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Flood monitoring using microwave remote sensing in a part of Nuna river basin, Odisha, India

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Abstract Floods adversely affect the life of people and property in the coastal districts. It is important to delineate the flood extent and pattern which helps in the vulnerability assessment and also to find out the intensity of damages to facilitate future planning and management. The study area is a part of the Nuna river basin, which suffers from the flood disasters frequently. The present study applies microwave remote sensing (RADARSAT-1 images) to monitor extent, depth and duration of 2003 and 2008 floods in the Kendrapara district of Odisha, India. RADARSAT-1 images of 4, 11, 13 and 20 September of 2003 and 18, 20, 22 and 24 September of 2008 were used to monitor the flood extent, duration and depth. The threshold method was used to delineate flood extent which was used for calculating flood duration and depth. Further, vulnerability assessment of the paddy crop was done to obtain intensity of damage in the area from the 2003 and 2008 floods. Field survey was done to verify and assess the generated results. Areas affected by more than 15 days of flood duration and depth of more than 3 m faced maximum loss. Both the years witnessed major floods in this area with an estimated damage of around INR 174 million ($3.6 million) in 2003 and INR 75 million ($1.6 million) in 2008.

Keywords Flood · Microwave remote sensing · RADARSAT-1 · Vulnerability · Damage

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1 Introduction

Hazards are natural events which occur individually or in combination with the other events at different times and place (Blaikie et al. 1994). With an increasing population density, people are more prone to settle in many hazardous areas making them more vulnerable to the hazards. For the developing countries, this is often more serious as they are already facing problems with respect to the accessibility to resources. Natural hazard generates big threats to human life and property and gives less warning time (Khan and Rahman 2007). Therefore, proper management is required to reduce the loss. Natural disasters develop from the hazards which adversely affect the environment and society, causing financial as well as environmental losses. Flood is one of the most destructive natural disasters causes more economic loss than other natural or technological disasters (Huang et al. 2008). Lives lost in the natural disasters have a major share in the flood loss. Rather, flood causes more losses and damage to the life and property when compared to any other hazards (NDMA 2008). Hence, flood monitoring is very essential to find out the intensity of damage in the affected areas. Vulnerability is intimately related to natural disasters and is also considered as the base of the disasters. Flood vulnerability was also discussed by many researchers (van der Veen and Logtmeijer 2005; Connor and Hiroki 2005). Flood vulnerability and risk assessment help in the future mitigation of the flood-affected areas. Some risk related works were also done with the vulnerability (Barredo et al. 2007). Blaikie et al. (1994) said that, it is necessary to understand the level of vulnerability of different groups of people to face the disaster, and this is decided by the socio-economic system of the area. Thus, in dealing with the vulnerability and damage of a natural disaster, social status of people also plays a major role.

Remote sensing has a key function now in the assessment and monitoring of natural disasters. Optical images were used before to distinguish flooded and non-flooded area by Rao et al. (1998) and Jain et al. (2006). Near infrared part of the electromagnetic spectrum is absorbed by the water bodies, and it appears dark in infrared satellite imagery which is useful to delineate the flood (Sanyal and Lu 2003), but in the cloudy atmosphere, it is difficult to map the flooded area using optical imagery. Radar signals can penetrate the weather phenomena and are very useful for flood delineation (Matgen et al. 2007). Passive microwave remote sensing was used by Temimi et al. (2005) for flood forecasting. Various studies were performed to delineate the flood extent and depth. Toyra et al. (2001), Hess et al. (2003) and Frappart et al. (2005) used the Synthetic Aperture Radar (SAR) for showing spatiotemporal pattern in inundated areas. A statistical model for SAR was proposed for predicting flood extent (Townsend and Foster 2002). The dielectric constant of water is exploited in case of microwave remote sensing. RADARSAT-1 is a Canadian satellite, which also uses SAR for monitoring changes in the environment as well as for supporting resource sustainability (Lillesand and Keifer 2000). It has longer wavelength which transmits energy at 5.3 GHz of frequency. RADARSAT-1 was used to extract land–water boundary (Xia et al. 2011, Wang et al. 2011), flood inundation, flood frequency (Hoque et al. 2011) and the backscatter values were used to identify land cover submerged under water (Shao et al. 2001). Chaouch et al. (2012) utilized RADARSAT imagery for identifying coastal area inundation during low and high tides.

The people of the study area were very poor, and their major stay is agriculture. They experienced huge economic loss from the floods which give further blow to their already poor economic condition. The main objective of the study was to assess the intensity of flood damage of 2003 and 2008 with respect to the paddy crop in the study area from the real-time microwave images. The vulnerability assessment was done, and damage in terms of monetary loss was calculated to compare the havoc of 2003 and 2008 floods for the future management purpose.

The present study was performed in a part of Kendrapara district of Odisha lying in the eastern part of India (Fig. 1) where flood disaster occurs almost every year. The entire region is surrounded by Nuna, Barandia and Chitrapala river networks, which overflow during monsoon period causing flood. Being an economically backward region, about 90 % of the population lives in the flood prone areas and thus faces major obstacles during floods and cyclones. The area extends from 20°22′N to 20°28′N and from 86°17′E to 86°29′E covering about 130 km^2. The annual minimum and maximum temperatures usually vary from 11.5 to 39 °C, respectively. The average annual rainfall is about 146.36 cm, and most of it occurs during the cyclonic storms and depressions. Super cyclone of 1999 caused huge loss of life and property here. The entire area and the surroundings are considered as very high damage risk zone by UNDP (2002) and BMTPC (1998).

2 Materials and methods

RADARSAT-1 images were used in the study. Description of the RADARSAT-1 is tabulated in Table 1. The SAR imagery of 4, 11, 13 and 20 September of 2003 and 18, 20, 22 and 24 September of 2008 along with the optical image and height information facilitates (Table 2) delineation of flooded and non-flooded boundary to measure the flood extent as well as to calculate depth and duration. Vulnerability and damage assessment were also done to evaluate the amount of loss that has occurred after the disastrous flood of 2003 and 2008.

A sequential flow of the adopted methodology is given in the flowchart (Fig. 2). Temporal RADARSAT-1 images, Cartosat-1, Cartosat DEM (digital elevation model) and LISS-IV images were taken for the study. After pre-processing of the images, land water delineation was done from the RADARSAT-1 images and permanent water bodies were marked from the Cartosat-1 and LISS-IV images. A permanent water body was subtracted from the water of the RADARSAT-1 which gives the actual flooded area for 2003 and 2008. The flood depth map was generated from the flooded area and the DEM which further gives the total flood inundation. Flood duration maps were obtained from the flood inundation and flood extent. Land use map was used to extract the paddy cultivated area from the agricultural class of the classification. It was again verified with the GPS survey by taking location points of the paddy fields during the survey. And on the basis of the field verified flood extent, depth and duration, the paddy vulnerability map was generated. Finally, paddy damage was obtained in terms of money from the vulnerability and on the basis of information on the total cost involved in the cultivation process from the field survey. All the results were verified from the field.

2.1 Pre-processing of RADARSAT-1 data

RADARSAT images can penetrate through the cloud cover and are very sensitive to the water bodies. Because of the dielectric constant, increase in the moisture content of the target usually increases the backscatter values of the radar. It is found that Radar backscatter from the crops with some amount of dew has 1.7–2.5 dB greater value than crops without dew (Wood et al. 2002). The intensity values are converted to the backscatter values which are represented in decibel (dB). The data were geometrically corrected for ensuring minimum possible root mean square (RMS) error and geo-referenced to Universal

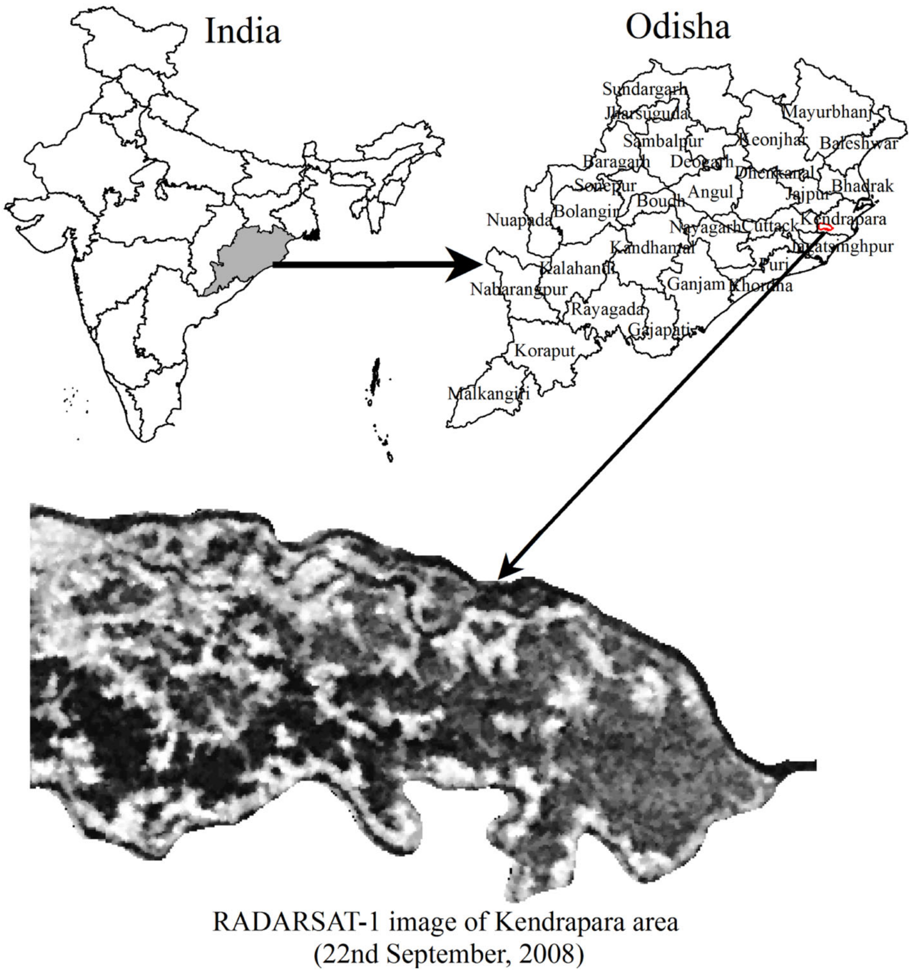

Fig. 1 Study area

Table 1 Specifications of the data used

Characteristics of the data	Specifications
RADARSAT beam mode	Scan SAR narrow
SAR band and polarization	Band C (5.3 GHz), HH polarization
Ground coverage (km)	300 × 300
Resolution (m)	50 × 50
Pixel spacing (m)	25 × 25
Satellite orbit	Sun-synchronous, descending orbit
Time of data acquisition (local)	0500–0630 h Indian standard time
Period of data acquisition	September, 2008

Table 2 Data used for the study

Data	Date of acquisition	Usage
RADARSAT images	4, 11, 13 and 20 September, 2003 18, 20, 22 and 24 September, 2008	Flood extent, depth and duration mapping, vulnerability curves and map, damage maps
Cartosat DEM	–	Height information of the whole study area.
Cartosat1 image	February, 2006	Permanent water body identification from the pre-flood image.

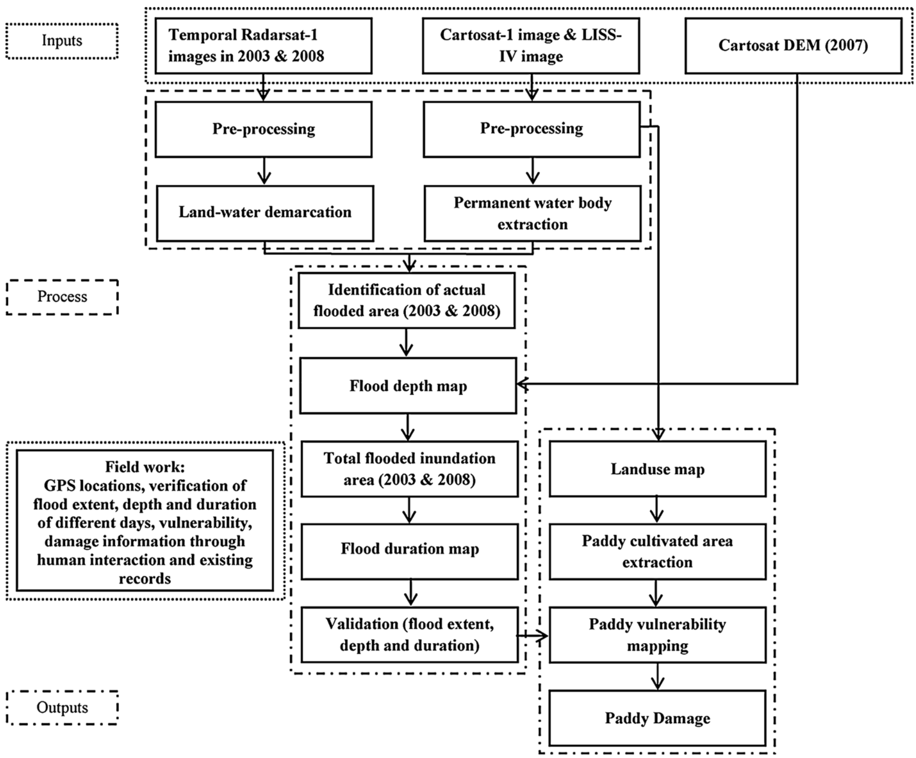

Fig. 2 Methodology

Transverse Mercator (UTM) projection. To remove the speckle errors, Gamma-MAP filter was used (Lopes et al. 1990). The DN value from the image was converted to the back-scatter (σ_0 in dBs) values:

$$\sigma_{0i} = 10 \times \log_{10}((DN_{\mathrm{i}}^2 + A_0)/A_{\mathrm{i}}) + 10 \times \log_{10}(\sin(\theta_{\mathrm{i}})) \qquad (1)$$

where the subscript i is the pixel number, θ is the incidence angle, A_0 and A_{i} are the scaling offset and gain constants (Chakraborty et al. 2005).

2.2 DEM generation and datum transformation

Cartosat DEM was generated for this study. Interior and exterior orientation (Grodecki and Gene 2003) of Cartosat 1 stereo pair was performed in LPS version 9.1. The GCPs were collected using Lieca500 single frequency GPS receiver. The received signals were differentially corrected with the help of the base station receiver data during the post-processing of GCPs. DEM of 10 m grid size was generated from the stereo block. The overall block triangulation accuracy achieved was 0.96 pixels. The DEM was projected into UTM projection zone 45, and WGS 84 was the horizontal and vertical datum. The DEM had negative height information because the WGS84 datum is approximately 60 m higher above the mean sea level (MSL). Hence, the conversion of WGS84 referenced height surface to MSL was necessary. The EGM96 vertical datum represents the MSL (Sun et al. 2003; Kaplan and Hegarty 2006). National Imagery and Mapping Agency (NIMA) and National Aeronautics and Space Administration (NASA) provide a well-known global geoid model by which derived elevation relative to WGS84 can be transferred to the EGM96 surface (Mukherjee et al. 2013). It provides a correction coefficient and computes geoid height over land areas (http://cddis.gsfc.nasa.gov/926/egm96/egm96.html). The WGS84 referenced surface was converted using the EGM96 Geoid model.

2.3 Extraction of flood extent, duration and depth

Flood extent shows the area under flood water and where damages could occur. For proper assessment of the flooded area, a specific flood boundary is required to be delineated. Water usually appears black as the backscatter value of water reaches nearly zero in the radar image (Chaouch et al. 2012). Among various methods for boundary delineation, threshold method (Bovolo and Bruzzone 2005; Temimi et al. 2011; Chaouch et al. 2012) was applied here for demarcating the flooded and non-flooded zone. A threshold value of around −12 dB was taken as the boundary line between flooded and non-flooded region. Threshold or density slicing involves division of histograms into two parts. To each part of the sliced histogram, a class name, like flooded and non-flooded, is given. The backscatter value of flooded water in the study area varies from −11.5 to −12.5 dB in different images of 2003 and 2008 which approximates to the average value of −12 dB. The threshold value was chosen based on the trial and error method as given by Gonzalez et al. (2004). Therefore, separate values within a range of −11.5 to −12.5 dB were used as the boundary line for flooded and non-flooded areas in all the images. It also conforms to the flood water backscatter values found in the HH polarized image like RADARSAT-1 in the work of Manjusree et al. (2012). The boundaries were verified from the field survey.

Flood duration indicates the period of water inundation in the field. Flood duration is one of the factors that shows a flood loss, particularly in the case of crops where flood with long duration and depth may damage the entire crop. RADARSAT-1 images of 4, 11, 13, 20 September of 2003 and 18, 20, 22, 24 September of 2008 were taken to estimate the flood duration. The 2003 images show gradual peak to lean flood from the first date (i.e. a gradual increase from the 4th September), while 2008 images show lean to peak flood period from the first date (i.e. flood decreases after the 18th September). Fourth September of 2003 and 22 September of 2008 had maximum or peak flood as obtained from the images. Derived flood extents for 4 days were used for computing the flood duration. For example, duration of the 2008 flood was calculated in the following way as described. The area which was observed to be flooded in only one image was categorized as flooded area below 2 days; flooded area in two consecutive images were categorized as flooded area from 2 to 4 days; flooded area in three consecutive images were categorized as flooded from 4 to 6 days; and finally, areas under flood water for all the days in four images were classified as areas with flood duration of more than 6 days. The process considered a period of images from 18 to 24 September of 2008 and 4 to 20 September of 2003 which were verified from the field.

Flood depth is the measure of flood water accumulation in a particular area. The flooded images of 2008 were considered, and depth of each day was estimated separately. The Cartosat DEM (10 m) of flooded area was extracted and was overlaid on the extent maps to get the highest elevated area affected by the flood. The highest elevated region of the study area where the flood had occurred was taken as the maximum flood water level. As the entire study area is a plain land near the coast, therefore, a very small difference in elevation is found. The calculated result of depth from the RADARSAT-1 image was verified from the field.

2.4 Vulnerability and damage assessment

Vulnerability is the degree of loss of the element at risk resulting due to the occurrence of any natural phenomena of a definite magnitude and is stated on a scale varying from 0 with no damage to 1 for total damage (Alexander 1993; In: Thakur et al. 2012). Thus, vulnerability gives the degree of loss. For assessing flood damage, various factors were considered. In this study, flood depth and duration were taken as the two indicators for flood vulnerability assessment for the years 2003 and 2008. Paddy is the dominant crop in the study area, long flood duration or greater depth has an adverse effect, particularly in the mature stage of the crop growth. Damage calculation involved the estimation of monetary loss due to natural disasters which was done by multiplying vulnerability with the total cost due to damage. Field data were collected for estimating damage of paddy. Height of paddy plants during the flood was an important factor for damage estimation with respect to the flood depth. The growth of local paddy plant or 'Beali' was considered in three stages, namely, initial stage (sowing) in June–July, middle stage in August–September and mature stage (harvesting) in October (Handbook of Agriculture: Indian Council of Agricultural Research 1980). The 2003 flood occurred in the middle stage of the crop growth while 2008 flood occurred towards the end of the middle stage. Photographs of the field survey are given in the Fig. 3.

2.5 Validation

All the results acquired from the images of the extent, depth and duration were validated by taking different flood points through GPS survey. Information about water level, vulnerability, damage and height of the paddy plants were obtained by a primary survey from the local people through questionnaire method (Thakur et al. 2012) and also from the secondary data. Location points of the paddy plants were taken during the field survey (2009), and the existence of paddy plants in those points during 2003 and 2008 floods were also verified from the local people. All the measurements are based on questionnaire method and information collected from the farmers and local inhabitants from different parts of the area in 2009, after the 2008 flood.

3 Results and analysis

3.1 Flood extent

Estimation of flood extent is a very important process for identifying flood hazard zones and for the management purposes. Hence, flood extent maps signify the most possible areas of damages. The study area is one of the worst flood-affected regions in India, where almost every year flood causes destruction to people. Thus, it is essential to demarcate flooded area here for controlling probable damages in future.

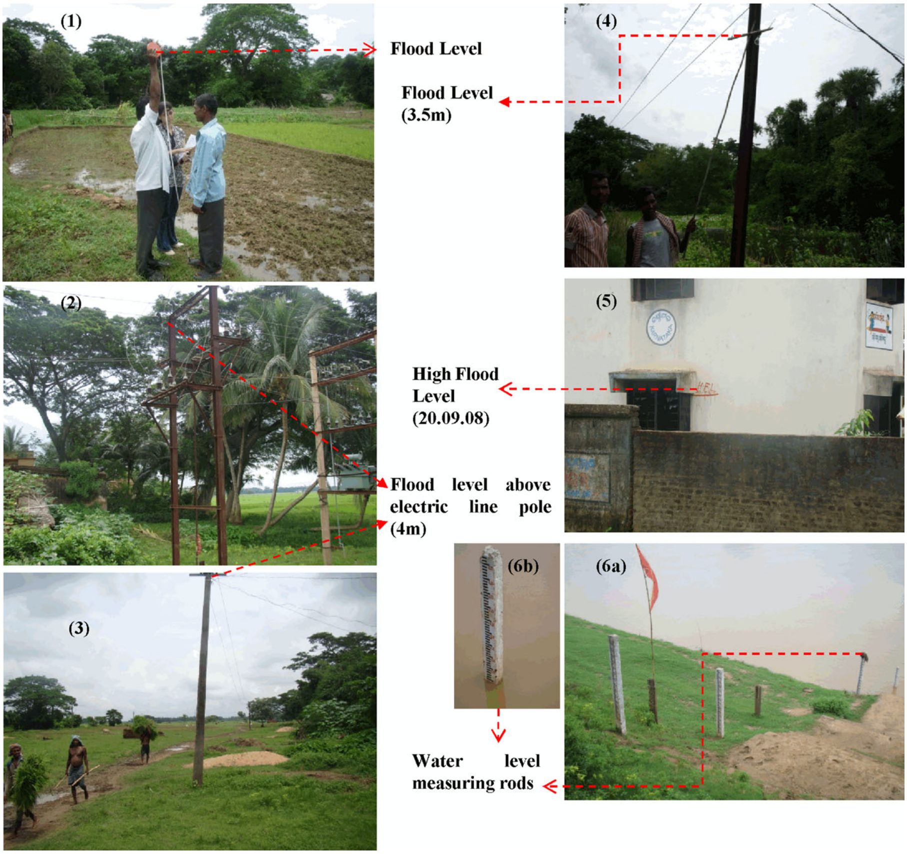

Fig. 3 *1–3* Photographs of 2003 flood depths as surveyed from the field (in 2009). *4–6* Photographs of 2008 flood depths as surveyed from the field (in 2009)

Flooded regions appear black in the images which help in identifying affected areas. Water when present as soil moisture gives high backscatter due to high dielectric constant. Smooth surface of water sends back the signal away from the sensor because of specular reflection and appears black in the RADARSAT images (Lillesand and Keifer 2000). Effect of waves again changes backscatter value, but in the present study area, there was very little effect of waves. Flood water extent of 2003 is illustrated in the Fig. 4 with peak flood in 4th September which gradually decreases in 11th, 13th and 20th September. On 4th September, the entire region was affected by peak flood with 72.15 km^2 area under water. The flood receded, and on 11th, 69.35 km^2 area was under flood water. The 2003 flood further reduced to 54.72 km^2 on the 13th, and it was less on 20th covering about 26.66 km^2. The eastern part was the most affected part of the region along with the south-west and some parts in the north. The flood water receded from the west to east and from 4th to 20th September. Flood water extent of 2008 is also given in Fig. 4 showing a gradual increase of flood water throughout the region from 18th to 22nd September. On the 18 of September, 2008, the region had minimum flood with 19.73 km^2 under flood water. The inundation was mainly in the western part. On 20th September, it progresses towards the east with an area of about 34.53 km^2 under submergence. Flood water further expands

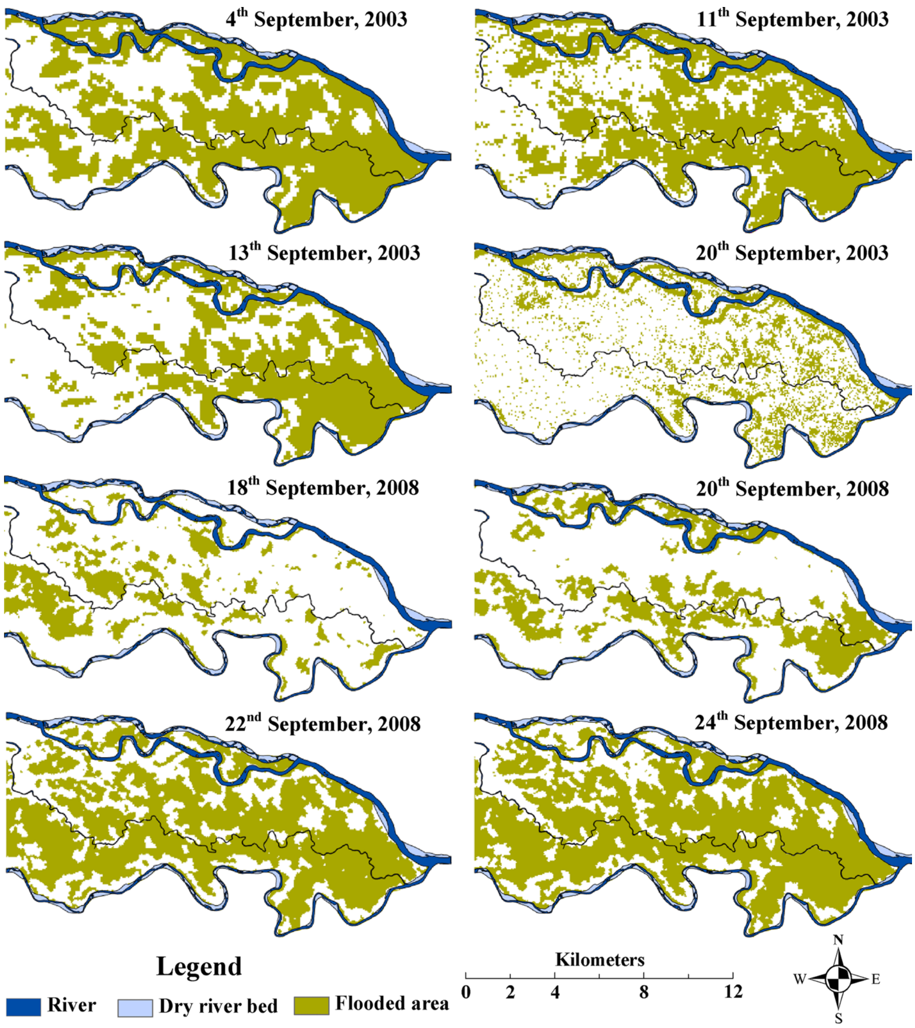

Fig. 4 Flood extent map of 4, 11, 13 and 20 September of 2003 and 18, 20, 22 and 24 September of 2008

during 22nd September and covers area of 76.93 km^2. This date signifies the peak flood day of the year and caused havoc in the region. From 24th September, flood started to recede as the total area under flood water was 73.07 km^2 which was <22nd September. Therefore, flood extent was least on 18th of September which gradually increases to reach the peak on 22nd September and then reduces on 24th.

3.2 Flood duration

The flood duration of 2003 and of 2008 (Fig. 5) is explaining the number of days for which different parts of the study area remained inundated. In 2003, the satellite images show a gradual decrease of flood water from the peak flood day. The 4th of September had peak flood which receded in the next 2 days of 11th and 13th September. On the 20th September, most of the flood water receded covering only few scattered areas in the north and

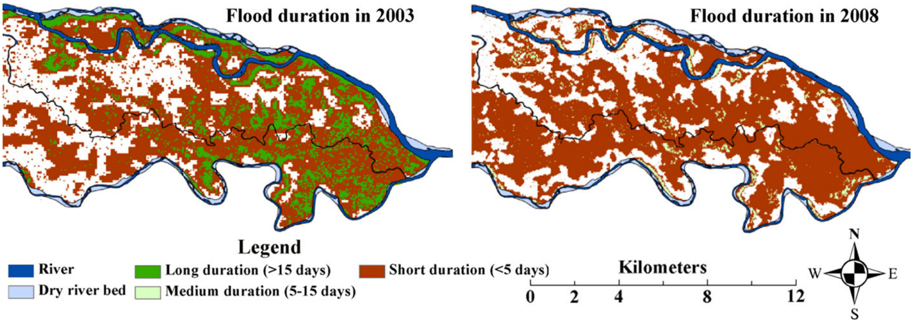

Fig. 5 Flood duration

east. As the eastern part was the lowest area with a slope towards the sea, a major portion of the flood water starts retreating from the west and accumulated in the eastern part. Thus, flood duration in most of the areas was more than 9 days, including the peak flooded day which decreases significantly on 20th. Some parts in the south-west showed decrease in flood water accumulation within 2 days after the 11th of September. In 2008, flood water started to advance from the western part of the region and submerged the entire area gradually. Although for the initial days, from 18th to 20th September, there was gradual progress of flood water, but suddenly it attained peak within next 2 days from 20th to 22nd September. Due to the high intensity of rainfall and breaching in some parts of the embankment within these 2 days, there was a large water logging and blockage in the entire area causing disaster. The western parts including some areas in the central and east had flood duration of more than 6 days. 4–6 days of the flood was found in the eastern and central parts, and the rest of the region had flood duration of 2–4 days. Few areas surrounding the major flooded zones had flood duration of <2 days. It was clearly observed that the study area remained under water for 2–4 days mostly (28.33 %), and less area was found under water for more than 6 days (10.21 %).

3.3 Flood depth

The flood depth maps of 2003 and 2008 (Fig. 6) are showing a level of water in the study area. The 2003 flood had less depth in the northern part of the study area and in some scattered parts of the south had <1 m or 2–3 m of depth. Apart from these few areas, the

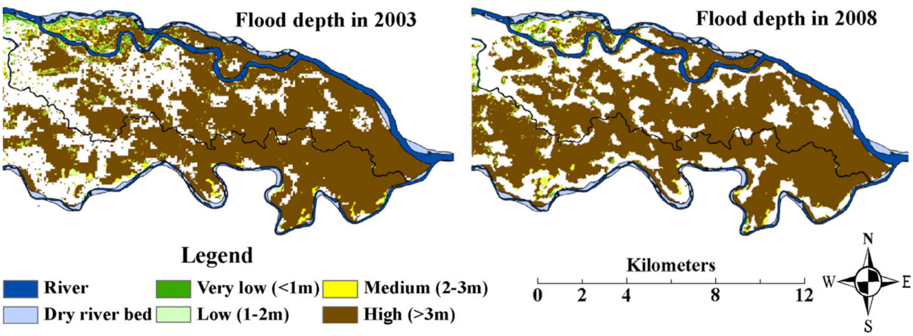

Fig. 6 Flood depth

rest of the region had a greater flood depth of more than 3 m. The elevation was very low in the east, so water accumulation was more in the eastern part. The south-western part of the study formed a pocket of low elevated area surrounded by little higher areas which resulted in flooding here. Another reason of flood water accumulation here was breaching in this part. About 1.5 km^2 area had low flood depth and 5.5 km^2 area had medium flood depth while more than 77 km^2 areas was facing the maximum flood depth of more than 3 m. The 2008 flood was also very severe with low and medium depth of water accumulation in the north and in a few portions of the south. The majority of the area experienced much more depth of flood water covering about 80 km^2. Medium and low water depth were observed in about 3.91 km^2 and in <1 km^2 area, respectively.

The results of flood extent, duration and depth extracted from the RADARSAT-1 images indicated a strong association with each other. It was observed that with increase in the extent, there was an increase in depth. And if the extent of water did not prolong in a particular area, the depth also would decrease. Therefore, the flood duration is influencing the depth. All these flood parameters are needed to be estimated and analysed to calculate the flood vulnerability and damage assessment of the crop which will further help in controlling the damage of the area.

3.4 Vulnerability assessment of the agricultural crop (paddy)

The flood vulnerability of the paddy crop was considered as it was the dominant agricultural crop of the region. Vulnerability depends on the flood depth and so primary data on the damage and the height of the paddy plants during the flooded times were collected from the field. Vulnerability value was estimated between the scale of 0 and 1. The vulnerability curves were generated by extensive field survey on the basis of the crop damage with the corresponding flood depth and duration. The curves were linear with straight line equation between two points. Both the flood depth and duration vary at different points on the curve with the corresponding vulnerability values. The curves were drawn considering the constant depth from 0 to 1 m, 1 to 2 m and more than 2 m with different durations. The paddy plants of the study area had a height of little more than 1 m, so the flood depth of 2 m and above was enough to destroy the crop if the flood duration was long. To assess the damage, the vulnerability scale used here shows that there was very high damage or vulnerability was nearly 1 with more than 2 m of flood depth and with 25–30 days of duration while with the flood depth of 0–1 m with 25–30 days of duration, vulnerability was much less (about 0.15). And for 1–2 m depth the vulnerability was around 0.9. Thus, if the depth of water is not much, then paddy plants can survive even with longer flood duration. It took only 15–20 days to reach the vulnerability of about 0.9 in case of >2 m flood depth, while the vulnerability was <0.9 even after 25 days of flood in case of 1–2 m depth. Again, this depends on the growth stage of the plant at the time of the flood. In the initial stages of growth, paddy plants remain under water for a long time, so longer flood duration with less depth may not be much destructive. Flood in both the years occurred at the middle stage of growth, in September when the height of the local paddy crop was around 2–2.5 feet. Greater depth of more than 2 m with long duration was harmful for the plant, but less depth during this period in some parts made the crop less vulnerable (Fig. 7).

The spatial maps of vulnerability of 2003 and 2008 are given in the Fig. 8. The 2003 flood caused more damage as the duration of this flood was longer. The vulnerability was quite high in the east (0.75–0.85) where the water depth was more and stayed for a longer time. Only few higher elevated areas were comparatively less vulnerable (0.30–0.60) in the east. The western and the northern parts of the study area were little higher in elevation and

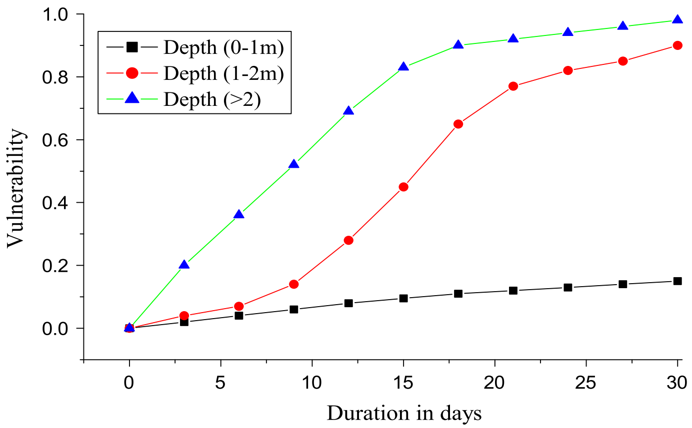

Fig. 7 Vulnerability curves

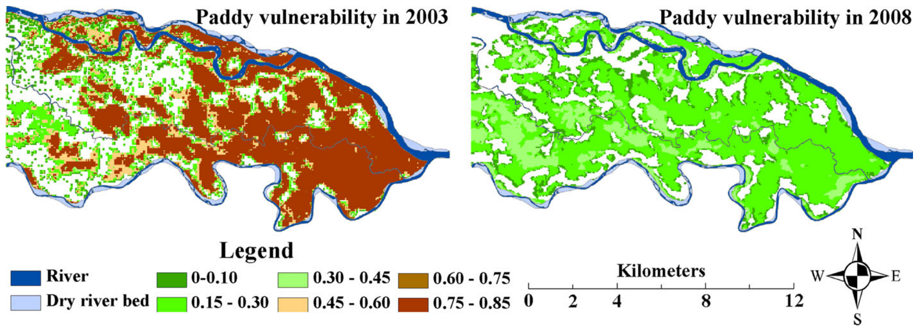

Fig. 8 Vulnerability of paddy in 2003 and 2008

thus experienced less depth and shorter flood duration causing less crop vulnerability. The paddy crop was 0–0.30 vulnerable in these areas. Medium to high vulnerability was observed in some pockets of the west and the central parts, which was because of the low elevations of these areas in comparison with the surrounding areas that has caused more depth and longer flood duration here. Thus, crops were more vulnerable in these parts. The 2008 map shows low vulnerability as the flood duration was less in this year. It was observed that although the duration of the flood was less, but the area extent of the flood was more in this year. Thus more cropped area was vulnerable and faced damage due to this flood. The paddy vulnerability varies from 0 to 0.45 in the entire region with the south-west and central parts being more vulnerable. Paddy fields in these areas experienced more damage as flood water stayed longer here, along with the eastern part. The 2008 vulnerability map shows that almost the entire study area was under flood threat, but 2003 was the year when farmers faced more damage.

3.5 Damage assessment of paddy

Damage is the estimated amount of loss in terms of money because of any natural disaster. The flood damage which can be quantified by money is tangible floods (Balica et al. 2013). In this study, damage calculation was done from the vulnerability for estimating the total

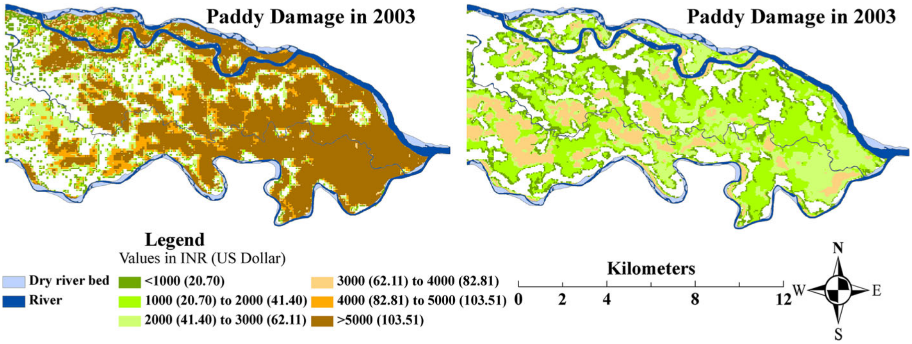

Fig. 9 Damage of paddy in 2003 and 2008

loss. It was done by multiplying vulnerability with the cost of the product or element at risk (paddy in this case). A field survey was conducted to collect information on the crop height and growth stage at the time of the flood and the loss of money at that time due to flooding. The flood hit the region in the middle stage of paddy in both 2003 and 2008, in September. Damage of the paddy crop in terms of Indian Rupees (INR) as well as in US dollar ($) is shown spatially all over the study area in Fig. 9 for 2003 and 2008. The exchange rate of $1 was INR 48.30 (according to the average exchange rate of 2009).

The loss was more in 2003 as the flood duration was more; entire east and the central part experienced loss of INR 4,000 ($83 approx) to >5,000 (>$104 approx). The east and central parts are the low regions of the study area which remain under water for longer time and thus experience greater loss. Some parts in the west experience less damage of paddy (INR 2,000–3,000 or $ 42–62 approx) as the vulnerability was also less here due to comparatively higher elevation and low flood depth and duration. In 2003, the western part experienced less damage in comparison with 2008 and many scattered areas of INR <1,000 (<$21) are observed in the north-central and northern parts.

The 2008 flood image, however, had more area under damage, but the overall damage in terms of money was less in comparison with 2003. Farmers faced greater loss during 2003 although the affected area was less. The region experienced maximum damage of INR >5,000 (>$104 approx) in about 44.66 % and 4,000–5,000 ($ 83–104 approx) in 7.68 % of the total study area in 2003, while 2008 flood did not experience that much of a loss. High losses in 2003 were observed in the major parts of the east, central up to a few parts in the west, while in 2008, maximum loss faced was INR 3,000–4,000 ($ 62–83 approx) in 17.43 % of the total area found scattered on the south-west and east. The rest of the flooded area in 2008 experienced loss of INR <1,000–3,000 ($ <21–62 approx) mainly in the east and central parts (Table 3). The western part of the study area experienced more damage in 2008 because of longer duration of stay of flood water in this area. Total loss of money in 2003 was INR 174 million ($3.6 million), and in 2008, it was INR 75 million ($1.6 million). Thus, the flood of 2003 was more disastrous, causing greater damages than 2008. The calculation of paddy crop damage was done on the basis of field survey. According to the farmers, the production cost for cultivating paddy in 1 acre of land was INR 12,000 ($249) (approx.), which provides around 20 quintals of paddy in normal time (all the values and information correspond to the average value of INR and US $ in 2009).

Table 3 Damage in 2003 and 2008 floods

Damage (INR)	Damage ($)	2003		2008	
		Area (km^2)	Area (%)	Area (km^2)	Area (%)
<1,000	<20.70	8.15	6.27	18.52	14.24
1,000–2,000	20.70–41.40	2.99	2.30	40.46	31.12
2,000–3,000	41.40–62.11	10.11	7.78	26.10	20.07
3,000–4,000	62.11–82.81	4.63	3.56	17.43	13.40
4,000–5,000	82.81–103.51	9.98	7.68	0	0
>5,000	>103.51	58.06	44.66	0	0
Non-flooded		36.08	27.75	27.50	21.15
Total		130	100	130	100

4 Conclusions

The research showed the intensity of damage in the study area during the 2003 and 2008 floods. Delineation of the flooded area, calculation of depth and duration from the RADARSAT-1 imagery was done to identify the damages of the worst floods in this area. Growth stages of the local paddy crops, investment of the farmers involved in this agriculture were considered for the damage calculation. Comparison of loss between the two big floods of 2003 and 2008 was also useful and necessary for future planning and management. According to the farmers during the field survey, the 2003 flood was more disastrous than 2008 flood. This happened due to greater flood duration in 2003 when the majority of the cropped area faced severe damage. And paddy being the dominant crop, most of the farmers experienced major economic loss. The results show that the flood depth and duration play a major role in determining the damage. The highly vulnerable areas have resulted in greater loss or damage (INR >5000 or $104). Areas with a great flood depth of >3 m have experienced maximum economic loss, such as in major parts in 2008 and in the east and central parts in 2003. The time of flood is also an influencing factor, as paddy plants at the matured stage experiences more damage. The 2003 and 2008 floods occurred almost in the mature stage of the crop resulting in more damage. As derived from the available data of RADARSAT-1 images, 2003 flood shows longer flood duration than 2008. However, the data for the entire flood duration of 2008 was not available, but the peak flood period (4 September, 2003 and 22 September, 2008) data were there within the available satellite images of both 2003 and 2008. The availability of more images in frequent intervals during the flooded time of 2003 and particularly 2008 may have given much better estimates. The results give damage of INR 174 million or $ 3.6 million in 2003 and INR 75 million or $ 1.6 million in 2008. This research helps in estimating economic loss faced by the poor farmers of this area for further allocation of resources and future management in various flood risk reduction programmes.

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