Chapter 4
Insight to the Potentials of Sentinel-1 SAR Data for Embankment Breach Assessment

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Abstract Embankment breaching is one of the serious issues on the innumerous streams of the Brahmaputra floodplains during the monsoon season, which extends from May to October, leading to major agricultural damages by inundation and sand casting. These floodplains are highly fertile areas supporting a dense population largely dependent on agriculture for livelihood. Therefore, continuous monitoring and management is required so that the annual loss due to embankment breaching can be minimized. Traditional on-site methods are laborious and time consuming. The use of Synthetic Aperture Radar (SAR) data for this application is recommended instead of commonly used optical remote sensing data due to its all-weather capability and high sensitivity towards dielectric constant. This study analyses the potentials of C-band dual polarized (VV + VH) SAR data for embankment monitoring and breach assessment such as identification of breach locations, length of breach and area affected due to inundation after occurrence of breach. For the purpose of study, Solengi river, a north bank tributary of the Brahmaputra in Assam is used as a case study. Temporal Sentinel-1 data are continuously analyzed to monitor critical points of embankments and develop a suitable methodology to operationalize embankment breach monitoring. The initial analysis shows encouraging results. This methodology, if successful, may be helpful to automate the process of monitoring embankment breaches enabling better decision making.

Keywords Sentinel-1 · SAR · Flood · Embankment breach assessment Monitoring

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1 Introduction

Embankments are artificial constructions raised on the banks of rivers that are prone to annual flooding in order to protect the low-lying communities and infra-structure residing next to them. Assam is one of the states of India where huge devastation occurs every year during monsoon due to flood leading to loss of valuable lives and property. Artificial embankments on the innumerous streams of the Brahmaputra valley act as lifelines during the flood season which extends from May to October. But these embankments are highly vulnerable to breaching leading to agricultural damage by inundation and sand casting [1]. Continuous monitoring and management is required so that the annual loss due to embankment breaching can be minimised. Traditional on-site methods are laborious and time consuming. Remote sensing offers the advantage of synoptic and temporal coverage thus reducing the effort and time required for assessment of breached areas. The use of Synthetic Aperture Radar (SAR) data for this application is recommended over the optical remote sensing data owing to its all-weather (clouds, fog, smoke and to some extent rain) capability and high sensitivity towards dielectric constant [2].

Since the successful launch of the first operational space-borne SAR sensor onboard ERS-1, SAR technology has advanced significantly and its potentials for various remote sensing applications has been widely evaluated. Consequently, several space-borne SAR missions have been launched by various countries, providing uninterrupted earth observation data for the remote sensing community. Numerous studies have used SAR data for various disaster monitoring and damage assessment applications [3–5]. On the other hand, there is a trade-off between spatial resolution, swath coverage and temporal resolution of remote sensing data. As far as flood monitoring is concerned, high spatial as well as temporal resolution data covering a larger swath is required for effective planning and decision making. The recent advancement of Terrain Observation by Progressive Scans SAR (TOPSAR), which is an optimized ScanSAR technique, solves the problems of scalloping and azimuth varying ambiguities [6]. Using TOPSAR, the recently launched SAR missions, such as Sentinel-1A/1B, are capable of providing SAR data with spatial resolution (Rz $\times$ Az: 5×20 m) and temporal resolution (12 days) covering a swath of 250 km, which can be particularly useful in flood monitoring and damage assessment [7, 8].

The backscatter thresholding technique, which is a pixel-based operation, has been extensively adopted for flood inundation mapping. If the water fraction is more than 50%, specular reflection is dominant that results in low backscatter [9, 10]. The histogram of SAR backscatter data over water abundant terrain is of bimodal nature. Several techniques have been proposed to automatically determine the threshold value based on bimodal histogram to separate water bodies from other land cover targets [11–13]. However, the bimodal distribution may lose prominence in some of the cases due to increased roughness caused by wind and rain [10, 14]. So, the bi-modal based automatic thresholding approaches may not be a reliable solution for effective monitoring. Unlike the above histogram thresholding processes, global thresholding approaches have also been extensively applied. In global thresholding technique, a single threshold for all the image pixels is used. Calibrated SAR data (backscatter) is a better representation of the target properties enabling comparison between temporal data as well as SAR data from different sensors [15]. Therefore, this study aims to analyse temporal Sentinel-1 SAR data and identify global threshold values for backscattering coefficients.

Sentinel-1 is providing SAR data in VV/VH polarizations for remote sensing community since 2014. [7, 16] have observed that like-polarization can better delineate open water features rather than cross-polarized data. However, the high soil moisture areas along with flood inundated areas can better help for embankment breach identification and its impact on the surrounding areas.

2 Materials and Methods

Around 40% of the state of Assam is prone to annual flooding which is further aggravated due to severe erosion and embankment breaching. Majority of the embankments in the state is prone to breaching not only due to heavy rainfall and flooding but also due to erosion, encroachment and soil condition. The Solengi river is one of the smaller north bank tributaries of the Brahmaputra river originating from the Arunachal Himalayas and flowing into the Brahmaputra in Biswanath district of Assam. The Solengi river like all other north bank tributaries of the Brahmaputra flows through steep slopes of the Himalayas and suddenly into almost flat terrain of the Brahmaputra plains in Assam. This sudden flattening of slope and heavy sediment in the river results in shallow braided channel in the floodplain region which is tremendously flashy in nature. The Solengi river is protected by embankments on both sides of its entire course through the flood-plain. Heavy rainfall during monsoon leads to sudden swelling of the shallow river which in turn leads to breaching at vulnerable locations during almost every flood season. Therefore this river has been chosen as a case study for demonstrating the capability of SAR data for detection of embankment breach locations and assessing its damage extent.

Sentinel-1 SAR data which operates in C-band (5.407 GHz) has been utilized for carrying out the study. Sentinel-1, part of the European Space Agency's Copernicus programme, consists of two satellites launched on 3 April 2014 and 25 April 2016 which operates in four modes of acquisition viz. Stripmap (SM), Interferometric Wide swath (IW), Extra-Wide swath (EW), and Wave (WV). The procured Sentinel images are dual polarization (VV and VH), with spatial resolution of 5 m $\times$ 20 m (Range $\times$ Azimuth). The observation mode of Sentinel-1 is interferometric wide swath (IW) mode having observation width of 250 km at an off-nadir angle ranging from 29.1° to 46.0°. The details of the eight Sentinel-1 SAR images collected over the study area between 9th April 2016 and 18th October 2016 are listed in Table 1.

Table 1 List of Sentinel-1 scenes used for this study

S. no.	Polarization (s)	Date of acquisition	Mode
1	VV/VH	9th April 2016	IW
2	VV/VH	3rd May 2016	IW
3	VV/VH	27th May 2016	IW
4	VV/VH	14th July 2016	IW
5	VV/VH	7th August 2016	IW
6	VV/VH	31st August 2016	IW
7	VV/VH	24th September 2016	IW
8	VV/VH	18th October 2016	IW

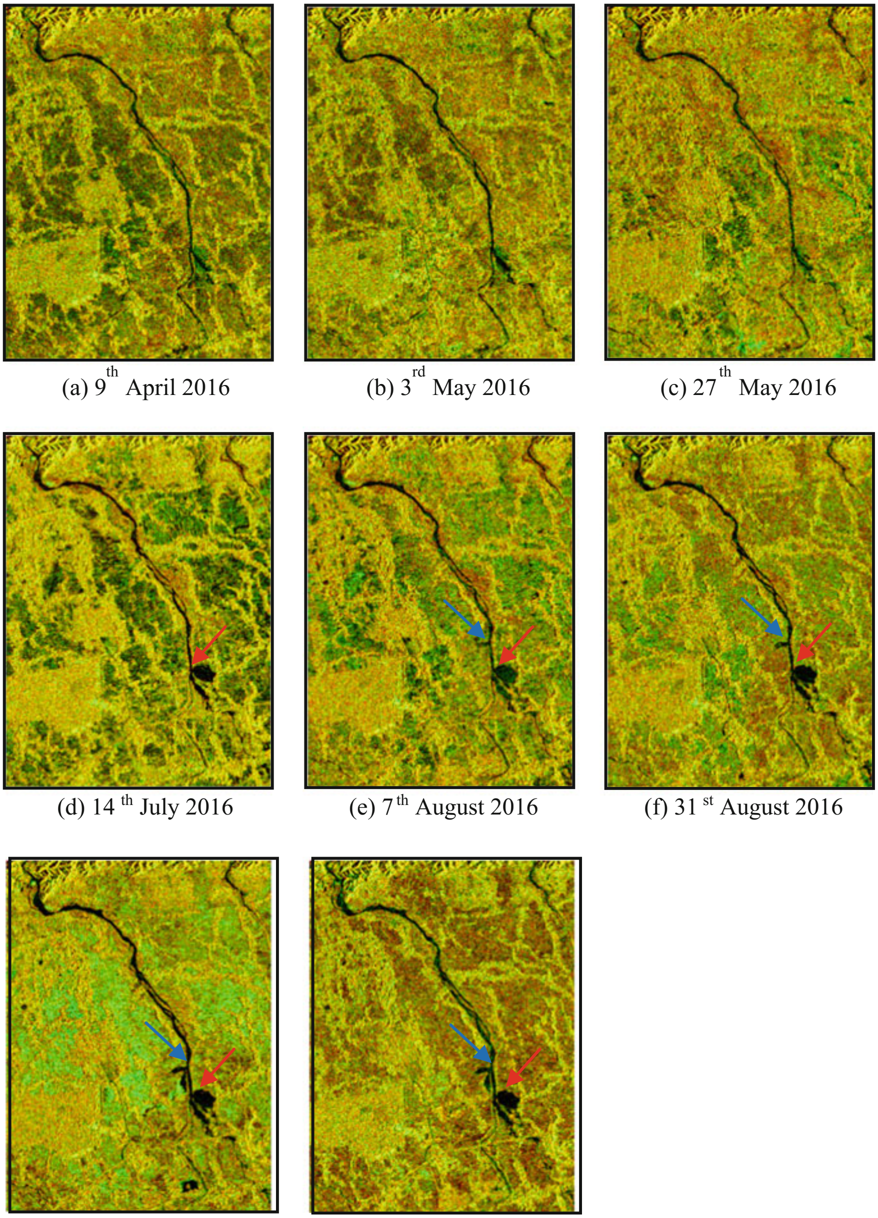
All the 8 scenes have been processed to generate calibrated and terrain corrected Sentinel-1 SAR images using Sentinel's Application Platform (SNAP). In this study, Refined Lee filter of 7×7 pixel size was applied to both like-polarized and cross-polarized images. Due to topographical variations of a scene and the tilt of the satellite sensor, distances can be distorted in the SAR images. So, terrain corrections are intended to compensate for these distortions so that the geometric representation of the image will be as close as possible to the real world. The SRTM 1 s HGT data has been used for range doppler terrain correction.

3 Results and Discussions

The eight temporal images downloaded for the entire monsoon season were pre-processed and analysed for identification of embankment breaches. Figure 1 shows all the processed images with cross-polarized VH band in red and like-polarized VV band in green for visualization. Two breach locations are identified and the first breach is identified on image acquired on 14th July, 2016. Another vulnerable area for breaching is observed on image of 7th August, 2016 due to seepage of stream water as high soil moisture area is detected. Embankment breaching in this location is finally observed on the image acquired on 24th September, 2016. If this water leakage condition could be identified in time, the second breach could have been prevented.

Figure 2 shows the histogram of backscatter values for both VH (Red) and VV (Green) polarizations acquired on 14th July 2016. It is observed that the bimodal nature of histogram, which is usually used for backscatter thresholding to separate out land and water bodies, is not prominent in VH whereas it is completely absent in the VV band. Therefore, global thresholding technique was applied and histograms were carefully analysed for selecting the threshold values.

Like-polarization (VV) data is commonly used for detection of open-water features, with low backscatter from open water and increase in backscatter as soil moisture increases [7, 16]. Figure 3 shows the comparison between VH and VV polarized data for 7th August, 2016. It is clearly seen that soil moisture areas are

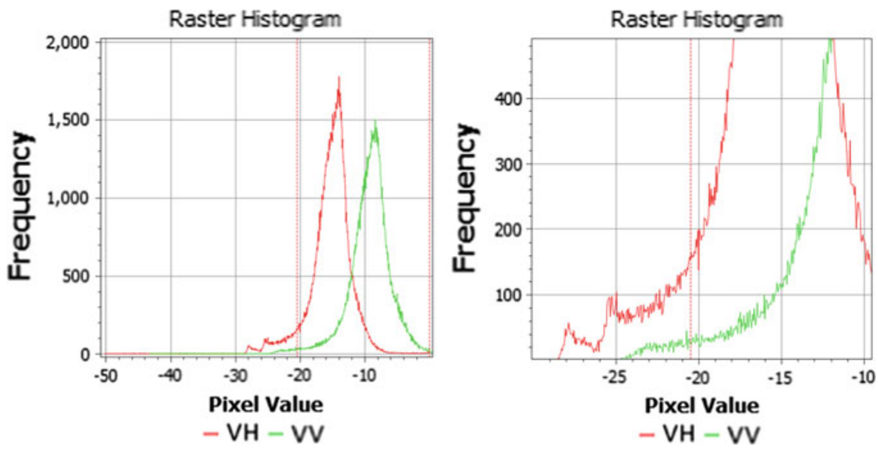


(a) 9th April 2016 (b) 3rd May 2016 (c) 27th May 2016

(d) 14th July 2016 (e) 7th August 2016 (f) 31st August 2016

(g) 24th September 2016 (h) 18th October 2016

Fig. 1 Temporal Sentinel-1 images acquired over study area



(a) Full view

(b) Zoom view

Fig. 2 Histogram of VH and VV backscatter values on 14th July 2016

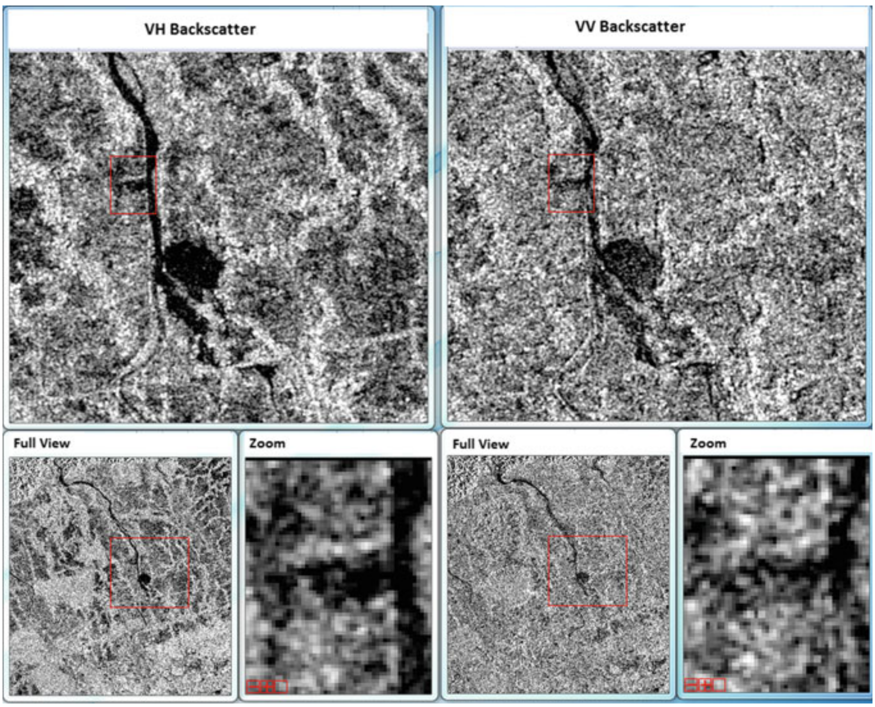
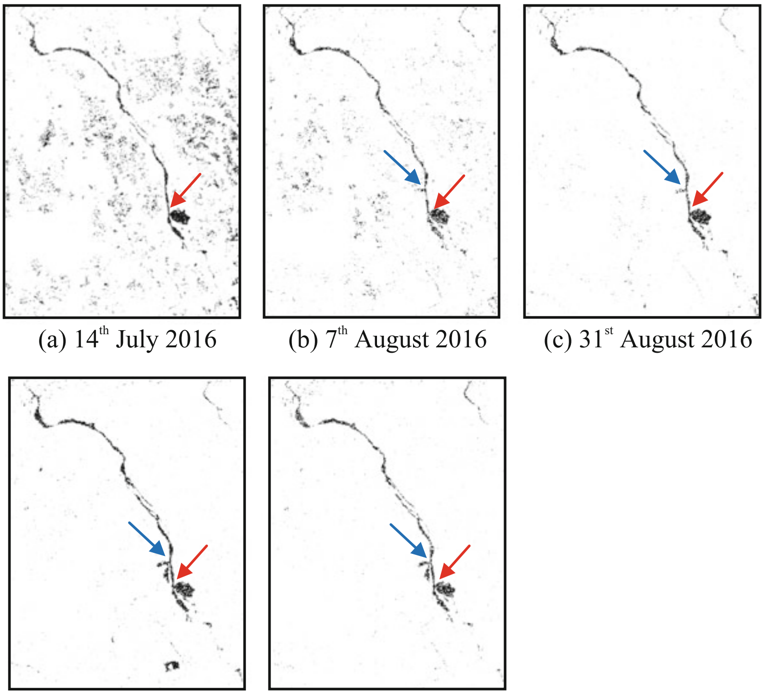


Fig. 3 Backscatter images of VH and VV polarization on 7th August 2016

more prominent in VH polarized data with low backscatter as open water compared to VV polarization with low backscatter from open water and high from soil moisture areas.

This analysis identified VH backscatter is suitable for identification of breaches and to create an inventory of the affected area due to breaching. The global threshold of −22.85 dB for VH backscatter has been defined from the analysis. Figure 4 shows the results of global thresholding technique applied to all the temporal images acquired after the occurrence of the first breach. Inundated areas due to embankment breaching and high soil moisture areas are highlighted. This technique can be effectively used for identifying embankment breaches and areas inundated due to breaching during the flood season as availability of optical data is scarce due to cloud cover during this season. It is observed that the first breach (identified on 14th July image) is of length 78.75 m affecting an area of about 65.89 acres. The second breach (observed on 24th September image) occurred slowly due to water seepage which was observed initially on 7th August 2016 image and reached to an embankment breach of 86.27 m length with affected area of about 30.22 acres on 24th September 2016.



(a) 14th July 2016 (b) 7th August 2016 (c) 31st August 2016

(d) 24th September 2016 (e) 18th October 2016

Fig. 4 Temporal inundated areas identified using thresholding technique

4 Conclusions

This study was an attempt to analyse the feasibility and potential of Sentinel-1 SAR data for embankment breach assessment. Eight temporal dual polarized (VV/VH) SAR datasets over Solengi river, Assam has been analysed. The results of the study shows that VH polarized data is more suitable for embankment breach studies. This study also portrays the potential of SAR data in identifying probable locations of embankment breaching if the breaching occurs slowly due to water seepage from weak areas under embankments. Two breaches have been identified in study area, where first breach was observed on 14th July 2016 of length 78.75 m with area affected 65.89 acres and second breach has occurred slowly due to water seepage on 7th August 2016, breaching to a length of 86.27 m with area affected 30.22 acres on 24th September 2016.

The results show that Sentinel-1 SAR data can be effectively used for embankment monitoring and damage assessment due to breaching. The process can also be automated using near real time Sentinel-1 SAR data along with accurate embankment information.

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