FORUM GEOGRAFIC

Forum geografic. Studii și cercetări de geografie și protecția mediului
Volume ***XIV****, Issue* ***2*** *(****December*** *2015), pp.* ***156-163***
*http://dx.doi.org/****10.5775/fg.2067-4635.2015.144.d***

Assessing flood inundation extent and landscape vulnerability to flood using geospatial technology: A study of Malda district of West Bengal, India

Sahana MEHEBUB[1], Ahmed RAIHAN[1], Hossain NUHUL[1], Sajjad HAROON[1*]

[1] Faculty of Natural Sciences, Department of Geography, Jamia Millia Islamia, New Delhi, India
* *Corresponding author*, haroon.geog@gmail.com

Received on <12-08-2015>, reviewed on <30-09-2015>, accepted on <07-11-2015>

Abstract

Assessment of flood risk zonation and landscape vulnerability to flood are fundamental aspects in flood risk management. Landsat 8 Operational Land Imager (OLI) and ASTER DEM data were used to assess landscape vulnerability to flood inundation and flood risk in Malda district of West Bengal state, India. Flood inundation map was prepared on the basis of water and non-water pixels on images (before and during the flood event). Flood risk map was prepared using equal interval of separation based on elevation and inundated flooded area. Flood inundation map was overlaid on the pre-monsoon land use/land cover map to produce landscape vulnerability to flood. The results revealed that 19% area of the district was flooded during monsoon flood event in 2014 and the agricultural area was most affected land use, sharing 62% of the total flood affected area, followed by river bed (21%), built up (7%) and vegetation (5%). The flood risk map of the district shows that temporary river islands, sand banks along the Ganga river course lie in low flood plain and were considered under high risk zone. The flood plain alongside minor stream drainage in southern, north-western and in between them comes under medium flood risk zones. Flood risk is low in areas which are away from the rivers. Non flooded areas were identified in high lands of eastern region of the district. Landscape vulnerability map shows that the blocks located along the Ganga river namely Kaliachak I, Kaliachak II, Kaliachak III, Manikchak, Ratua I were highly vulnerable to flood. The study suggests that efforts should be made to remove the sediments for increasing the depth of river. Spurs and bed bars should be constructed to avoid great loss of prime agricultural land, property and lives of people.

Keywords: *flood, risk, landscape vulnerability, Malda District, remote sensing and GIS*

Rezumat. Evaluarea extensiunii inundaţiilor şi a vulnerabilităţii peisajului la inundaţii folosind tehnologie geospaţială: studiul districtului Malda din Bengalul de Vest, India

Evaluarea zonării riscului la inundaţii şi a vulnerabilităţii peisagistice la inundaţii sunt aspecte fundamentale în managementul riscului la inundaţii. Landsat 8 Operational Land Imager (OLI) şi ASTER DEM data au fost utilizate pentru a estima vulnerabilitatea peisajului la inundaţii şi evaluarea riscului la inundaţii în districtul Malda din statul Bengalul de Vest, India. Harta inundaţiilor a fost obţinută pe baza pixelilor water şi non-water de pe imagini satelitare (înainte şi în timpul fenomenului). Harta riscului la inundaţii a fost realizată utilizând intervalul egal de separaţie bazat pe elevaţie şi zone inundate. Harta inundaţiilor a fost suprapusă peste hărţile de utilizare/acoperire a terenurilor ante-muson pentru a obţine vulnerabilitatea peisajului la inundaţii. Rezultatele au demonstrat că 19% din suprafaţa districtului a fost inundată în timpul inundaţiilor din 2014 şi că suprafeţele agricole au fost cele mai afectate (62% din totalul suprafeţelor calamitate), urmate de albiile râurilor (21%), zone construite (7%) şi zone cu vegetaţie (5%). Harta riscului la inundaţii a districtului arată că insulele temporare, bancurile de nisip de-a lungul râului Gange se află în lunca inundabilă joasă şi sunt considerate a fi expuse unui risc crescut. Luncile joase aparţând reţelei hidrografice situate în sud, nord-vest şi între acestea sunt expuse unui risc mediu la inundaţii. Zonele neinundabile au fost identificate în ţinuturile mai înalte din partea de est a districtului. Harta vulnerabilităţii peisajului arată că blocurile situate de-a lungul râului Gange, mai precis Kaliachak I, Kaliachak II, Kaliachak III, Manikchak, Ratua I sunt foarte expuse la inundaţii. Studiul sugerează că sunt necesare eforturi pentru îndepărtarea sedimentelor astfel încât adâncimea râului să crească. Contraforturi şi bancuri de nisip ar trebui folosite pentru a preveni pierderile de terenuri agricole, proprietăţi şi vieţi omeneşti.

Cuvinte-cheiel: *inundaţii, risc, vulnerabilitatea peisajului, Districtul Malda, teledetecţie şi SIG*

Introduction

Flood as a common hydrologic extreme is a regular phenomenon in India. The rainfall received in India is erratic in nature and unevenly distributed both in time and space. Nearly 40 million hectares of area gets inundated every year in India (NRSC, 2015). West Bengal is one of the highly vulnerable states to flood. It is affected by severe floods during monsoon every year, causing irreparable loss to property and life. Out of the total geographical area, about 42% is susceptible to flood in West Bengal (Government of West Bengal, 2014). Flood inundation and flood vulnerability maps are significant components of flood risk management and mitigation. These maps can provide accurate geospatial information about the extent of floods and can be used as planning tools to assess flood risks and landscape vulnerability (Jung et al., 2013; Turner et al., 2013; Gilles et al., 2012). Flood inundation mapping, using remote sensing and GIS techniques is an intuitively useful tool for monitoring flood extent and assessing its impact on land use and land cover. Landsat Thematic Mapper is widely used for detecting flood extent globally (Bhavsar, 1984; Ruangsiri et al., 1984). Surface elevation data (ASTER DEM) can effectively be utilized for flood zonation mapping by overlaying flood inundation map in GIS environment.

Forum geografic. Studii și cercetări de geografie și protecția mediului
*Volume **XIV**, Issue **2** (**December 2015**), pp. **156-163***
*http://dx.doi.org/**10.5775/fg.2067-4635.2015.144.d***

Various studies have demonstrated effectiveness of remote sensing data for monitoring and analyzing flood hazard and flood mapping. It has been efficiently utilized for mapping flood extent in a coastal floodplain using Landsat TM and DEM data (Wang, 2010); the use of digital elevation models for flood hazard mapping (Leenaers&Okx, 1989); micro landform classification and flood hazard assessment (Ho, 2011); flood risk zonation and mapping (Mohan et al., 2011); flood hazard zonation and flood vulnerability assessment (Sanyal&Lu, 2005); flood hazard mapping (Venkata&Rajib, 2004); evaluation of flood water depth using radiometric remote sensing (Lyon and Hutchinson, 1995); uncertain flood inundation models (Horritt, 2006); remote sensing and GIS based mapping of flooded areas (Brivio et al., 2002); calibration of uncertain flood inundation models using remote sensing (Mason et al., 2009), application of remote sensing in flood management (Sanyal&Lu, 2004).

This study aims to assess flood inundation and its impact on landscape. Evidence is given from Malda district, India. This study also attempts to explore the effectiveness of remote sensing and GIS tools for suggesting an appropriate methodology for flood inundation mapping and landscape vulnerability.

Study area

Malda district, where 80% of annual precipitation is received in four wet months from June to September, is traditionally identified as one of the flood-prone areas in India (Nihar et al., 2014). The Ganga river is known to have undergone several shifts of its course in the vicinity of the Malda region because of a combination of several fluvial and topographical features. With rapid growth of population, the banks of Ganga and its tributaries marked residential, commercial and industrial development (Thakur et al., 2011). Excessive rainfall within a short duration of time very often causes flood during monsoon in the district. Apart from the monsoon climate, shifting course of river, porous soil profile, collapse of bank in chunks and consequently submergence of bank into water are claimed to be the major causes of flood in the study area (Iqbal, 2010).

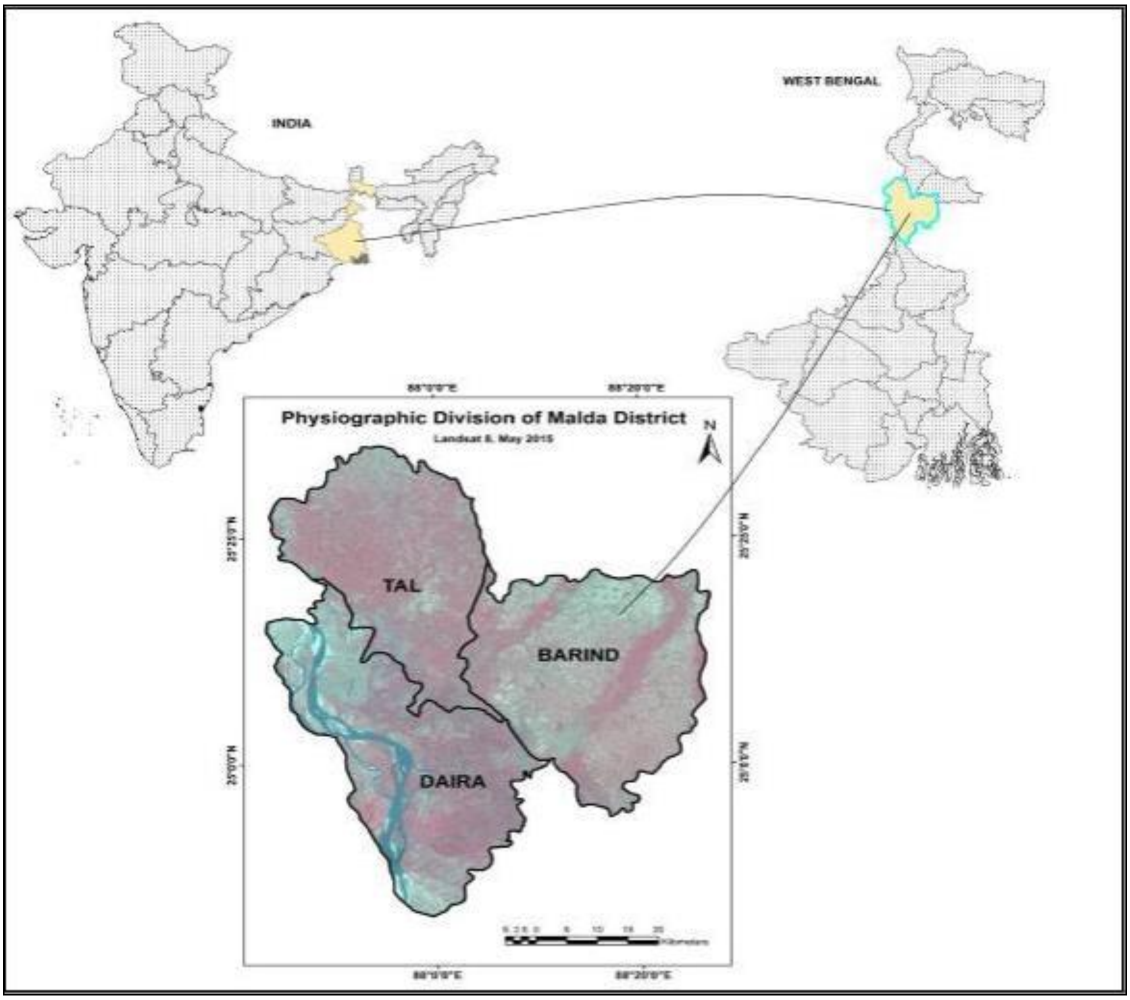

Fig. 1: Location of the study area

Flooding brought by the Ganga and the Mahananda not only causes huge damage of crops and infrastructure, but also leads to massive siltation of reservoirs (Sanyal, 2005). This situation reduces capacity of the existing dams to store water and creates problems to control floods. Farakka Barrage was constructed to divert the Ganga water towards the Bhagirathi and the Padma rivers and to release the sediment load into the deeper part of estuary (Rudra, 2004; Sinha 2012). The main objective of constructing the barrage was not let the water drain into the Hugli river. Due to this obstruction the river made new course in upstream of Farakka barrage affecting Malda and Murshidabad districts (Banerjee and Chakroborty, 1983; Banerjee, 1999). Change in the Ganga river course and river bank erosion are main causes of flood in the district. Flood occurrence has become a regular phenomenon and its magnitude has increased over the decades (Rudra, 2004; Rudra, 2010; Banerjee, 1999; Mukhopadhyay, 2003. Manikchak, Kaliachak-II, Kaliachak-III and Ratua-I blocks (administrative divisions) of the district were more subjected to erosion and flood.

Malda district has two distinct subdivisions, (English Bazar and Chanchal) which are divided into 15 blocks spreading over 3,733 square kilometers area. The district is situated between 24º40′20″ N to 25º32′08″ N latitudes and 88º28′10″ E to 87º45′50″ E longitudes (Fig. 1). The district consists mainly of low-lying alluvial plains sloping towards the south. The North Eastern part of the district contains a few elevated tracts. The river Mahananda flows from north-east to south-east and divides the district into eastern and western regions. Further, the river Kalindri divides the western region into northern and southern regions. The eastern part is comparatively high and undulating while western part is low and fertile. Three broad sub-regions can be identified physiographically within Malda district on the basis of nature of topography and soil, i.e. Barind, Diara and Tal. The Barind region of mature alluvium lies on the eastern margin of the Mahananda River. The Diara is a relatively well-drained flatland formed by the fluvial deposition of newer alluvium in the transitional zone between the Barind upland and the marshy Tal tract of the Ganges (West Bengal Development and Planning Department, 2007).

Database and methodology

Landsat 8 OLI data of pre-monsoon and monsoon (2014) were used for flood inundation mapping and ASTER DEM data was used to assess the landscape vulnerability to flood and flood risk in Malda district. The study area was extracted using Survey of India (SOI) topographical sheet (RF 1:50,000). The methodology adopted for flood inundation and landscape vulnerability to flood is presented in Fig. 2 and described as follows:

Land use and land cover map

Land use and land cover maps of the study area for pre-monsoon and monsoon (2014) were generated by supervised classification and maximum likelihood method was used for this classification. Final grouping of spectral classes was done on the basis of land cover classes. The generalized images were reclassified to reduce classification error and to improve the accuracy of the classification. Finally land use/land cover maps of pre monsoon and monsoon period were prepared.

Normalized difference water index

Normalized difference water index (NDWI) was derived to identify water related surface. The main advantage of NDWI is that near infrared (NIR) is highly sensitive to moisture content in the soil and the vegetation canopy. The Normalized Difference Water Index (NDWI) was employed to reach the goal of isolating water and non-water features. McFeeters's NDWI equation was used to separate water cover area from non water area. This equation is designed to maximize the reflectance of a water body by using green wavelengths and minimize the low reflectance in near infrared (NIR) of water bodies. Consequently, the water body information was enhanced and the background (vegetation and soil features) information was restricted in McFeeters's NDWI equation (McFeeters, 1996). Thus water body was identified by applying a threshold to McFeeters's NDWI images:

$$NDWI = \frac{Green - NIR}{Green + NIR}$$

where NIR is the reflectance or radiance in a near infrared band (0.85-0.88 μm OLI and 0.76-0.90 μm for TM) and Green is the reflectance or radiance in a visible channel (0.53-0.60 μm OLI and 0.52-0.60 μm TM).

Flood mapping using Landsat 8 images

Water versus non-water areas were delineated on Landsat image before and during flood events and were compared to determine flooded areas. After identifying water and non-water areas on both images (one acquired before the flood event and the other during the flood) using the above criteria, determination of areas that were flooded was made. The area indentified as dry or non-water on the May (pre-monsoon) image was classified as water on the August (monsoon) image and considered to be flooded. The area identified as dry on both May and August images was considered non-flooded.

Flood risk zonation

A flow accumulation model was created using the ASTER GDEM 2 and the inundated flood map was reclassified into high risk, moderate risk, low risk,

Forum geografic. Studii și cercetări de geografie și protecția mediului
Volume XIV, Issue 2 (December 2015), pp. 156-163
http://dx.doi.org/10.5775/fg.2067-4635.2015.144.d

and non-flooded area using equal interval of separation based on elevation. The overall accuracy of GDEM 2 for flood risk zonation was around 17 meters at the 95% confidence level and a horizontal resolution on the order of 75 meters. The vertical (root mean squared error) accuracies generally varied between 10 and 25 meters.

Landscape vulnerability to flood inundation

The inundated flood map was superimposed on the pre monsoon land use classes to examine the landscape vulnerability.

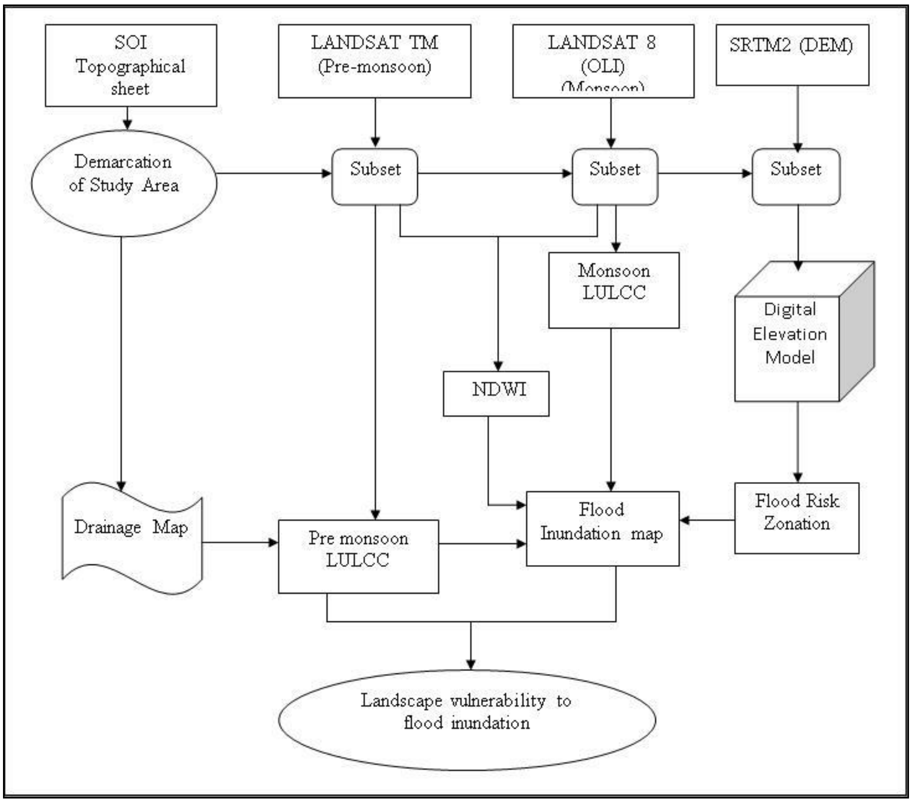

Fig. 2: Flow chart of the methodology

Result and discussion

Flood inundation

The mean value of the NDWI during flood was 0.492 for the flooded areas and 0.2264 for the non-flooded areas. The NDWI values <0 indicate non flooded area and values between 0 and 0.3 indicate moist soil while values >0.3 indicate water on the map (Fig. 3).

Of the total area of the district, 19% area was affected by flood. Ratua I, Manikchok and Kaliachok I, Kaliachok II, Kaliachok III were affected by the flood brought by river Ganga. Habibpur block in south eastern part of this district experienced flood caused by the Tangan river. Among physical divisions of this district, Daira physical division was mostly affected by flood (Fig. 4).

Flood risk zonation

Four flood risk zones (high, medium, low and non-flooded) were delineated in the district (Fig. 5). The stabilized river islands occupied by vegetation and agricultural crops were clearly identified with the help of remote sensing satellite data. These islands lie in low floodplain and were considered under high risk zone. Sand banks and temporary river island are flooded during the rainy season every year. The flood plains alongside minor stream drainage in southern, north-western and in between them fall under low and middle level flood plains and were identified as medium risk zones. Low level and middle level flood plains get submerged every year during monsoon season. Flood risk is low in areas which are away from the rivers. Non-flooded area is identified in the eastern region comprising Barind region.

A vast portion of the lowlands (ground elevation lower than 30 m) is located near the river Ganga and in the eastern and southern zone experiences frequent and deep inundation. The high risks areas in the plain correspond well with the areas that experienced a high flood level (24 m) and were submerged during flood of August due to monsoon rainfall. Very low and low hazard areas also coincide well with the non-inundated areas shown in flood inundation maps prepared from ASTER DEM and

Landsat 8 data in 2014 (Fig 4 and 5). Moderate hazard risk areas were identified mainly at elevations between 30 and 50 m near the outlet for flood water from the upper parts of the rivers.

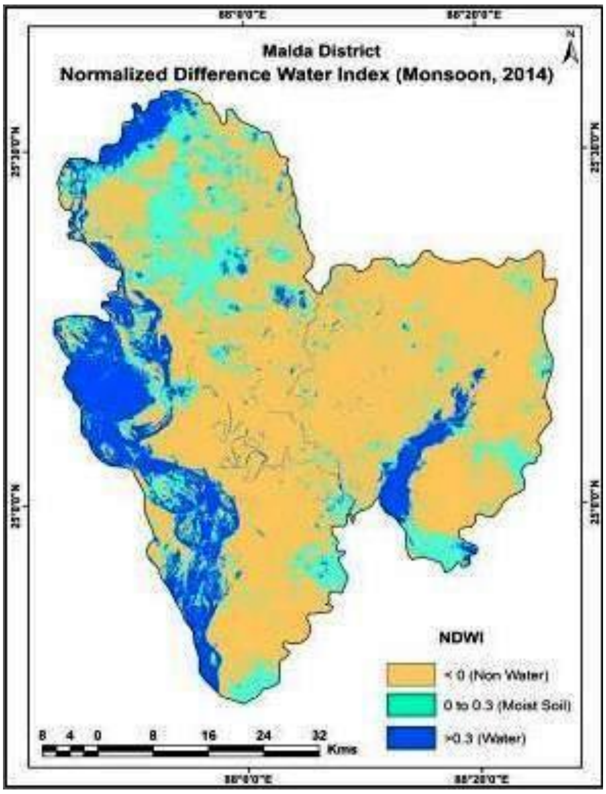

Fig. 3: NDWI (monsoon), 2014

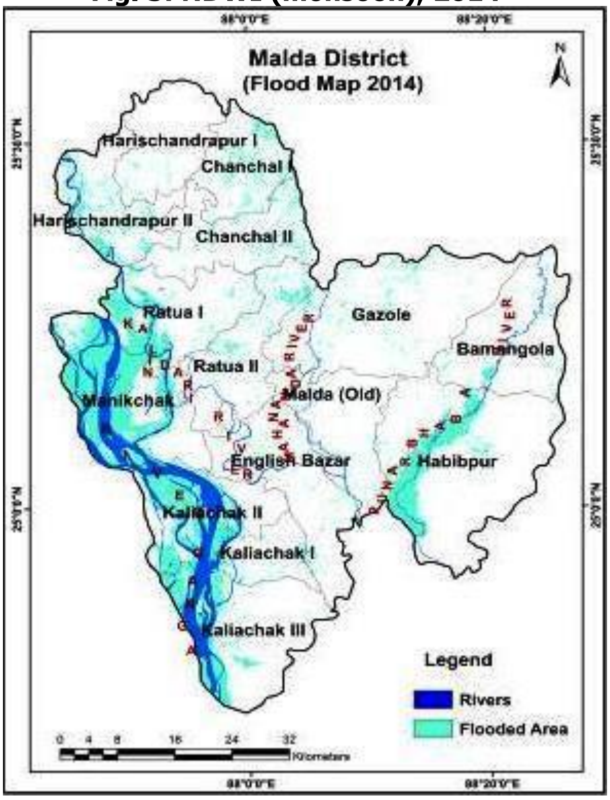

Fig. 4: Extent of flood, 2014

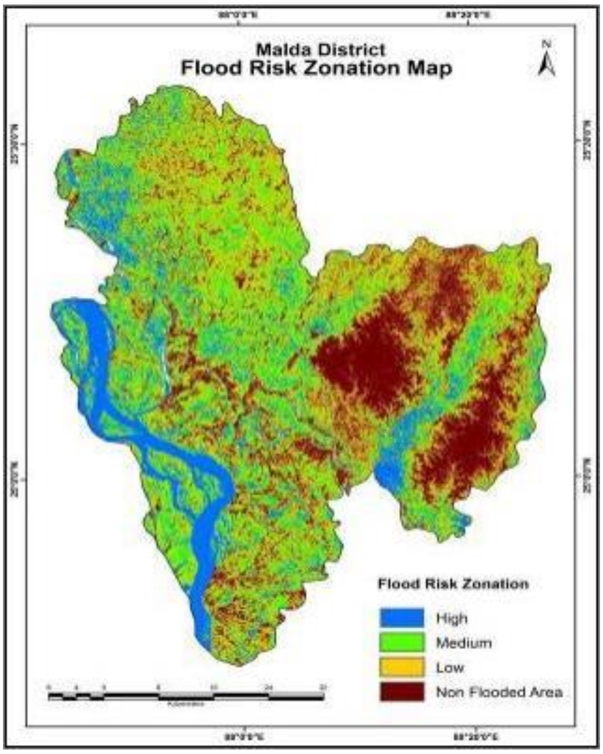

Fig. 5: Flood risk zonation

Pre-monsoon land use and land cover

Land use and land cover map of Malda district during pre-monsoon season, 2014 was prepared to overlay flood inundation map and to assess landscape vulnerability to flood (Fig. 6).

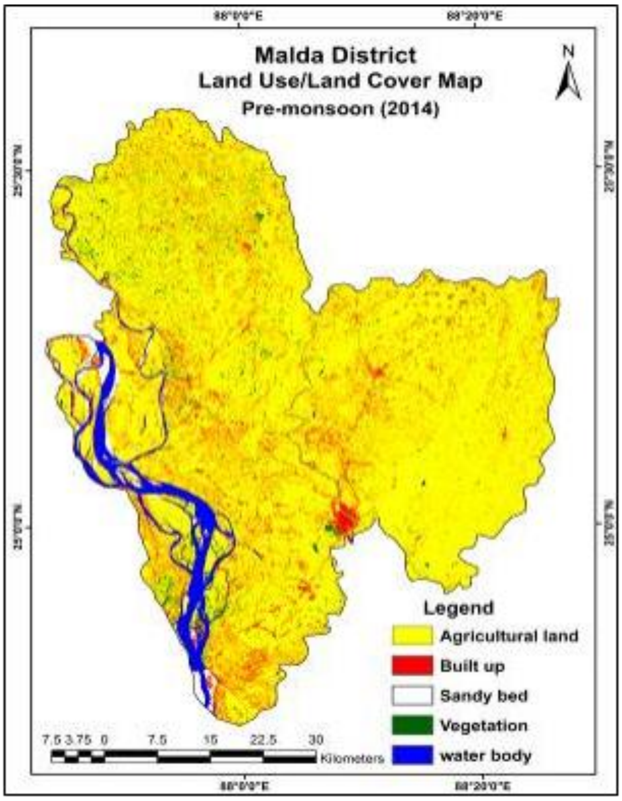

Fig. 6: Pre-monsoon land use land cover

Forum geografic. Studii și cercetări de geografie și protecția mediului
*Volume **XIV**, Issue **2** (**December 2015**), pp. **156-163***
*http://dx.doi.org/**10.5775/fg.2067-4635.2015.144.d***

Areas under various land use categories and their percentage is presented in Table 1. Five land use categories were identified viz. built-up, sandy bed, agriculture, vegetation, and water body in the study area. Table 1 revealed that agriculture occupied the largest area (82%) followed by built up area (9.2%).

Table 1: Land use/land cover in Malda district (before flood event)

Land use/land cover classes	Area in hectares	Area in percentage
Built up	35,657	9.2
Sandy bed	3,830	1.0
Vegetation	12,268	3.2
Agriculture	3,19,529	82.4
River bed	16,397	4.2

Landscape vulnerability to flood inundation

Of the total agricultural area (82.42%) nearly 14% area under paddy was vulnerable to flood thus affecting the crop production in the district. About 30% vegetation cover was flooded resulting in the degradation of ecosystem and 15% built up area was exposed to flood rending many people homeless. The high and moderate risk areas were lying between flood plain areas and low slope gradients along the Ganga river. The flooded areas along the Ganga River and along the tributary of the Mahananda River were primarily agricultural land and vegetation area (Fig. 7)

Figure 8 shows the area of each land use/land cover class affected by flood. It revealed that about 45,953 hectares of agriculture, 5,361 hectares of built up, 3,726 hectares of vegetation cover area of their respective total areas was affected during the flood in the district. Patches of flooded areas in the north, north-west and south-west of the image were identified mainly in southern river bed, fallow land and cultivated land.

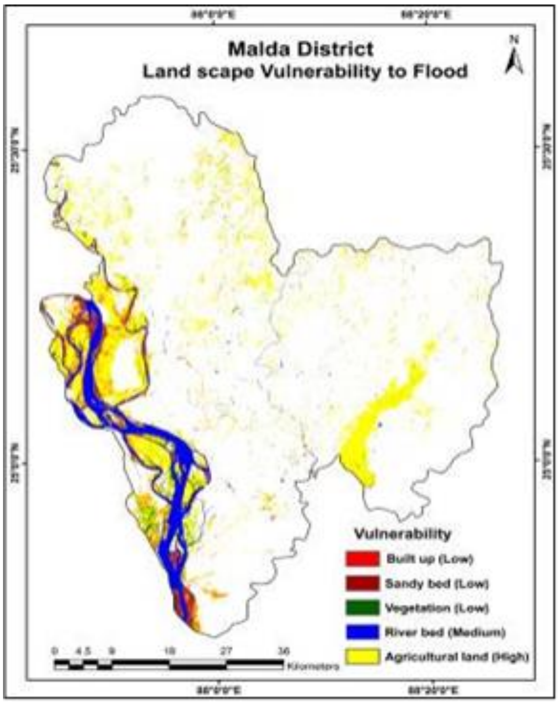

Fig. 7: Flood risk zonation

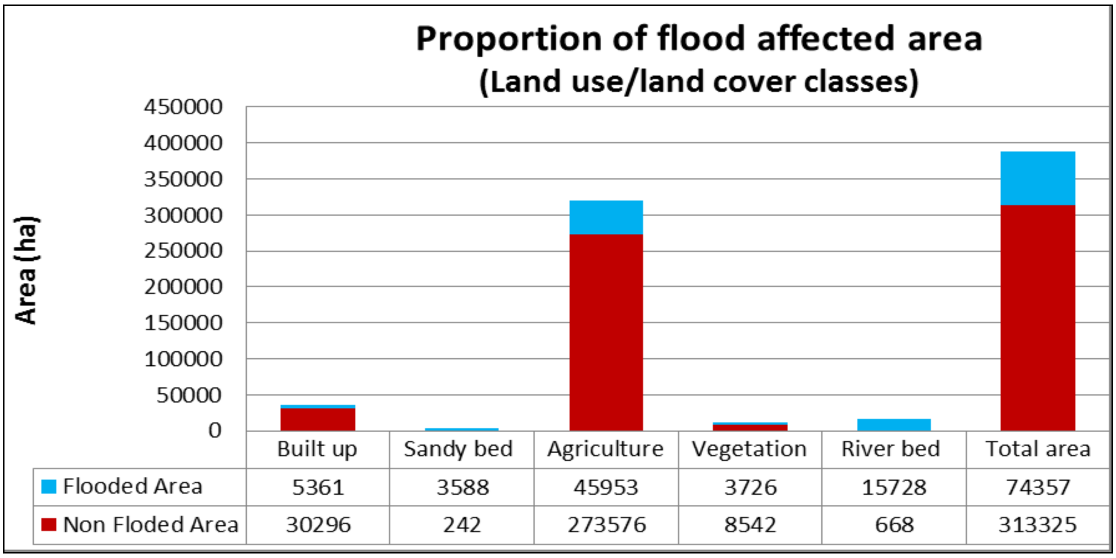

Fig. 8: Percentage of land use classes affected by monsoon flood

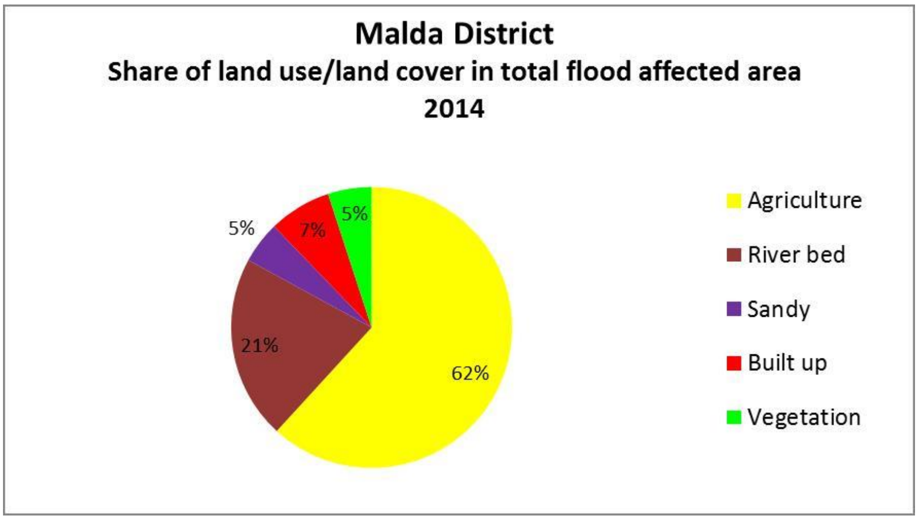

Fig. 9: Land use share in total flood affected area of Malda, August 2014

These three categories were severely affected by the flood in terms of size and percentage of the total flooded area in Malda district. It should be noted that most of the relatively higher elevated areas were not flooded on 3 August 2014. Of the total flood affected area (74,357 hectares), agriculture shared the largest proportion (62%) followed by river bed (21%), built up (7%), vegetation (5%) and sandy bed (5%). It is clearly evident that the agriculture is severely affected by the flood every year in the study area (Fig. 9).

Conclusion

Remote sensing and GIS tools have proved useful for preparing flood inundation, flood risk and flood vulnerability maps. Flood extent was measured by analyzing water versus non-water targets on Landsat 8 images (one acquired before and the other during the flood event). Flood risk zonation map was prepared using equal interval of separation based on elevation and inundated flooded area. Flood inundation map and pre monsoon land use land cover map was compared to assess impact of flood on various land use and land cover classes. Of the total area of the district, 19% area was affected by flood during 2014. Flood vulnerability map based on height shows that areas along the Ganga river namely Kaliachak I, Kaliachak II, Kaliachak III, Manikchak, Ratua I, and Harischandrapur-II and Habibpur were inundated areas and therefore were categorized as highly vulnerable blocks in the study area. Chanchal I, II, English Bazar, and part of Gazol came under medium vulnerability category. These blocks located at relatively higher location were less affected by flood. Low vulnerability blocks comprised of southern parts of Kaliachak I, Kaliachak II, English Bazar and parts of Habibpur. Flood inundation map revealed that area under paddy was largely affected by the flood (62%) followed by river bed (21%), built up (7%), Sands (5%) and vegetation (5%). Of the total area of individual land use classes, agriculture (14%) was highly affected followed by vegetation (30%), and built up (15%). Field investigation revealed that declining depth of the river Ganga and shifting of its course near Kaliachak I, Kaliachak II, Kaliachak III, Manikchak and Ratua blocks are the prime reasons for frequent flood in the study area. The study suggests that efforts should be made to remove the sediments for increasing the depth of river near the affected area of Malda district. Earlier levees were constructed along Farakka covering the parts of Kaliachak, Manikchak and Ratua blocks but these have been eroded. Therefore, the measures such as construction of short spurs and bed bars for diverting flow should be adopted to save agricultural land, property and human lives.

Acknowledgement

We are grateful to the anonymous reviewers for their constructive comments and suggestions in improving overall quality of the manuscript.

References

Banerjee, M. (1999). A report on the impact of Farakka Barrage on the human fabric, On behalf of South Asian network on dams, rivers and people (SANDRP), http://www.sandrp.in/dams/impact_frka_wcd.pdf. Accessed on July 1, 2015.

Banerjee, S.N., Chakroborty, P. (1983). Some observations on recent trends of shifting of the Ganga between Rajmahal and Ahiron. J Geol Soc, India 24:318-321.

Bhavsar, P.D., (1984). Review of remote sensing applications in hydrology and water resource management in India. Adv. Space Res, 4, 193–200.

Brivio, P.A., Colombo, R., Maggi, M., Tomasoni, R. (2002). Integration of remote sensing data and GIS for accurate mapping of flooded areas. International Journal of Remote Sensing, 23(3), 429-441.

Dhar, O.N., Narayan, J. (1966). A study of rainspell associated with the unprecedented floods in the Kosi river. Ind. J. Meteorol. Geophys., special volume, April issue, India Met. Dept. publ., 37-42.

Dhar, O.N., Nandargi, S. (1998). Floods in Indian rivers and their meteorological aspects. In V. S. Kale (ed.) Memoir No. 41 of the Geological Society of India on Flood Studies in India, Bangalore, 1-25.

Gilles, D., Young, N., Schroeder, H., Piotrowski, J., Chang, Y.J. (2012). Inundation mapping initiatives of the Iowa flood center: Statewide coverage and detailed urban flooding analysis. Water, 4, 85–106.

Goswami, A.K. (1983). Studies on the nature of floods in the depressed belt of southern West Bengal. Geographical Review of India, 41, 189-201.

Government of West Bengal, (2014). Annual Flood Report for the year, Advance Planning, Project Evaluation & Monitoring Cell Jalasampad Bhavan, Salt Lake Kolkata – 7000 091

Horritt, M.S. (2006). A methodology for the validation of uncertain flood inundation models. Journal of Hydrology, 326, 153-165.

Ho, L.T.K., Umitsu, M. (2011). Micro-landform classification and flood hazard assessment of the Thu Bon alluvial plain, central Vietnam via an integrated method utilizing remotely sensed data. Applied Geography, 31 1082-1093.

Iqbal, S. (2010). Flood and erosion induced population displacements: a socio-economic case study in the Gangetic riverine tract at Malda district, West Bengal, India. Journal of Human Ecology, 30(3):201-211.

Jung, Y., Merwade, V., Yeo, K., Shin, Y., Lee, S.O. (2013). An approach using a 1D hydraulic model, Landsat imaging and generalized likelihood uncertainty estimation for an approximation of flood discharge. Water, 5, 1598–1621.

Lyon, J.G., Hutchinson, W.S. (1995). "Application of a radiometric model for evaluation of water depths and verification of results with airborne scanner data" Photogrammetric Engineering and Remote Sensing, 61, 161-166, 1995.

Leenaers, H, Okx J.P. (1989). The use of digital elevation models for flood hazard mapping. Earth Surface Processes and Landforms, 14, 631–40.

McFeeters, S.K. (1996). The use of the Normalized Difference Water Index (NDWI) in the delineation of open water features. International Journal of Remote Sensing, 17:7, 1425-1432.

Mukhopadhyay, S. (2003). River bank erosion and land degradation, a study of river Ganga, land degradation and desertification. Rawat Publication, New Delhi, pp 366-373.

Mason, D.C., Bates, P.D., Dall Amico, J.T. (2009). Calibration of uncertain flood inundation models using remotely sensed water levels. Journal of Hydrology, 368, 224-236.

Mohan, K., Kumar, S. Raku, K.N.P. (2011). Flood risk zones: A mapping exercise using remote sensing data and GIS, Journal of Applied Hydrology, Vol. 24 (1 & 2), pp. 32-35.

Nihar, R.S., Roy P.K., Majumadar, M. Bhattacharya, S. Biswasroy, M. (2014). Six Years Major Historical Urban Floods in West Bengal State in India: Comparative Analysis Using Neuro Genetic Model. American Journal of Water Resources, 2014, Vol. 2, No. 2, 41-53.

Norman, N.S., Nelson E.J., Zundel, A.K. (2001). Review of automated flood plain delineation from digital terrain models. Journal of Water Resource Planning and Management, 127, 394–402.

National Remote Sensing Centre, (2015). Disaster management support for flood, Indian Space Research Organization, Hyderabad, India.

Ruangsiri, P. Sripumin, R. Polongam, S. Kanjanasuntorn, P. Wongparn, S. (1984). State of Flooding in the Mun-Chi River Basin area, N. E. Thailand by Digital Landsat Data Analysis; Remote Sensing Division, National Resource Council of Thailand: Bangkok, Thailand.

Rudra, K. (2004). The encroaching Ganga and social conflicts: the case of West Bengal. India. Independent Broadcasting Associates, Littleton, p 40, http://www.ibaradio.org/India/ganga/extra/resource/Rudra.pdf Accessed on 07 July 2015.

Rudra, K. (2010). Dynamics of the Ganga in West Bengal, India (1764–2007): implications for science-policy interaction. doi:10.1016/ Quaternary International, 161-169.

Sanyal, J., Lu, X.X. (2005). Remote Sensing and GIS-Based Flood Vulnerability Assessment of Human Settlements: A Case study of Gangetic West Bengal, India, Hydrological Processes, 19, 3699-3716.

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

Sinha, R., Ghosh, S. (2012). Understanding the dynamics of large rivers aided by satellite remote sensing: a case study from Lower Ganga Plains. Geocarto Int., 27, 207–219.

Thakur, K.P., Laha, C., Aggarwal, S.P. (2011). River bank erosion hazard study of river Ganga, upstream of Farakka barrage using remote sensing and GIS Nat Hazards (2012) 61:967–987 DOI 10.1007/s11069-011-9944-z _ Springer Science+Business, Media B.V. 2011.

Turner, A.B.; Colby, J.D.; Csontos, R.M.; Batten, M. (2013). Flood modeling using a synthesis of multi-platform LiDAR Data. Water, 5, 1533–1560.

Venkata, B.G., Rajiv, S. (2004). GIS in Flood Hazard Mapping: a case study of Kosi River Basin, India, Conference Proceedings of Map Middle East, UAE.

Wang, Y. Colby, J.D., Mulcahy, K.A. (2002). An efficient method for mapping flood extent in a coastal floodplain using Landsat TM and DEM data. International Journal of Remote Sensing, 2002, vol. 23, No. 18, 3681–3696.

West Bengal Development and Planning Department. (2007). District Human Development Report: Malda, Development & Planning Department Government of West Bengal, 5-6.