economy which is largely agrarian during monsoon season.

Data used

Due to persistent cloud cover over the basin, data from microwave Synthetic Aperture Radar (SAR) were preferred

*For correspondence. (e-mail: cmbhatt@nrsc.gov.in)

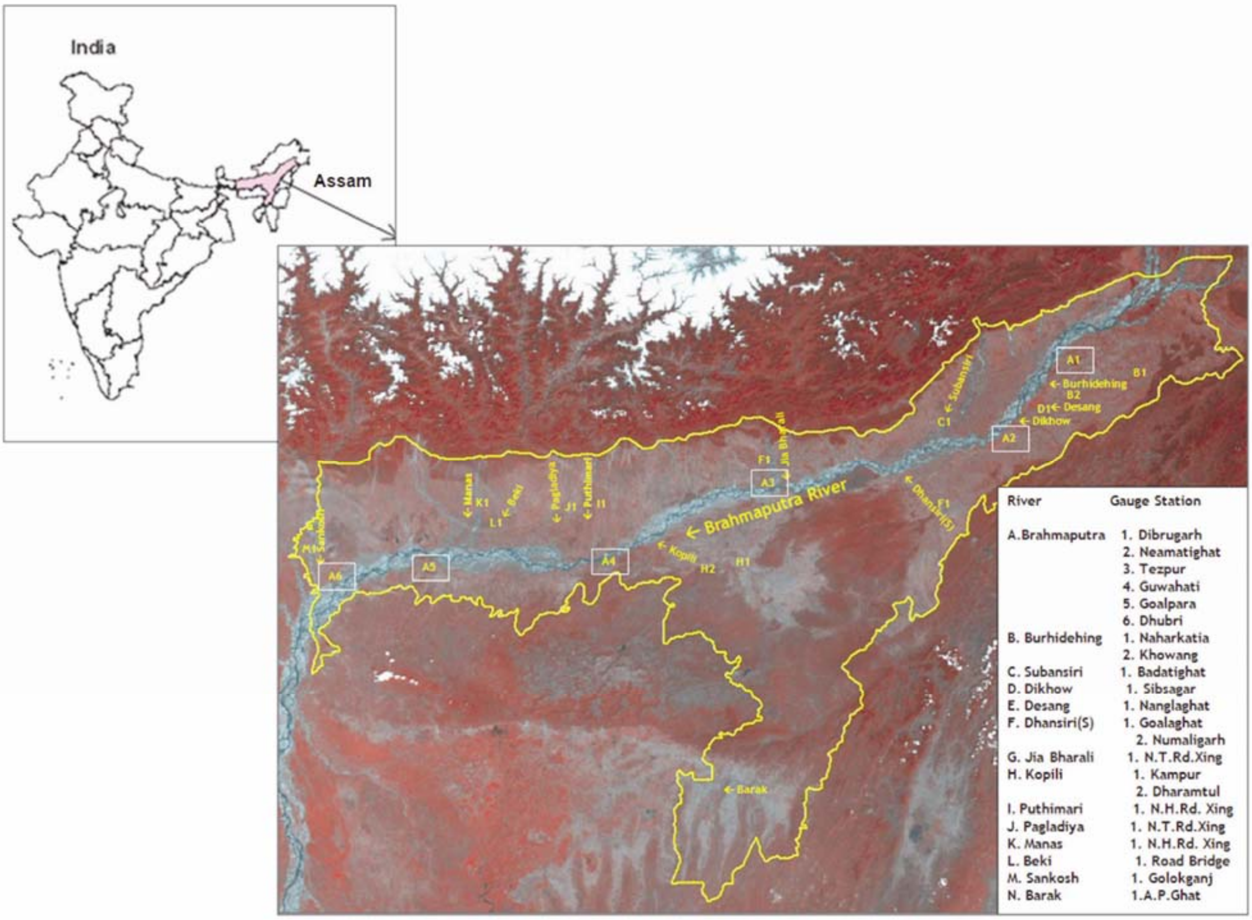

Figure 1. Location map of the study area and location of Central Water Commission gauge stations along Brahmaputra river and associated tributaries.

for mapping and monitoring of floods as the SAR sensors can image the Earth through clouds and enable dynamic hydrological events like floods to be captured[17]. Microwave Scan SAR Wide Beam Mode satellite data of 27, 29 and 30 June and 2 July 2012 were used for delineation of flood-inundated areas. For an overview of the flood situation in the Assam Valley, which is very long having an approximate width of about 720 km, Scan SAR Wide Beam Mode data having a swath of 500 km and moderate resolution 50 m (pixel spacing) were used. SAR data in HH polarization which is less sensitive to small-scale roughness of waves on the water surface than VV-like polarization or cross-polarization, and with shallow incidence angles (20–49°) which provide better discrimination between open water and non-flood areas were used[18]. Cloud-free optical data for part of Assam were acquired from Indian Remote Sensing (IRS) Resourcesat-2 LISS (Linear Imaging Self-Scanning Sensor)-III (23.5 spatial resolution) data of 29 June 2012 and Resourcesat-1 LISS-III data of 1 July 2012, and pre-flood Resourcesat-1 AWiFS (Advanced Wide Field Sensor) data of 13 February 2012 for comparison of the flood situation before and during inundation and understanding of the flood problem.

Daily water-level data provided by Flood Forecasting Monitoring Directorate, Central Water Commission (CWC) for the stations located in Assam (Figure 1) were used for generating flood hydrographs and understanding flood progression and recession. Gridded population data of the world (GPW, CIE-SIN) version 3 for 2010 available at 2.5 arc-min resolution were downloaded and used for identifying the flood-affected population.

Methodology

The methodology adopted for the analysis is explained below and shown in Figure 2. In the present study raster-based analysis was carried out using ERDAS Imagine (version 9.3) and the GIS-based analysis was done using ARC GIS (version 9.3).

Flood inundation mapping

For delineation of flood inundation, microwave SAR data were pre-processed. This involves the generation of beta naught (dB) image and then computation of sigma naught (dB) and incidence angle (degrees) images. SAR data have an inherent granular noise called speckle which degrades the quality of the image and makes interpretation and classification more difficult. Therefore, the SAR images were filtered to suppress speckle using median filter. The speckle-suppressed images were then geometrically corrected with master reference images to a defined projection system for positional accuracies. Thresholding is one of the most frequently used techniques to segregate flooded areas from non-flooded areas in a radar image[19]. Backscatter response at river cross-sections and flood pockets in near and far ranges is evaluated by drawing the transect lines and an average backscatter range is chosen. From the average backscatter profiles generated, it is observed that the backscatter of water is in the –15 to –25 dB range. Using a variable incidence angle threshold model, intensities within these ranges are regarded as water, whereas pixels with intensities above the threshold are regarded as non-flooded. To extract the flood inundation layer, a mask which comprises the water bodies, river channel, waterlogged areas and hill boundaries is applied to the output layer derived from thresholding process. Mask layer is prepared from pre-flood data and land-use/land-cover data. Further refining of the flood inundation layer is carried out by grouping and removing the stray pixels using the clump and sieve tools. Finally, using recode command a single bit flood inundation layer is generated containing flooded (grid code = 1) and non-flooded (grid code = 0) classes.

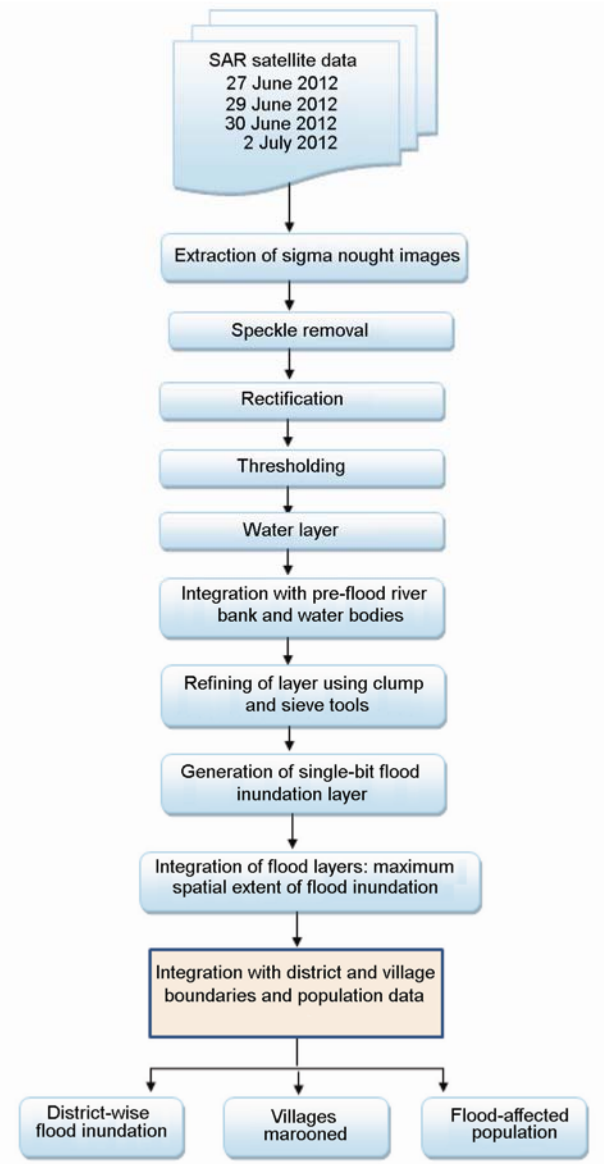

Figure 2. Flowchart of the methodology adopted for satellite data analysis, generation of flood inundation layer.

Computation of flood inundation statistics

The maximum spatial extent of flood inundation layer is converted from raster to vector format. The output flood polygon coverage is then integrated with the Assam district boundary coverage using Union command. From the integrated flood and district layer, districts having flood inundation (grid code = 1) are selected based on the logical expression using Select command. Calculate Area command is then used to compute area for each polygon with values representing the area of the polygons in square units of the output coordinate system. The area computed is then converted to hectares using the Calculate Field command. Finally, using Summary Statistics area of flooded polygons within each district is summarized and the output is stored as a table (dbf file) format.

Identification of villages marooned

To identify the villages marooned in a district, flood inundation layer is extracted using Clip command for each district. The Clip command uses the district boundary (clip coverage) to cookiecut features and attributes from the flood inundation layer (input coverage). The layer clipped is integrated with the village boundary layer of the corresponding district using Union command. Further, using the Select command villages having flood inundation are identified and their area is computed and converted to hectares. The flood inundated area is then summarized using Summary Statistics based on the village name and stored in form of a table (dbf file) format.

Identification of flood-affected population

The flood footprint (i.e. maximum flood spatial extent) was intersected with the GPW 2010 population data downloaded for the Indian subcontinent. The Zonal Statistics Function in the ARC GIS Spatial Analyst tool was used to obtain the population affected due to flooding in each district.

Table 1. Water level of Brahmaputra and associated tributaries between 22 June and 2 July 2012

		Water level 2012										
Station	River	22-Jun-12	23-Jun-12	24-Jun-12	25-Jun-12	26-Jun-12	27-Jun-12	28-Jun-12	29-Jun-12	30-Jun-12	1-Jul-12	2-Jul-12
Dibrugarh	Brahmaputra	105.38	105.17	105.51	**106.09**	**106.26**	**106.05**	**105.73**	**105.73**	105.18	105.01	104.86
Neamatighat	Brahmaputra	84.86	**85.71**	**85.50**	**86.22**	**87.21**	**87.08**	**86.63**	**85.90**	**85.42**	**85.26**	**85.18**
Tezpur	Brahmaputra	63.83	64.15	64.78	64.92	**65.51**	**66.06**	**66.11**	**65.93**	**65.28**	64.64	64.14
Guwahati	Brahmaputra	47.38	47.46	47.94	48.65	48.80	**49.8**	**50.36**	**50.51**	**50.51**	**50.21**	49.21
Goalpara	Brahmaputra	34.90	34.90	35.01	35.44	35.96	**36.38**	**36.8**	**36.98**	**37.07**	**36.90**	36.22
Dhubri	Brahmaputra	27.91	27.87	27.89	28.08	28.56	**29.16**	**29.56**	**29.83**	**29.91**	**29.90**	**29.40**
Naharkatia	Burhidihing	116.58	116.87	117.29	118.90	118.80	118.63	118.5	117.60	NA	NA	116.67
Khowang	Burhidihing	99.75	99.96	100.29	101.77	**102.60**	**102.75**	**102.88**	**102.67**	101.70	NA	100.53
Nanglamoraghat	Desang	92.47	92.20	92.94	93.95	93.95	94	93.7	92.99	NA	NA	91.18
Shivsagar	Dikhow	90.47	**92.86**	**92.61**	91.75	91.89	91.9	91.24	90.43	NA	NA	89.83
Badatighat	Subansiri	80.09	80.50	80.58	80.77	81.64	82.03	81.85	81.44	NA	NA	80.17
Golaghat	Dhansiri (S)	87.40	87.94	87.77	87.36	87.18	87	88.1	87.49	NA	NA	87.02
Numaligarh	Dhansiri (S)	75.64	77.22	**77.48**	77.05	**77.51**	**77.95**	**78.2**	**77.70**	77.12	76.63	76.59
Jiabharali_NTX	Jiabharali	76.75	**77.41**	**77.46**	**77.70**	**77.66**	**77.37**	**77.14**	76.78	76.44	76.21	76.40
Kampur	Kopilli	56.44	56.51	56.43	56.19	58.63	**61.17**	**61.56**	**61.49**	60.09	59.86	59.20
Dharmatul	Kopilli	51.56	51.73	51.81	52.06	52.79	55.42	55.8	55.95	**56.13**	**56.10**	55.98
Puthimari_NHX	Puthimari	51.10	51.36	51.42	51.24	**52.92**	**52.6**	**52.09**	51.45	51.02	NA	50.54
Pagladiya_NTX	Pagladiya	51.37	51.21	51.05	51.42	52.25	**53.42**	**53.26**	52.41	51.86	NA	51.23
Beki NHX	Beki	44.55	44.92	44.89	45.08	**45.43**	**45.5**	**45.34**	44.93	44.73	44.70	44.54
Manas NHX	Manas	46.42	46.55	46.50	46.91	**48.68**	**48.77**	**48.46**	47.40	NA	NA	46.46
Golakganj	Sankosh	28.25	28.60	28.59	28.82	29.52	29.76	29.83	29.74	29.29	NA	28.65
APGhat	Barak	17.41	17.44	17.24	17.20	18.39	**20.34**	**21.05**	**20.78**	19.29	NA	17.10

Bold letters: Above danger level.
Source: Central Water Commission (CWC) Water and Related Statistics, 2010 document, www.cwc.nic.in/ISO_DATA_Bank/W&Realted-Statistics_2010.pdf; accessed on 10 September 2012 and daily water level data, www.india-water.com//ffs/index.htm

Floods in Brahmaputra and its tributaries

Hydrological observations

In India, CWC is the national nodal organization which carries out the flood forecasting activity on the major rivers and has fixed warning level (WL) and danger level (DL) at important sites. A river is said to be in flood when its water level touches or exceeds DL at that particular site; when the water level is 1 m or more above DL, it is known as major flood[20,21]. Table 1 shows that all the sites along the Brahmaputra river and its associated tributaries were below DL till 22 June 2012. On 23 and 24 June 2012, the water level started rising and at few sites crossed DL, but the rise was not steady. However, from 25 June 2012 onwards, the water level started rising steadily crossing WL and then DL mark. On 26 June 2012, nine sites were flowing above DL, whereas at 15 sites water level had crossed DL by 27 June and at 17 sites the river water had crossed the DL mark on 28 June (Table 1). The Brahmaputra river was flowing above DL continuously for three days (27–29 June 2012) at the six gauge stations located along the river and most of them had attained the peak flood level during this period. It is also interesting to note that the peak water level attained during this event by the Brahmaputra river at most of the gauge stations was only a few centimetres below the previous high flood level (HFL), especially at Dibrugarh where the difference between the previous HFL (106.48 m acquired on 3 September 1998) was just 0.22 m and at Neamatighat where the difference between the previous HFL (87.37 m, acquired on 11 June 1991) was just 0.16 m (Table 2). A perusal of the peak water level data shows that after the Brahmaputra river at Dibrugarh (the first river gauge station on Brahmaputra river in Assam) reached the peak flood level on 26 June 2012, there was a time lag of 4 days for the water at Dhubri (the last river gauge station on the Brahmaputra river in Assam) to attain the peak flood level on 30 June 2012 (Table 1). The severe floods in the Brahmaputra valley in Assam due to the rise in water levels of the Brahmaputra river and its associated tributaries probably resulted due to heavy incessant rainfall in the upper catchment areas of the Brahmaputra basin, caused by active monsoon conditions prevailing over the region during the third week of June.

Table 2. Deviation of water level of the Brahmaputra and associated tributaries from the danger level (DL) and high flood level (HFL) during June and July 2012

FF site	River	Warning level (m)	DL (m)	HFL (m)	Date/month/ year	Maximum level 2012	Deviation from DL	Deviation from HFL
Dibrugarh	Brahmaputra	104.70	105.70	106.48	3/9/1998	106.26	0.56	–0.22
Neamatighat	Brahmaputra	84.04	85.04	87.37	11/7/1991	87.21	2.17	–0.16
Tezpur	Brahmaputra	64.23	65.23	66.59	27/08/1988	66.11	0.88	–0.48
Guwahati	Brahmaputra	48.68	49.68	51.46	21/07/2004	50.51	0.83	–0.95
Goalpara	Brahmaputra	35.27	36.27	37.43	31/07/1954	37.07	0.80	–0.36
Dhubri	Brahmaputra	27.62	28.62	30.36	28/08/1988	29.91	1.29	–0.45
Naharkatia	Burhidihing	119.40	120.40	122.69	17/06/1973	118.90	–1.50	–3.79
Khowang	Burhidihing	101.11	102.11	103.92	25/08/1988	102.88	0.77	–1.04
Nanglamoraghat	Desang	93.46	94.46	96.49	6/9/1998	94.00	–0.46	–2.49
Shivsagar	Dikhow	91.40	92.40	95.62	8/7/1974	92.86	0.46	–2.76
Badatighat	Subansiri	81.53	82.53	86.84	28/06/1972	82.03	–0.50	–4.81
Golaghat	Dhansiri (S)	88.50	89.50	91.30	11/10/1986	88.10	–1.40	–3.20
Numaligarh	Dhansiri (S)	76.42	77.42	79.87	24/09/1985	77.95	0.53	–1.92
Jiabharali_NTX	Jiabharali	76.00	77.00	78.50	26/07/2007	77.70	0.70	–0.80
Kampur	Kopilli	59.50	60.50	61.86	16/06/1973	61.56	1.06	–0.30
Dharmatul	Kopilli	55.00	56.00	58.09	21/07/2004	56.13	0.13	–1.96
Puthimari_NHX	Puthimari	50.81	51.81	55.04	27/07/2007	52.92	1.11	–2.12
Pagladiya_NTX	Pagladiya	51.75	52.75	55.45	8/7/2004	53.42	0.67	–2.03
Beki NHX	Beki	44.10	45.10	46.20	4/8/2000	45.50	0.40	–0.70
Manas NHX	Manas	47.81	48.42	50.08	15/09/1984	48.77	0.35	–1.31
Golakganj	Sankosh	28.94	29.94	30.95	8/9/2007	29.83	–0.11	–1.12
APGhat	Barak	18.83	19.83	21.84	1/8/1989	21.05	1.22	–0.79

Source: CWC.

Maximum spatial extent of flood inundation

The flood inundation layers generated from the satellite data analysis of 27, 29 and 30 June and 2 July 2012 are integrated to obtain the maximum spatial extent of inundation during this flood event. From the integrated analysis of multi-date-derived flood layers it is observed that about 4.65 lakh ha, which constitutes about 6% of the state's TGA, was inundated due to flooding. Figure 3 shows the maximum spatial extent of flood inundation observed from analysis of 27 June to 2 July 2012 satellite data. Of the 27 districts in Assam, in 8 districts, namely Kamrup (R), Marigaon, Barpeta, Nowgong, Lakhimpur, Karimganj, Cachar and Darrang, more than 10% of TGA was affected by flooding. Fifteen districts, namely Jorhat, Nalbari, Kamrup (M), Sonitpur, Dhemaji, Sibsagar, Golaghat, Hailakandi, Goalpara, Dhubri, Dibrugarh, Bongaigaon, Udalguri, Karbi Anglong and Tinsukia had about 5–10% of the TGA area inundated (Figure 2).

Figure 4 *a* shows the flood situation in parts of Dhemaji, Dibrugarh, Sibsagar and Tinsukia districts located in Upper Assam as on 29 June 2012. It can be observed that during the lean period, braided appearance of channels along with sand bars of the Brahmaputra and the Burhi Dihing (tributary) joining from the south are clearly visible, whereas when the river is in spate it appears to be a single huge channel and large areas adjoining the river are observed to be engulfed under water on both banks of the Brahmaputra and the Burhi Dihing. Areas freshly inundated by flood water appear in greenish-blue tone, whereas those where flood inundation is receding appear in dark bluish-black tone; vegetation is denoted by red colour, sand in white tone and river water in blue tone. Kaziranga National Park, a world heritage site and habitat for the endangered Asian one-horned rhinocerous species was significantly affected by the flood waters, which led to the death of several wild animals. About 13,181 ha (31% of the total park area) of the Kaziranga National Park is estimated to be submerged. Figure 4 *b* shows the flood situation in Kaziranga National Park as on 1 July 2012.

Villages marooned

The flood waters marooned several villages in the state and many villages were surrounded by flood water for several days. About 3829 villages were affected by floods as on 2 July 2012. In Nowgong district itself, which is one of the worst flood-affected areas, about 312 villages were flooded up to 2 July 2012. It is observed that out of the 312 affected villages, about 77 were marooned for more than 6 days, 85 villages for 4–5 days and 75 villages for 1–3 days (Figure 5).

Flood-affected population

Information on the number and spatial distribution of the population affected due to floods is required by the

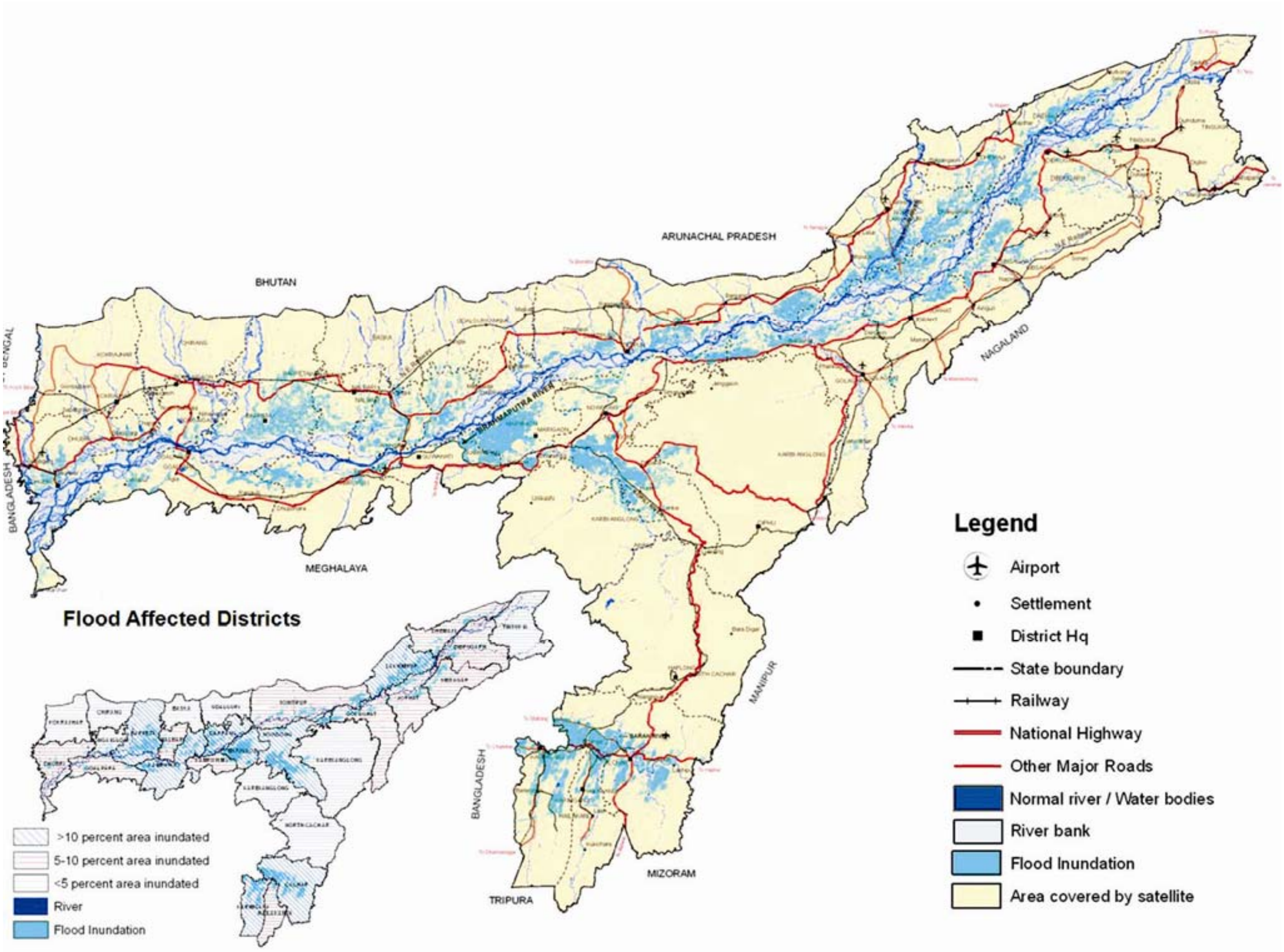

Figure 3. Maximum spatial extent of flood inundation observed from analysis of 27 June to 2 July 2012 satellite data and flood-affected districts.

administrators for extending help. Due to the Brahmaputra floods of June–July 2012, about 23 lakh people in Assam were estimated to be affected. Nowgong had the highest population, i.e. about 2.94 lakhs people affected by the flood waters, followed by Barpeta with 2.78 lakhs, Cachar 2.19 lakhs, Marigaon 2.13 lakhs, Karimganj 2.05 lakhs, Lakhimpur 1.35 lakhs, Sonitpur 1.21 lakhs and Kamrup (M) 1.14 lakhs.

Satellite-based understanding of flooding in Assam

From the analysis of the satellite images acquired, it is clearly observed that the Brahmaputra river after traversing the Himalayan ranges and entering the plains of Assam, deposits sediments along the main river course, which reduces the cross-sectional area of the river, the channel carrying capacity and raises the river bed above the flood plain. These result in conditions conducive for bank erosion, channel avulsions and breaching of flood-control structures, especially in the upper parts of Assam. The Brahmaputra river on entering the Assam plains, changes from a single channel to a braided channel pattern. The width of the river increases from 0.3 km to as wide as 12 km due to the large amount of sedimentation (bluish-white tone) along the main course of the river. The Brahmaputra is the fourth largest river in terms of average discharge at the mouth, with a flow of 19,839 $m^3 s^{-1}$, and second in terms of sediment transport per unit drainage area in the world[22]. Because of the sedimentation and subsequent rise in the river bed level, DL mark at Dibrugarh station has been revised by CWC from 104.70 to 105.70 m. The change in river flow pattern and sedimentation pattern is due to change in the gradient of the river, which is as steep as 4.3–16.8 m/km upstream of Pasighat and drops to 0.62 m/km near Pasighat[23].

In the middle and lower parts of Assam, the gradient of the river gradually becomes as flat as about 0.1 m/km. Due to these gentle slopes and flat terrain, vast areas are generally inundated along the Brahmaputra river course every year in Assam, whenever the river is in spate during monsoon season. Severe flooding is observed from satellite images in parts of middle Assam due to change in the geomorphological landscape. In this stretch the

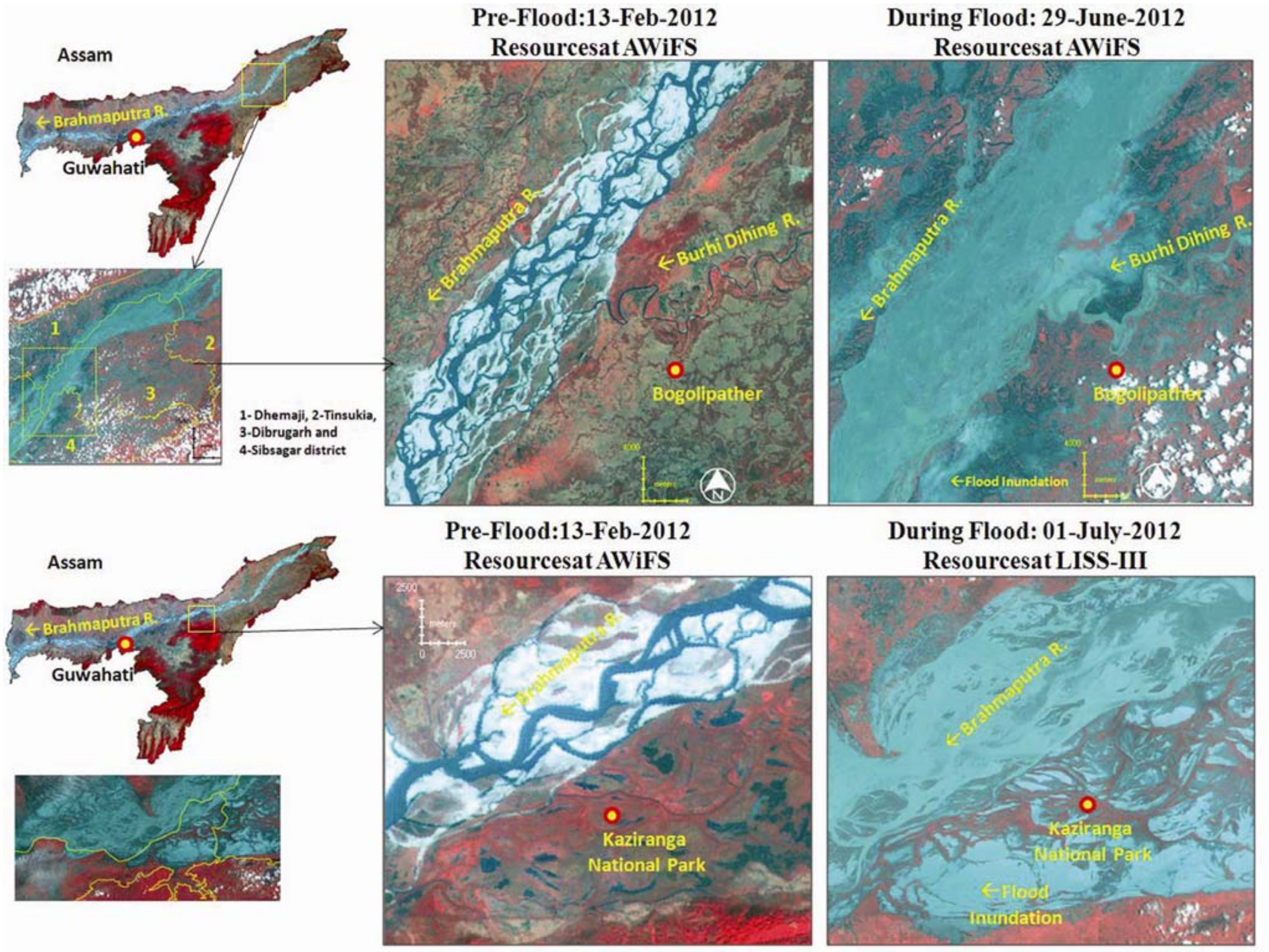

Figure 4. (Top) IRS Resourcesat AWiFS satellite image showing flood inundation as observed on 29 June 2012 in parts of Dhemaji, Dibrugarh and Sibsagar districts. (Bottom) IRS Resourcesat-2 LISS III image of 1 July 2012 showing flood inundation observed in parts of Kaziranga National Park.

Brahmaputra changes from braided channel pattern to a single channel as it passes through Guwahati and the width of the river narrows down to 1 km from 10 to 15 km upstream. This narrowing down of the channel restricts the free flow of water when the river is in spate and subsequently leads to spilling of flood waters and flooding conditions in the upstream areas located along the river, especially in parts of Guwahati, Kamrup (M), Marigaon and Darrang districts. It is observed from the satellite images that the regions lying towards north of Brahmaputra river, characterized by steep slopes and many tributaries like Subansiri, Jia Bharali, Dhansiri, Puthimari, Pagladia, Manas, Champabati, Saralbhanga and Sankosh bring down a lot of sediment, leading to drainage congestion, rising of the bed and reduction in the cross-sectional area of the channel and carrying capacity and shifting of the river course and therefore aggravate the flooding problem in the northern part of Assam.

For finding long-term sustainable solution to the flooding problem in Brahmaputra basin, an integrated approach involving a combination of both structural (river control structures) and nonstructural measures (watershed management and strengthening early warning) is required to be taken making use of the advanced technologies like satellite images and GIS. Remote sensing technology due to its repetitive and synoptic coverage, and cost-effectiveness can be useful for studying and monitoring floods, channel aggradation, river shifting and proximity of river course to the embankments by the planners for taking measures required for channel stabilization and strengthening of embankments before the onset of monsoon season.

Conclusion

Floods in the Brahmaputra basin of India have been a recurring feature causing extensive devastation to existing infrastructure, including roads, bridges, embankments, buildings and crops. The present study demonstrates that

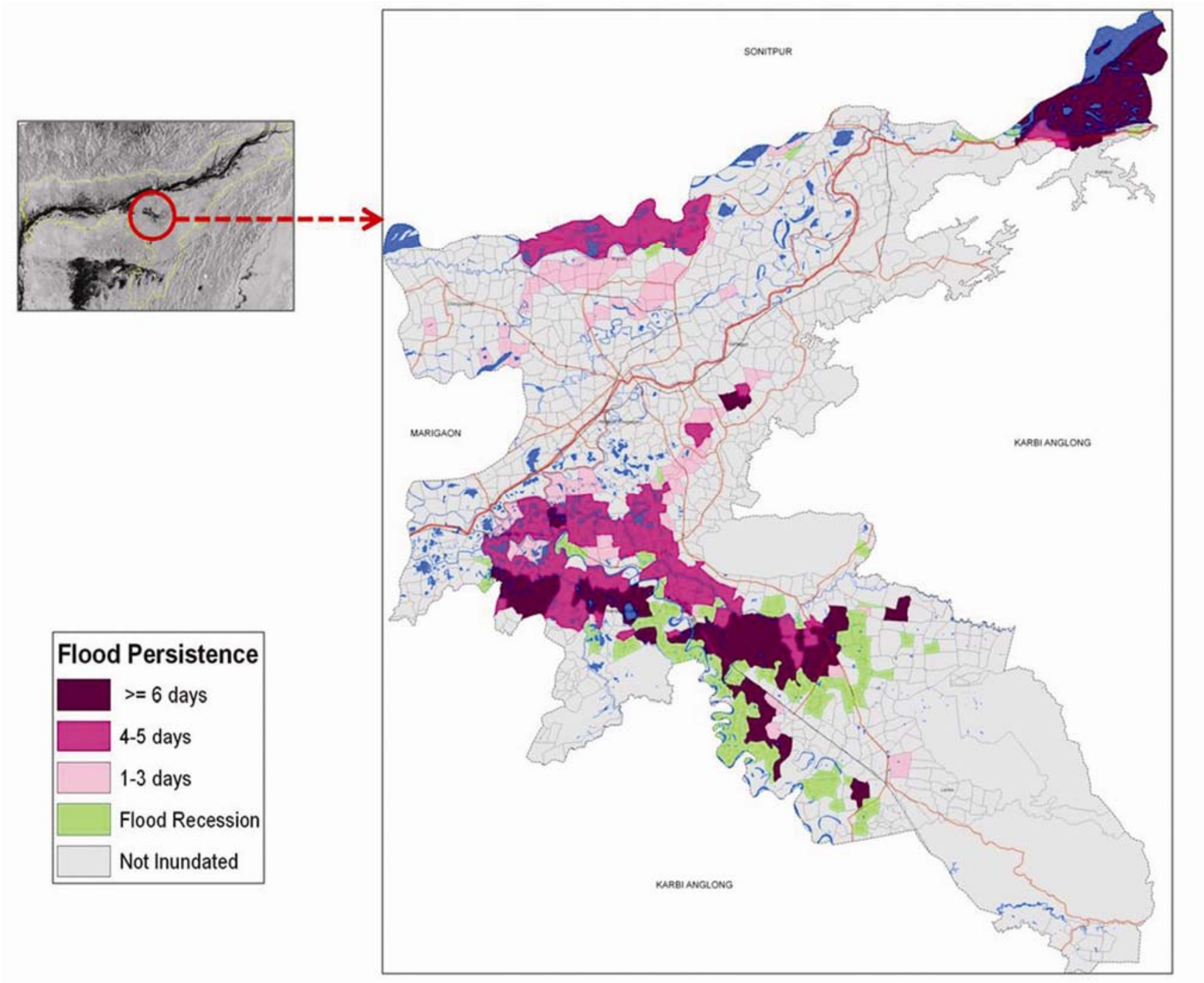

Figure 5. Flood persistence map for Nowgong district based on satellite data analysis of 27 and 29 June and 2 July 2012.

satellite images can be one of the most cost-effective ways to capture the flood disaster footprints, identification of areas vulnerable to flooding and understanding the flooding problem in a better way. Flood inundation footprints when used in conjunction with GIS technology can help in identifying flood persistence, marooned villages and population affected and therefore help decision makers and planners in prioritizing their efforts in a more judicious manner. Gridded population dataset can provide a rapid estimate of the population affected due to floods and can be useful in humanitarian aid. Flood mitigation in vast basins like the Brahmaputra requires an integrated approach involving a combination of both structural and non-structural measures to be taken making use of the advanced technologies like remote sensing and GIS technology.

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