Extraction of detailed level flood hazard zones using multi-temporal historical satellite data-sets – a case study of Kopili River Basin, Assam, India

Shivaprasad Sharma SV, Parth Sarathi Roy, Chakravarthi V, Srinivasarao G and Bhanumurthy V

ABSTRACT
Kopili River Basin is one of the chronic flood affected basins of Brahmaputra River, lies in north-eastern part of India. This study attempts to utilize the historical spatial data on flood inundation layers derived from multi-temporal remote sensing images for identifying villages falling in various flood hazard severity zones. A total of 183 flood events were mapped in the basin in the last two decades. About 3.89 lakh hectares which is 29% of Kopili River Basin area is affected by floods during 1977, 1988 and 1998–2015. The flood hazard zonation frequency is determined treating each village as minimum unit of entity and based on the number of times affected by flood events in a given year. About 742 villages are categorized as very low to low and 396 villages fall in moderate flood hazard zone and more than 150 villages are categorized between high to very high flood hazard zones.

KEYWORDS
Flood hazard; severity; Kopili; remote sensing; India

Introduction
Flood is one of the worst natural disasters affecting the socio-economic life of millions of people every year. More than one-third of the earth’s surface, inhabited by over 82% of the world’s population, was affected by floods during 1985–2003 (World Bank 2005). India’s high risk and vulnerability is due to its unique geographical setting, climate, topography and population. Floods have been causing huge losses to lives, properties, livelihood systems, infrastructure and public utilities (NDMA 2008). According to National Flood Commission, out of a total geographical area (TGA) of 329 million hectares about 40 million hectares is prone to floods. On an average, loss to life is about 1590 and loss in financial terms is 13,000 million. (Gopalakrishnan 2002)

The most flood prone areas in India are Brahmaputra, Ganga and Meghana River Basins which carry about 60% of total Indian river flow. Brahmaputra valley is variably inundated by the floods of Brahmaputra River and its tributaries. The highly braided Brahmaputra River is both snowfed and rainfed river and has continuous flow throughout the year. The river experiences highest water levels and strongest flows in the summer monsoon season (Rakhecha 2000). The occurrences of frequent floods in the Brahmaputra valley are attributed to a host of interrelated factors of natural, hydro-meteorological and anthropogenic origin (V P Singh et al. 2004). More than 40% of its land surface is susceptible to flood damage, the total flood prone area in the Brahmaputra valley is about 3.2 million hectares (Goswami et al. 2001). High intensity rainfall along the foothills bordering the
valley in a very short period of time and peaking of tributaries at the confluences eventually give rise to high flood levels of Brahmaputra. The flooding of tributaries also aggravates the overall flood situation in the valley.

The river receives innumerable tributaries flowing down the northern, north-eastern and southern hill ranges. Kopili River is one of the ten principal south bank tributaries of river Brahmaputra (Singh et al. 2004). The inadequate drainage carrying capacity of the tributaries compounded by evacuation of rain water and as well as spills of sub-tributaries further worsens the flood situation.

These severe cases of riverine flooding caused by variety of reasons calls for a flood management/flood controlling measures in the valley. The need for frequent monitoring and mapping of flood disasters requires a satellite based remote sensing approach. Satellite remote sensing has the capability to capture flood disaster footprints with reasonably higher accuracy. Earlier studies conducted in various parts of globe suggest the fact that satellite images are rich source of information which can capture flood disaster events for assessing the disaster impact and taking up flood mitigation activities (Islam & Sado 2000; Sanyal & Lu 2006; Bhatt et al. 2013; Bhatt & Rao 2016).

Satellite remote sensing systems from their vantage position have unambiguously demonstrated their capability in providing vital information and services for disaster management (Rao UR 1994). Flood hazard zonation (FHZ) mapping is a necessary and handy non-structural pre-requisite for prioritizing land use practices and planning better flood mitigation activities. It gives us the inventory of severity of events and their flood patterns to understand the geomorphological conditions of the basin.

Conventionally hazard zonation mapping is envisaged using variety of information such as ground truth, soil characteristics, hydrological and hydraulic information coupled with flood depth information derived from Digital Elevation Model (DEM). These parameters are very exhaustive and time-consuming and may not be readily available (Sinha et al. 2008).

There are various techniques being used to derive FHZ. (Diakakis 2011) compiled a flood hazard map based on the peak flow rates derived from instantaneous unit hydrographs for two catchments in Greece across each basin. Rahman et al. 2007 have generated FHZ map for Bogra district of Bangladesh using Multi-Criteria Evaluation (MCE) approach.

The present paper is an attempt to generate a village-wise FHZ map by integrating the historic annual flood inundation layers captured from multi-temporal satellite data-sets taking village as a stratum.

Environmental setting of the study area

Kopili Basin has a total geographical area (TGA) of about 1,355,600 hectares. It is located between 91–93° E long. and 25–27°N lat. (Figure 1). Kopili River is one of the principal south bank tributaries 297 km in length contributing the flow into Brahmaputra River and it originates from the south-western slope of the Shillong Peak (Kusre et al. 2010). The elevation of the basin ranges from 74 to 1967 m (Kumar et al. 2014). The area of the basin lies between Assam and Meghalaya states and is mostly inundated by frequent floods due to high precipitation and rising water levels of Kopili River and accumulation of flow in its low lying areas. The basin has a moderate and sub-humid climate with the annual rainfall of the study area ranging from 980 to 1700 mm. The average annual runoff of the basin is 600 mm approximately, more than 80% of the runoff occurs in monsoon season. The area receives its maximum rainfall during the months of June to September. Varied climatic zones are experienced owing to the study area’s differential topography.

Flood problem in Kopili River Basin

Kopili River Basin has a long history of flooding and it is one of the ten principal south tributaries of Brahmaputra River. The catchment is well drained by several smaller sub-tributaries like Kolong, Jamuna, Diju, Misa, Haria and Digaru. The Kolong River is structurally protected by an earthen
embankment called Hatimura dyke as an adhoc means of protecting Nagaon town in Assam state, India, from recurring flood hazards. The river experiences large floods due to rise in bed level of Brahmaputra River and massive sedimentation in its course, attributed mainly to the aftermath of Great Assam earthquake of 1950 (Minakshi and Goswami 2014). Kopili, one of the principal south bank tributary of Brahmaputra River, flows from east to west and receives its inflows from several minor streams Diju, Misa, Haria and Digaru apart from Kolong River coupled with precipitation in its catchment areas. The areas experience severe drainage congestion coupled with the pressure of evacuation of rain water flow into Brahmaputra River ultimately leading to severe cases of flood inundation in its adjoining areas. There were 12 major floods during 1986–2001 (Khadg Singh 2004) of which four major floods were observed at Kampur gauge site and eight floods were recorded at Dharamtul gauge site. The recent unprecedented floods of 2012 (Bhatt et al. 2013) caused due to the Kopili River crossing its danger level (DL) at Kampur gauge site consecutively for a period of three days from 27 June 2012 to 29 June 2012 and at Dharamtul gauge site during 30 June 2012 – 1 July 2012 has caused severe damage to live stock and property. Nagaon district which is drained by Kopili River and its tributaries was the worst flood affected during 2012 unprecedented floods affecting more than 312 villages for a period of five days.

Data used

Remote sensing and ancillary data

About 183 multi-temporal and multi-sensor satellite data-sets comprising of both Indian Remote Sensing (IRS) series and Synthetic Aperture Radar (SAR) RADARSAT satellite data of Canada acquired during the flood seasons of 1977, 1988 and 1998-2015 were considered for analysis. IRS and RADARSAT data were not available during 1970s and 1980s, archived data from Landsat 1-3 and Landsat 4-5 of 1 Jul 1977 and 23 Sep 1988, respectively, of Kopili Basin area were downloaded (http://earthexplorer.usgs.gov) and flood inundation layers were extracted. Figure 2(a—c) shows the
Materials and methods

The present study utilizes the Spatio multi-temporal historical data-sets acquired during the flood seasons of 1977, 1988 and 1998–2015. The satellite images were geometrically and radiometrically geo-referenced and resampled to 50 m spatial resolution before they could be used for the extraction of flood inundation layers. The geometric registration of images was performed to attain the positional accuracy and for seamless integration and analysis with master database (Lambert Conformal Conic, Modified Everest projection). All data-sets were corrected with sub-pixel level accuracy. The satellite data-sets used for mapping were Resourcesat-1/2 AWiFS data (56 m), IRS 1 C/1 D WiFS (188 m), RADARSAT data (50 m), RISAT-1 CRS data (36 m), Landsat 1-3 and 3-5 archive data of 1977 and 1988, respectively, of (30 m) spatial resolutions. The property of all-weather independent and ability to penetrate clouds makes SAR data suitable for flood inundation mapping. Canada-based RADARSAT series and IRS SAR data of RISAT-1 operating in C-band (5.35 Ghz) are utilized for the present study. RADARSAT and RISAT-1 (Coarse Resolution) CRS data trace swaths of 500 and 220 km on ground with spatial resolutions of 50 and 36 m in ScanSAR wide beam mode.

High incidence angles coupled with wide swath and Horizontal,Horizontal (HH) polarization is usually preferred for flood mapping and monitoring for RADARSAT and as well as RISAT-1 series satellite data-sets. The SAR images were filtered using $3 \times 3$ window median filter to suppress the salt and pepper effect in the images and sigma nought image is generated. Water is extracted from the geometrically co-registered sigma nought images using the variable incidence angle threshold method (Srinivasulu et al. 2005).
Water bodies are extracted from the optical data using unsupervised classification by giving maximum number of classes and main active river channel, its tributaries and permanent water bodies are classified and converted into vector format. On-screen digitization techniques are used for delineation of river bank lines and hills and these layers are subtracted from the state mask to generate a mask which eliminates all the permanent water bodies, hills and the stray pixels are grouped and eliminated using post-editing tools and the flood inundation layer is finalized (Flood Inundation Mapping Manual 2007).

All such inundation layers generated for each date in a given calendar year are stacked using ERDAS Spatial Modeler tool to generate annual composite inundation layer representing the spatial extent of flood inundated areas. All the layers from 1977, 1988 and 1998–2015 were integrated using Spatial Modeler tool and a flood hazard layer is generated. The hazard layer was integrated with the master database and detailed damage statistics in various hazard severity zones are generated. The detailed procedure is shown in Figure 3.

Flood hazard zonation

FHZ is one of the most important non-structural measures, which facilitates appropriate regulation, and development of floodplains thereby reducing the flood impact. Conventional flood hazard mapping techniques use historical flood data to map floodplains (Khanna et al. 2005). In addition to a record of peak flows over a period of years, a detailed survey (cross sections, slopes and close contour maps), maps such as soils, physiography, land use, vegetation, population density, infrastructure and settlements along with hydraulic roughness estimates is required before the extent of flooding for an expected recurrence interval can be determined. FHZ map requires mainly flow information and it is essential to have a fine resolution DEM to model in areas whose terrain is very flat. In the case of Kopili River Basin, the topography of the area is relatively flat which requires a hydrologically conditioned fine resolution DEM to model which is not available for most of the floodplains. With these constraints it is difficult to prepare FHZ maps conventionally. Satellite datasets acquired during flood times are available over a period of time for Kopili River Basin which was being utilized for generation of FHZ mapping.

Results and discussions

This section presents the results of the spatial extent of inundation, observed flood occurrence frequency and elevation zones and provides the assessment of possible factors resulting in the flooding.

Spatial extent of inundation

The FHZ layer is generated based on integration of annual flood inundation layers extracted from the analysis of 183 multi-temporal and multi-date satellite data-sets acquired during floods. The hazard layer depicts the areas subjected to floods during study periods as 20-times flooded, 10-times flooded, etc. Based on number of times flooded five hazard severity zones are classified (Table 1). Very high indicates the areas which are inundated almost every year, high indicates 13 –16 times, moderate indicates 9 –12 times, low indicates 5 –8 times and very low category indicates the areas which are inundated 1 – 4 times.

The total flood hazard affected area in Kopili River Basin during 1977, 1988 and 1998–2015 is about 3.89 lakh hectares which is about 29% of the total basin area (Table 2). About 71% of the basin area which is 966,504 hectares is not affected by flood and majority of the area falls under Meghalaya state of Kopili River Basin.
Observed flood occurrence frequency

Kopili River experiences on an average a minimum of three flood waves in a flood season from May to mid October (Singh et al. 2004). The intra-annual flood waves are considered to accommodate the number of flood waves experienced in monsoon period. For deriving a village-wise FHZ frequency, the FHZ layer is integrated with village database (Census 2011), taking village as a...
stratum, the number of times a particular village is inundated is extracted. Depending on this, the villages are categorized into various flood hazard severity zones ranging from very high to very low.

It is observed that during the years 2000 and 2002, the basin has experienced three peak flood waves. During 2004, 2007 and 2012, two peak flood waves were observed and during the years 1999, 2001, 2005, 2008, 2013 and 2014 there are zero flood peaks which implies that the river has not witnessed any flood peak. A river is said to be in flood when it crosses the DL at a particular/discharge/G/D site (Dhar and Nandargi 1998). It is observed from the study that Kopili River has crossed danger mark and reached flood peaks as shown in Table 3. The years which witnessed zero flood peaks are mainly due to the intense rainfall in its catchment area leading to the flooding due to flow accumulation in low lying areas.

Table 1. Flood hazard zonation Schema - Extent of inundation times the flood events.

| Sl.No | Hazard   | Frequency of flood inundation during 1977,1988 and 1998–2015 (years) |
|-------|----------|-----------------------------------------------------------------------|
| 1     | Very high| 20–17 (almost every year)                                              |
| 2     | High     | 16–13                                                                 |
| 3     | Moderate | 12–9                                                                  |
| 4     | Low      | 8–5                                                                   |
| 5     | Very low | 4–1                                                                   |

Table 2. Area statistics of spatial extent of inundation.

| Sl No | Hazard   | Area (hectares) | Percentage (with reference to total basin area) |
|-------|----------|-----------------|-------------------------------------------------|
| 1     | Very high| 18,944          | 1                                               |
| 2     | High     | 29,447          | 2                                               |
| 3     | Moderate | 61,174          | 5                                               |
| 4     | Low      | 91,310          | 7                                               |
| 5     | Very low | 188,221         | 14                                              |
| Total |          | 389,096         | 29                                              |

Table 3. Year-wise frequency of flood mapped and area affected.

| Sl No | Year | Number of times mapped | Flood-affected area (hectares) | Number of flood peaks mapped | Percentage of Flood affected with reference to total flood affected area |
|-------|------|------------------------|--------------------------------|-------------------------------|-------------------------------------------------|
| 1     | 1977 | 1                      | 135,586                        | NA                            | 35                                              |
| 2     | 1988 | 1                      | 44,743                         | NA                            | 11                                              |
| 3     | 1998 | 8                      | 122,645                        | 1                             | 32                                              |
| 4     | 1999 | 5                      | 180,588                        | 0                             | 46                                              |
| 5     | 2000 | 4                      | 147,414                        | 3                             | 38                                              |
| 6     | 2001 | 3                      | 64,272                         | 0                             | 17                                              |
| 7     | 2002 | 6                      | 199,444                        | 3                             | 51                                              |
| 8     | 2003 | 7                      | 203,126                        | 1                             | 52                                              |
| 9     | 2004 | 14                     | 246,170                        | 2                             | 63                                              |
| 10    | 2005 | 5                      | 31,292                         | 0                             | 8                                               |
| 11    | 2006 | 5                      | 98,215                         | 1                             | 25                                              |
| 12    | 2007 | 19                     | 218,294                        | 2                             | 56                                              |
| 13    | 2008 | 18                     | 137,891                        | 0                             | 35                                              |
| 14    | 2009 | 11                     | 41,955                         | 1                             | 11                                              |
| 15    | 2010 | 21                     | 80,467                         | NA                            | 21                                              |
| 16    | 2011 | 15                     | 47,148                         | 1                             | 12                                              |
| 17    | 2012 | 19                     | 127,177                        | 2                             | 33                                              |
| 18    | 2013 | 5                      | 56,381                         | 0                             | 14                                              |
| 19    | 2014 | 6                      | 115,554                        | 0                             | 30                                              |
| 20    | 2015 | 10                     | 102,315                        | 1                             | 26                                              |
| Total |      | 183                    | 389,096                        |                               | 18                                              |

Note: NA, not available.
Classification of elevation zones

Kopili Basin has a flat topography and representation of villages in various flood hazard severity zones was done by overlaying the village database on Shuttle Radar Topography Mission (SRTM) DEM of 30 m spatial resolution. Further, the DEM was classified into various elevation ranges: 0–60, 60.1–104, 104.1–156, 156.1–206 and 206.1–233 m as shown in Figure 4. It was observed that very high to moderate flood hazard zones correspond well with the low lying regions of the basin whose elevation zones range between 0 and 60 m and low flood hazard zones are falling in relatively high elevation zones of >100 m. The no-flooded regions are the areas which are at elevation range 156–233 m.

FHZ frequency was categorized according to their occurrence as no-flood, low, moderate and high. The inundated area that is common in all the images was categorized as the high frequency area. The least inundated areas which were mapped least no. of times were categorized as the low flood hazard severity areas, respectively. Non-inundated area in all the images was classified as no-flooded areas (Table 4).

There are 2051 villages (Census 2011) in Kopili River Basin. Out of which more than 1293 villages, about 63% of the villages, are flood affected. About 99 villages in Nagaon district and 45 villages from Morigaon are categorized in high flood hazard zone which makes them the worst flood affected districts in the basin. The detailed district wise villages affected are shown in Figure 5.

Table 4. Flood hazard frequency zonation schema.

| No of times flood affected/frequency | Hazard severity |
|-------------------------------------|-----------------|
| 0                                   | No-flooded      |
| 1–30                                | Very low        |
| 31–60                               | Low             |
| 61–90                               | Moderate        |
| 91–120                              | High            |
| >120                                | Very high       |
More than 742 villages of Kopili River Basin are lying in very low to low flood hazard frequency and 396 villages are in moderate flood hazard zone and a total of 155 villages are categorized between high to very high flood hazard zone. About 321 villages in Kopili River Basin remain unaffected or categorized as no-flooded zones as shown Figure 6.

Village-level flood hazard frequency zonation maps can be used to prioritise the relief and rehabilitation measures during the disaster situation and the decision-makers can concentrate on flood mitigation measures in the areas which are frequently prone to floods. These flood frequency maps are a valuable input towards District Disaster Management Plan (DDMP) at various levels.

**Conclusions**

The history of flooding in Kopili Basin is an age-old phenomenon. The area has been experiencing severe floods due to the flat terrain and gentle slopes coupled with severe drainage congestion and massive sedimentation contributed by several streams. The present study successfully utilizes the Spatio multi-temporal satellite data-sets acquired during the flood seasons of 1977, 1988 and 1998–2015 to demonstrate the capability of satellite remote sensing in effectively capturing historical flood events. The availability of multi-temporal historical satellite data-sets has enabled deducing of the village-wise flood hazard zones which was otherwise was not possible by field methods in inaccessible and data scarce areas. The flooding in low lying areas mainly corresponds to high and low flood hazard zones. It is observed that flooding is not only experienced due to rise in the water levels but also due to accumulation of flow in its low lying areas.

The village-wise FHZ map is a critical scientific input towards integrated basin flood management programme. The hazard zonation maps are step towards carrying out flood vulnerability assessment in the basin and helps in prioritizing of vital installations by carrying out the sensitivity analysis of infrastructure and essential facilities at risk of being flooded. The technology intervention coupled with flood risk mapping, FHZ and vulnerability mapping at micro-level will add as a major input towards effective flood mitigation/preparedness strategies.

The future scope of the study can be extended by validating the satellite-based flood inundation versus the observed flood modelled with independent data sources like precipitation, water levels and its impact on the socio-economic factors, land use and infrastructure and carry out detailed
village-wise flood risk assessment as part of flood mitigation activities which helps the decision-makers and planners to give a sufficient lead time to habitats to move to safer areas.

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Disclosure statement

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ORCID

Shivaprasad Sharma Sv http://orcid.org/0000-0001-7483-9747
Parth Sarathi Roy http://orcid.org/0000-0002-6803-6785

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