Flood risk assessment using multi-criteria analysis: a case study from Kopili River Basin, Assam, India

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ABSTRACT
A multi-criteria analysis (MCA) approach to describe the effective utilization of geospatial techniques for disaster risk reduction at village level in Kopili River Basin (KRB) of Assam State, India is presented. The KRB is chronically flood affected due to seasonal monsoon and rise in water levels of Kopili River. Based on the MCA approach using flood hazard layer derived from the spatio-multi-temporal historic satellite data-sets (comprising of sensors from RISAT-1 SAR, Radarsat SAR and IRS AWiFS), socio-economic data (based on five census variables), infrastructure (road network) and land use vulnerabilities (cropped and uncropped areas), flood risk zones are derived. Our study elucidates that 24,837 ha of crop area spread across 95 villages in the KRB falls in high risk zone, about 39,209 ha distributed in 150 villages falls under moderate-high risk zones and remaining area spread over 162 villages is more or less unaffected. The proposed approach can be applied elsewhere in other river basins to estimate the flood risk so as to mitigate the disaster risk posed by the floods.

KEYWORDS
Flood risk; multi-criteria; Kopili; Assam; vulnerability

Introduction
Brahmaputra river basin in India is chronically flood affected owing to its large catchment area which frequently overtop its bankful discharge and submerge the Brahmaputra plains (Kale 2003; Prasad et al. 2006, Dikshit and Dikshit 2014). The Brahmaputra river basin is predominantly influenced by the tropical south west monsoon (during a short spell of June–September) which accounts for almost 90% of the total rainfall in the region (Singh et al. 2004). The physiography and unique orographic position of the basin coupled with high dynamic monsoon setting often leads to repeated colossal floods in the region. The river experiences one of the strongest flows and high water levels even in the pre-monsoon season (Rakhecha 2002). There are multitude of factors which contribute to the perennial flood problems of the Brahmaputra basin such as tremendous population pressure intruding into the flood plains of the river, the menace of bank erosion and siltation of the main channel and its tributaries leading to severe drainage congestion (Minakshi and Goswami 2014). The floods in the basin are causing severe damage to the livestock, property and infrastructure on a repeated basis during every monsoon season (Bhatt et al. 2013). An increase of 28% of rainfall during the month of June 2012 had led to breaching of the embankments of Brahmaputra tributaries at 43 locations which has caused serious damage to the Assam state (IFRC 2012). The vulnerability to flood disasters due to increase in extreme precipitation events coupled with the rise in the
developmental activities in the hazard-prone areas poses a major challenge to the disaster managers in future (Intergovernmental Panel on Climate Change 2012).

The Kopili River Basin (KRB), well-drained by the principal south bank tributary of Kopili River is located between the sub-humid regions of Assam and Meghalaya states. Large part of the basin is covered by alluvial soils. Several minor streams are contributing their flows to the basin apart from the discharge received from the mean annual precipitation of 1760 mm. The KRB is chronically flood affected; hence, a need exists to understand the recurrent flood phenomena and ways to tackle it by utilizing proper flood management procedures and disaster risk reduction measures. One of the prime pre-requisite for carrying out effective disaster risk reduction strategy is to prevent or avoid the damages caused by a flood to the community. There are two types of flood controlling measures viz. (i) structural measures by way of constructing flood retention walls, dykes, reservoirs, detention basins, and (ii) the non-structural measures which include flood forecasting, flood proofing and flood hazard zoning (Li et al. 2016).

The structural measures of flood control requires extensive ground truth information, survey and manpower which is often time consuming, whereas for a basin like KRB which is being chronically affected by floods requires the monitoring on a regular basis. Satellite remote sensing in combination with hydro-meteorological data of the river basin can serve as a beneficial input in monitoring the floods. It is well known that regular monitoring of the vast extent of flood-affected areas is possible using satellite remote sensing technology. Use of multi-sensor satellite data for monitoring the floods (both during and after) has been effective for carrying out damage assessment (Prasad et al. 2006). On the other hand, the geographic information system (GIS) paves the way to visualize the damages and also to generate detailed assessment of the quantum of damages occurred in the flood-affected regions. Historic and multi-temporal satellite data-sets of the flood-affected regions can be used to assess the vulnerability of a region during the onset of extreme rainfall or rise in the water levels of the rivers in the nearby vicinity. The field-based methods of recording hydrological parameters on a regular basis during the monsoon season is a difficult task and at times may fail to yield reliable information, particularly when the flood events are extreme. In such cases, the satellite remote sensing technology provides useful information (Sanyal and Lu 2004).

In the present study, all of the flood inundation events occurred in the KRB during the period 1998–2015 were captured using a combination of sensors from both RADARSAT SAR, RISAT-1 SAR (microwave) and Indian remote sensing (IRS) series AWiFS (advanced wide imaging sensor) satellite (optical) data-sets. The first step towards flood management strategy is to assess the flood risk situation by identifying the frequent flood-affected regions by adopting the non-structural measures of classifying the flood hazard zones using multi-temporal historic flood inundation layers followed by assessing the multi-dimensional vulnerability (Physical, Social, Economic and Environmental) of the region. This exercise will be used to develop a comprehensive flood risk map as an input towards disaster reduction measure culminating into a flood management strategy.

The flood risk assessment is successfully attempted by many researchers. For e.g. Hailin et.al. (2009) had used the multi-year average precipitation, average number of rainstorm days across the years, topographical factor and flood frequency to derive the flood risk maps. Scheuer et al. (2011) had worked on the flood risk assessment by considering social, economic and ecological dimensions of flood risk by drawing a comparison between the starting point (without coping capacities) and endpoint views (with coping capacities). Sharma et al. (2012) have estimated the village flood risk index for Nagaon district of the Assam state by deriving flood hazard zonation from the historical flood inundations observed during 1998–2007 with population density infrastructure (road network) and land use (cropped areas) as indicators (to classify the villages on various risk severity zones ranging from high to low). Elsheikh et al. (2015) have identified flood risk areas using GIS with multi-criteria decision analysis considering the annual rainfall, basin slope, drainage network and the type of soil. Appropriate weights had been assigned to the parameters using analytical hierarchy process. Using multi-temporal satellite data and multi-criteria evaluation technique,
Hazarika et. al (2016) have assessed the flood risk of Dhemaji district, Assam state by integrating the flood vulnerability and risk assessment.

In the present study, we have used the multi-criteria analysis (MCA) to classify the villages falling in KRB into various flood risk zones namely high, moderate and low by taking the product of flood hazard zonation layer derived from the spatio multi-temporal analysis of satellite data and different vulnerability indicators (social, infrastructure and land use), taking village as a stratum.

**Study area**

KRB is located between 91°–93° E longitude and 25°–27°N latitude (Figure 1). The basin is drained by a myriad of several minor rivers namely Diju, Misa, Haria, Digaru, Kolong and Kopili following dendritic drainage pattern. The Kopili River, which accommodates the flows from several other streams, in addition to the seasonal precipitation joins the Brahmaputra River after passing a length of over 297 km from the Shillong peak of Meghalaya state. The basin falls in sub-humid region with minimum temperatures ranging from 11°–11.2°C in winter and touches a maximum of 33°C during the summer. The mean annual rainfall received by the basin is ~1760 mm during the short monsoon spell (June–September) every year. The topography of the basin is gently undulating with the master slope being towards the northwest and northeast. The flood plains of the Kopili River are more or less flat. The minimum and maximum elevation of the basin ranges from 74 to 1967 m, respectively (Kumar et al. 2014). Nagaon and Morigaon are the most densely populated districts of the basin. A total of 57 flood events were reported in KRB by the Kampur and Dharamtul gauge/discharge stations during 1987–1998 (Dhar and Nandargi 2000). The Great Assam Earthquake of 1950 had caused the bed levels uplifted, thereby large sediments were deposited on the river banks leading to overtopping of banks (Minakshi and Goswami 2014).

![Figure 1. Location map of the study area. Settlements are shown as red dots and gauge stations as red triangles. Kopili River and drainage shown as solid line in blue are overlaid on the Shuttle Radar Topographic Mission (SRTM) 30 m digital elevation model data (background image).](image-url)
Materials and methods

Data used

In the present study, a total of 181 spatio multi-temporal satellite data-sets comprising of IRS Resourcesat-1/2 AWiFS and microwave synthetic aperture radar (SAR) data of both IRS Series RISAT-1 and Canada-based RADARSAT-1/2 series (both operate in C-band [5.35 Ghz] and HH [Horizontal Horizontal]) polarization data was acquired during the flood seasons of 1998–2015 (Table 1). The Radarsat SAR Scan SAR wide data has 500 km swath and 50 m spatial resolution, whereas RISAT-1 coarse resolution scanner data has 220 km swath with 36 m spatial resolution. In addition, the partially cloud-free optical data-sets comprising of IRS series Resourcesat AWiFS were also acquired to assess the flood situation in the region. Resourcesat-1/2 AWiFS operates in the visible region with Red, Green, Blue and short wave infrared region bands with a swath of 740 km and a spatial resolution of 56 m. All these satellite data-sets are resampled to 50 m (pixel spacing) spatial resolution for uniformity and seamlessness of the flood inundation layers. The source of socio-economic data is from the Census of India (Census 2011) and land use/cover data is obtained from multi-temporal Resourcesat–2 terrain-corrected LISS–III data of 2011–2012 (National Land Use/Land Cover Mapping project, NRSC, Department of Space).

Multi-criteria analysis

MCA is a decision-making tool developed for solving complex multi-criteria problems that include qualitative and/or quantitative aspects of the problem (Mendoza et al. 1999).

MCA employs two methodologies namely, Ranking and Rating. Ranking is attributed to each decision element which reflects the degree of importance it imparts to the decision, whereas Rating is a bit similar to ranking but numerical scores are assigned to show the level of importance it has in the decision-making. The flood risk assessment is an amalgamation of both hazard and multiple vulnerability dimensions and each is assessed differently with respect to the level of impact it has on the society or environment.

Applications of MCA in combination with GIS (Malczewski 2006) are available in literature. For e.g. Raaijmakers et al. (2008) had utilized MCA to perform risk analysis in ‘Ebro Delta’ in Spain by considering different risk perceptions of a commoner within a given social system. Musungu et al. (2012) have used GIS and multi-criteria evaluation approach to assess the flood risk posed to the informal settlements of graveyard pond in Cape Town, South Africa. Malczewski (2006) had provided a holistic review on spatial multi-criteria decision analysis.

The application of spatial MCA for flood risk assessment is relatively new concept and only a few examples exist. Referring to the case studies reported by Brouwer and van Ek (2004), Janssen et al. (2003), Penning-Rowsell et al. (2003), Socher et al. (2006) and Bana et al. (2004), one can notice that flood risk assessment using MCA is mainly focused to evaluate the flood mitigation rather than risk mapping (Meyer et al. 2009). Cowen (1988) opined that GIS can be effectively used as a decision supporting tool to address the problems related to spatially referenced data. Malczewski (2006), on the other hand, opined that multi-criteria decision analysis compiles the information from geographical domain and considers the preferences of decision-maker to reach to a viable decision-making.

Table 1. Details of data-sets used in the study.

| S.No | Satellite/sensor                  | Spatial resolution (metres) | Period       | Source                                      |
|------|-----------------------------------|----------------------------|--------------|---------------------------------------------|
| 1    | Radarsat-1/2 (Scan SAR Wide)      | 50                         | 1998–2015    | National Remote Sensing Centre (NRSC)       |
| 2    | RISAT-1 (Coarse Resolution Sensor)| 36                         | 2012–2015    | NRSC                                        |
| 3    | Resourcesat-1/2 (AWiFS)           | 56                         | 2003–2015    | NRSC                                        |
| 4    | IRS 1C/1D WiFS                    | 188                        | 1998–2001    | NRSC                                        |

Note: The detailed date-wise availability of satellite data is mentioned in Appendix-1 as supplementary material.
Flood risk assessment is realized by the product of flood hazard zonation and the sum of vulnerabilities derived from various vulnerability indicators and criteria followed in deducing the social, infrastructure and land use parameters represented by

\[
\text{Flood risk assessment} = \text{Hazard} \times \{\text{Social, Infrastructure (Roads), Land use Vulnerabilities}\}
\]  

(1)

**Derivation of flood hazard zonation layer**

The flood hazard zonation layer of KRB is generated using the spatio-multi-temporal satellite datasets acquired during the flood seasons of 1998–2015 (for more details see Sharma et al. 2016). Inundation layer pertaining to each flood event is extracted and all such flood inundation layers are integrated to form one annual inundation layer. Similarly, all the annual inundation layers are integrated to generate a flood hazard zonation layer for the basin. The framework for deriving flood hazard zonation layer is shown in Figure 2.

![Figure 2. Extraction of flood hazard zonation layer.](image)
In the present paper, our objective is to do a comprehensive flood risk assessment of KRB using various criteria involving the segments like social, infrastructure and land use vulnerabilities. The flood risk assessment requires assessing the flood damages/losses using spatial analysis with reference to both space and time. Hence, a thorough assessment of vulnerabilities of the community and their resistance/coping capacities needs to be ascertained. The following aspects are analyzed to derive a flood risk map of the basin.

1. Assessment of social vulnerability to the impact of flood hazards on the society and environment using a set of variable indicators like household composition, gender (female population), poverty (population of scheduled castes/tribes (SC/ST)) and unemployment (population of illiterates).
2. Infrastructure vulnerability pertaining to roads.
3. Land use vulnerability with respect to the impact of flood hazard on the cropland areas which would directly affect the livelihood of the society in the event of a potentially damaging flood.

Figure 3 shows the detailed methodology adopted by us to derive the social, infrastructure and land use vulnerability indices. The vulnerability indices generated in this study are based on the weightages assigned to each parameter based on their level of estimated significance they impart on the society/community.

Preparation of inputs

The layers pertaining to administrative, infrastructure (roads) and drainage line, etc. are used to extract the village-wise damage statistics. The land use/cover map (1:50,000 scale) was generated as a part of ISRO Census project. The shuttle radar topographic mission (SRTM) digital elevation model (DEM) data of 30 m posting was downloaded from USGS (http://earthexplorer.usgs.gov/).
Derivation of socio-economic vulnerability index

Social vulnerability is more often than not describes the population/individual characteristics comprising of age, race, health, poverty and employment (Cutter et al. 2003; Fekete 2009; Fekete 2010). The information pertaining to losses incurred due to vulnerabilities of social aspects are largely ignored due to the difficulty in quantifying them (Cutter et al. 2003). Social vulnerability index for KRB is derived by making use of the indicators comprising of number of households, female population, population of scheduled castes/tribes (SC/ST) (people below the poverty line) and population comprising of illiterates, taking village as stratum. The village spatial database of Kopili basin is integrated with the Census of India data of 2011. The village database coupled with census data is integrated with the flood hazard zonation layer of Kopili basin to assess the impact of flood inundation on the demography of the area to observe the effect of human susceptibility to varying severities of flood hazard. In the present study, it is assumed that the areas with maximum density of population will have their associated physical structure and livelihood options (Pramojanee et al. 1997), hence higher weightages are assigned to dense population centres in the case of socio-economic vulnerability.

Derivation of infrastructure vulnerability index

The assessment of infrastructure vulnerability (roads) was carried out by considering the metalled and un-metalled roads as the primary indicators and weightages are given accordingly. Metalled roads have been assigned higher weightages because of their economic value. This is obvious because any damage to such structures would cost considerable loss to the community besides hampering the smooth functioning of local governments. The village layer coupled with infrastructure layer is integrated with the flood hazard zonation layer in order to identify the roads falling in high – very high flood hazard zones. Accordingly higher weightages are assigned to the road network based on the level of significance it has in the smooth functioning of the community.

Derivation of land use vulnerability index

Paddy crop is grown three times a year in KRB, hence, the cropped area and uncropped areas are considered as indicators in the assessment of land use vulnerability in the current scenario. The land use/cover layer generated as part of ISRO Census project of the year 2012–2013 is integrated with the village layer and then with the flood hazard zonation layer. The integration enables one to identify the number of villages that fall in cropped and uncropped areas. Higher weightages are assigned to all the cropped areas and lower weightages to non-cropped areas, respectively.

Finally, flood risk assessment is estimated using Equation (1).

Results and discussions

The KRB is one of the most flood-prone regions of the country due to the emptying of various tributaries into the river coupled with excessive amount of rainfall in a short spell of 4 months (June-September) every year. The repeated events of floods in the basin are assessed by integrating the annual flood inundation layers captured from satellite data during the last 18 year flood seasons to classify villages into various flood hazard severity zones. The flood risk assessment is carried out by using MCA approach which in the present study is a result of the product of flood hazard and vulnerability, which is a function of Socio-economic, Infrastructure and land use vulnerability indices.
**Hazard vulnerability**

Depending on the flood hazard severity level, the flood hazard zonation layer is classified as low, moderate and high and weightages of 0.3, 0.6 and 1 are assigned accordingly. Low flood hazard zone signifies that the area was inundated at least 1–8 times in the last 20 years (1977, 1988 and 1998–2015) and moderate hazard zone is classified if the area is inundated 9–12 times and high hazard zone for 13–20 times as shown in Table 2. It is observed that about 649 villages are falling in Low flood hazard severity against 95 villages falling in high flood hazard zones. About 162 villages remain unaffected which comprises of about 16% of the total number of villages. The high flood hazard zones are mostly confined to the areas adjacent to Kopili river where the maximum elevation is about 60 m (SRTM 30 m DEM), and low and moderate flood hazard zones comprising of about 74% of total number of villages are those areas whose elevation is between 61–156 m as shown in Figure 4(a).

**Social vulnerability**

The flood vulnerability is a function of adaptive capacity, elements at risk, exposure and their susceptibility to flood hazard severities and probability (Scheuer et al. 2011). Social vulnerability assessment characterizes the human interaction and their coping capacities in the event of a major disaster, which varies both geographically and temporally. In the present context, 5 variables from Census-2011 data of India are considered for carrying out vulnerability calculations. Household composition, gender (female), poverty (population of scheduled castes/tribes (SC/ST) and unemployment (illiterate population) at village level are considered and weightages are assigned appropriately depending on the level of significance as shown in Table 3. Higher weightages are assigned to those villages which comprise more number of households, female population and population consisting of large number of SC/ST and illiterates and lower weightages are assigned to villages which comprise less number of population. Because the physical structure and economic assets vary in accordance with the population density of a community (Pramojanee et al. 1997), higher weightages are assigned to villages which are densely populated in five census variables. Social vulnerability index derived from the sum of the vulnerability indices from the five census variables are shown in Table 4.

Figure 4(b) shows the social vulnerability of Kopili River basin. About 454 villages are falling in low vulnerable zones and about 73 villages in high vulnerable zones.

**Infrastructure vulnerability**

National highways, state highways, district and village roads which are metalled are given higher weightages in the current study because any damage to these structures would severely affect the relief and rescue operations in the event of a flood disaster. About 82% of villages falling in KRB have metalled roads and they are given a weightage of 0.6 as shown in Table 5. Figure 4(c) shows

### Table 2. Showing the flood hazard index.

| S.No | Flood hazard classification | Number of times/years the area was subjected to flood inundation during 1977, 1988 & 1998–2015 | Hazard index | No. of villages affected |
|------|----------------------------|-------------------------------------------------|---------------|-------------------------|
| 1    | Low                        | 1–8 times                                       | 0.3           | 649                     |
| 2    | Moderate                   | 9–12 times                                      | 0.6           | 93                      |
| 3    | High                       | 13–20 times (almost every year)                 | 1             | 95                      |
| 4    | Unaffected                 | 0 times                                         | 0             | 162                     |
Figure 4. (a) Flood hazard vulnerability, (b) Social vulnerability, (c) Infrastructure (roads) vulnerability, (d) Land use vulnerability.
Figure 4. (Continued)
the infrastructure vulnerability of the Kopili basin. District and village roads which are in close proximity to the left and right banks of the Kopili River also fall in the low-lying areas.

### Land use vulnerability

The basin is covered by fertile alluvial soil which allows the crops to grow throughout the year. Paddy, the main crop cultivated in this region, is sown almost three times a year. Other crops include maize, wheat and tea plantations are also grown in this region. Land use vulnerability is mainly assessed by the impact of flood hazard on the cropped areas and accordingly higher weights are assigned to the cropped regions when compared to uncropped areas as shown in Table 6. Cropped areas which comprise more than 90% of total number of villages are assigned a weightage of 1 and uncropped areas are assigned a weightage of 0.3. Figure 4(d) shows the land use vulnerability map of the basin.

### Table 6. Land use vulnerability index of Kopili Basin.

| S.No | Infrastructure vulnerability index | Road-type          | Vulnerability | No. of villages |
|------|-----------------------------------|--------------------|---------------|-----------------|
| 1    | 1                                 | Croplands          | High          | 949             |
| 2    | 0.3                               | Uncropped lands    | Low           | 50              |
The flood risk assessment is calculated as:

\[ \text{Risk} = \frac{\text{Hazard}}{\text{Vulnerability}} \]  

which is further mentioned as:

\[ \text{Flood Risk Assessment} = \text{function of Hazard Assessment, Vulnerability Assessment, Elements at risk and Risk Analysis} \]  

(Flood Risk Assessment = function of Hazard Assessment, Vulnerability Assessment, Elements at risk and Risk Analysis) (Van Westen et al. 2009).

Figure 5 shows the flood risk assessment for KRB, which is derived from MCA in conjunction with GIS by integrating the hazard zonation with the total vulnerability index. It is inferred that about 35 villages are falling in high risk zone, 124 villages in moderate risk zone and 676 villages in low risk zone (Table 7). The high risk zones are mainly confined to the low-lying areas whereas the moderate risk zones fall along the banks of the Kopili River. About 162 villages are unaffected by the severities of the flood because they are located on higher elevation when compared to high and moderate risk zones.

The demography data of 2011 (Census 2011) is utilized to assess the impact of flood hazard on various population centres of KRB to understand the social vulnerability of the basin at village level. Household composition, gender, poverty and unemployment are used as prime vulnerability indicators to derive the village level social vulnerability Index on a scale of 0–4. Indicator > 4 being high vulnerability and 0–2 being low. It is observed that about 54% of the population is falling between moderate to high social vulnerability zones and these are the centres where high infrastructure

| S.No | Risk index | Risk severity | No. of villages | Risk area (hectares) |
|------|------------|---------------|-----------------|---------------------|
| 1    | > 4        | High          | 35              | 12,830              |
| 2    | 2–4        | Moderate      | 124             | 26,379              |
| 3    | 0.2–1.99   | Low           | 676             | 160,015             |
| 4    | 0          | Unaffected    | 162             | 189,872             |
|      |            | Total         | 162             | 389,096             |

Table 7. Flood risk index of Kopili Basin.

Figure 5. Flood risk map of Kopili Basin.
vulnerability zones are concentrated. From the present study, it is very much evident that the vulnerability parameters selected for deriving various vulnerability indices are in fact the driving factors for assessing the flood risk which in turn is complemented by the hazard indicators. The flood hazard zone is one contributing factor but in order to effectively implement the mitigation/disaster reduction measures, there is a need to decrease the vulnerability and risk of the residents living in the flood hazard prone areas. It is also important to implement the land use regulation practices effectively in the vulnerable regions of the basin.

Conclusions

The main objective of the study is to develop an approach based on MCA and GIS to assess the flood risk by integrating the flood hazard zonation with social, infrastructure and land use vulnerabilities at village level keeping the KRB as one of the case studies. In the present approach, flood risk assessment was realized by making use of the formula proposed by ADPC, 2005. The social vulnerability index is derived with a set of four variable indicators using Census, 2011 data of India and the impact of flood hazard on resilience of various communities is studied. It is estimated from the proposed analysis that about 540 villages fall in moderate–high social vulnerability zones and about 132 villages in high infrastructure vulnerability zones and 82% of the villages for which agriculture is the main source of livelihood come under high vulnerable zones. The flood risk assessment zone is the cumulative effect of assessing the impact of flood hazard on various vulnerability parameters. Out of 3.89 lakh hectares of flood hazard area, about 4% of the hazard area falls in high risk zone and about 150 villages comprising 10% of total flood hazard area fall under moderate–high risk zones. Evaluation criteria employed in assigning weights to various vulnerability (social, infrastructure, land use) parameters is mainly dependent on the assumption that the vulnerability of a village is more when the density of population is more and as the densely populated areas have more economic assets and livelihood options, the impact of flood hazard on these areas also become more.

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Disclosure statement

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