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RESEARCH ARTICLE

Integrated Use of LANDSAT 8, ALOS-PALSAR, SRTM DEM and Ground GPR Data in Delineating Different Segments of Alluvial Fan System in Mahananda and Tista Rivers, West Bengal, India

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Abstract In this study, visible near infrared, shortwave infrared spectral bands of Landsat 8 satellite sensor, two polarisation channel of L band ALOS-PALASAR sensor, SRTM-DEM derived digital elevation data were processed to delineate different geomorphic components of alluvial fans of Tista-Mahanada fan complex. We found image composite of independent components, principal components of Landsat 8 bands were effective in delineating proximal and distal fan segments. Fused images of Landsat 8 and ALOS data were used for enhancing incised distributaries and paleochannels. Field data on depositional sequence of fans, were used to substantiate the image based delineation. Topographic breaks along selected longitudinal profiles (identified with the changes in land use and drainage pattern) of digital elevation data were conjugately analysed using Landsat false colour composites. GPR survey along selected transect highlights the vertical dislocation in the recently deposited sequences of alluvial fan regime indicative of post depositional disturbances.

Keywords ALOS-PALSAR · Alluvial fan · Landsat-8 · GPR data fused products · IC composite · PC composite

Introduction

Study of fluvial systems using remote sensing data has been carried out for various rivers. e.g. Kosi, Gandak rivers of India and also some important rivers of tropical region (Rossetti et al. 2012; Zani et al. 2012; Chakraborty et al. 2014; Sinha et al. 2014a, b; Pati et al. 2015).

Alluvial fan has been regarded as the one of the important depositional landform of fluvial process; which is formed at the base of the mountain front where river emerge out from mountains (Blair and McPherson 1998). Depositional processes, morphology and morphometry of alluvial fans are related to climate, base level change, lithology, tectonic activity and morphometric properties of the catchment (Koss et al. 1994; White et al. 1996; Blair and Mcpherson 1998; Harvey 2002; Viseras et al. 2003; Crosta and Fratini et al. 2004; Applegarth and Stefanov 2006; Harvey 2012; George et al. 2015).

At tectonically active mountain fronts, where the mountains are rising with respect to the adjacent basin, alluvial fans tend to aggrade vertically and vertical accommodation space for deposition is high (Goswami and Yhokha 2010; Bahramai 2013). Therefore, vertical growth of fan sediment is generally high (Bahramai 2013). In such cases, alluvial fans are characterised with high width to length ratio with lack or absence of incised channels and head ward valleys (Bahramai 2013). Therefore, it is important to understand the different fan segments of larger fan complex in terms of their shape (quantitative parameters), drainage distribution, sedimentary facies (Blair and McPherson 1994). Further, study of the changes in gullies, incised channels, and channel avulsion is also important to understand the variation in discharge, sediment character and tectonic control on such changes. Numerous Quaternary mountain-attached alluvial fans occur all along the foothills of the Himalaya. It is well known that the alluvial fans of eastern India occurs side by side and essentially are low gradient mega fan with the development of different small fans within each mega fan system (Chakraborty and Ghosh 2010).

Similar mega-fans have been also reported and studied by various workers across the world. In this regard, multi-

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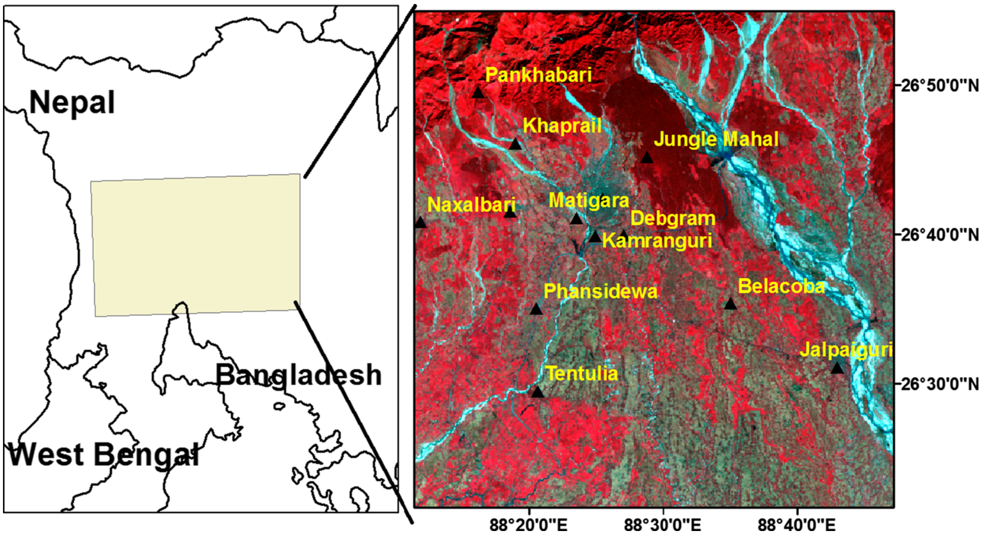


Fig. 1 **a** Schematic diagram showing thelocationof the study area. **b** Landsat 8 satellite image composite of the study area. In the image, red = band 4, green = band 3 and blue = band 2 of Landsat 8 data

Table 1 Details of the earth observation data and other geophysical data collected in the field

Data	Band nos.	Spectral domain (µm)	Spatial domain	Date of acquisition
Landsat 8 data (operational land imager sensor)	Six (VNIR), SWIR) bands	Blue: 0.45–51 Green: 0.53–0.59 Red: 0.64–0.67 NIR: 0.85–0.88 SWIR-1:1.57–1.65 SWIR-2: 2.19–2.29	30 m for VNIR-SWIR bands,	20-11-13
ALOS-PALSAR data (data product 1.5)	HH and HV channels	L bands (30–100 cm)	12.5 m	20-10-14
Shuttle Radar Terrain mapper (SRTM)	C band Microwave data	C band (5.6 cm)	90 m	–
GPR data (AKULA 2000 GPR system)	–	400 MHz	–	22–25 May, 2015

temporal satellite data were used to analyse changes on a megafan deposit in Amazonia (Rossetti et al. 2012). In their study, it was demonstrated that abandoned depositional surfaces were related to the specific type of vegetation growth. Delineation of specific type of vegetation or agricultural product can therefore, help in demarcating specific set of depositional surface. Further, spectral contrast of these fans may be also conspicuous. Earlier studies on Tista mega fan could identify the different fans within megafan complex and associated terraces were also reported (Chakraborty and Ghosh 2010).

Although different fan lobes were identified within the Tista and Mahananda fan deposit, the fans developed at the western part of Mahananda River have not been studied in detail in comparison to the fans formed at the eastern part. Criteria to be used to delineate different fans based on spectral contrast observed in the spectral bands of satellite, drainage pattern and land use pattern have not been discussed in the literature. Given the dimension of these Alluvial fans (> 10 km^2), the identification and study of many of the fan features may not be possible in the field and hence the remote sensing data analysis becomes necessary for such studies (DeCelles and Cavazza 1999; Fontana et al. 2014). Further, it is also essential to understand the post depositional modifications happened due to land use practices, superimposition of floodplain features above the fans or any other probable reasons like neotectonic activity etc. (Pati et al. 2011) based on interpretation of image-enhanced products of earth observation sensors. It has been proved that the fans developed at the eastern part of Himalayan mountain front were controlled primarily by the fluctuation of the Asian monsoon rather than Himalayan tectonics (Kar et al. 2014). In present study, we have attempted synergistic use of optical (inclusive of VNIR and SWIR), microwave remote sensing data for delineating different sub-components of alluvial fans by relating land use and agricultural pattern with depositional surface using image analysis method of enhanced products derived using datasets of optical and microwave sensors. Results of image interpretation were verified in the field along selected traverses.

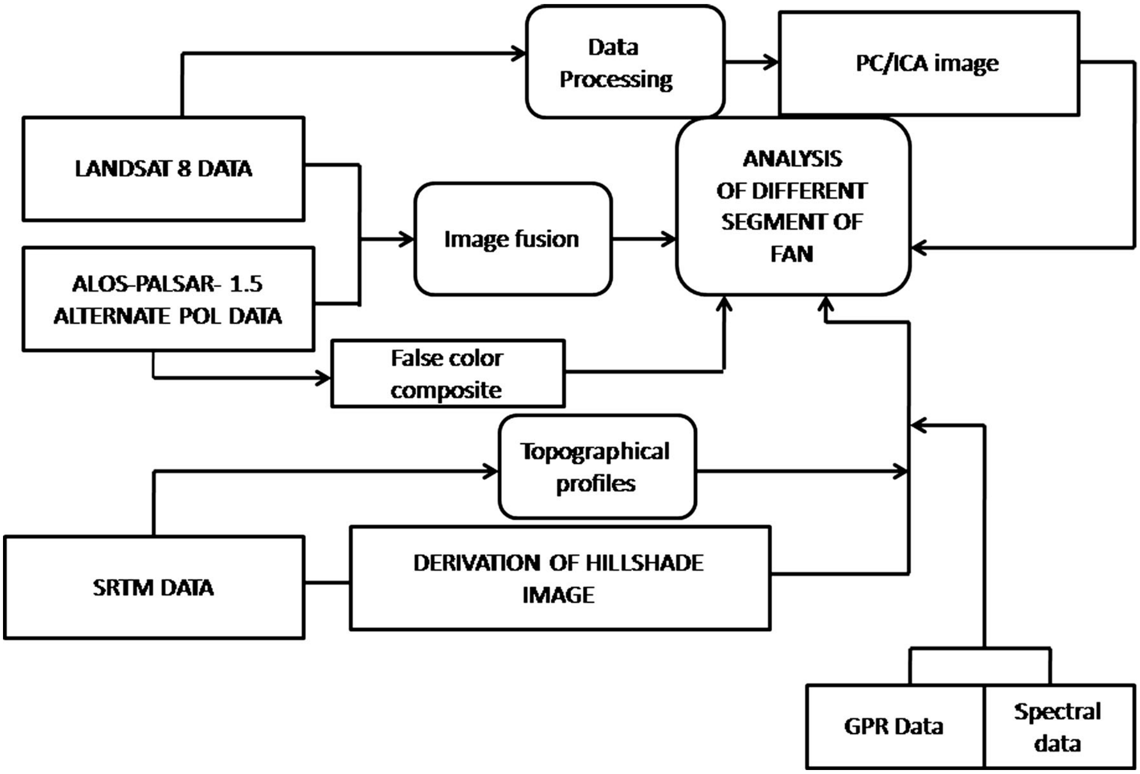


Fig. 2 Flow diagram of the methodology

Identification of lineaments was attempted using image signatures highlighting sudden change in drainage direction, land-use contrast and also from the topographical contrast derived from digital elevation image and profiles (Tarolli 2014). GPR profile along selected point along the identified lineament were used validate image based observations and also understand the impact of the lineament in disturbing the upper depositional sequence of fans.

Study Area

Present study area is situated at the northern part of West Bengal and it is at the junction of two countries—India and Nepal (Fig. 1). Geologically, study area is constituted with Quaternary deposits formed by southern bound Himalayan rivers like Tista and Mahananda; main rivers of the present study area. Quaternary deposits are composed of gravel, pebble rich sand and sandy clay etc.

Materials and Methods

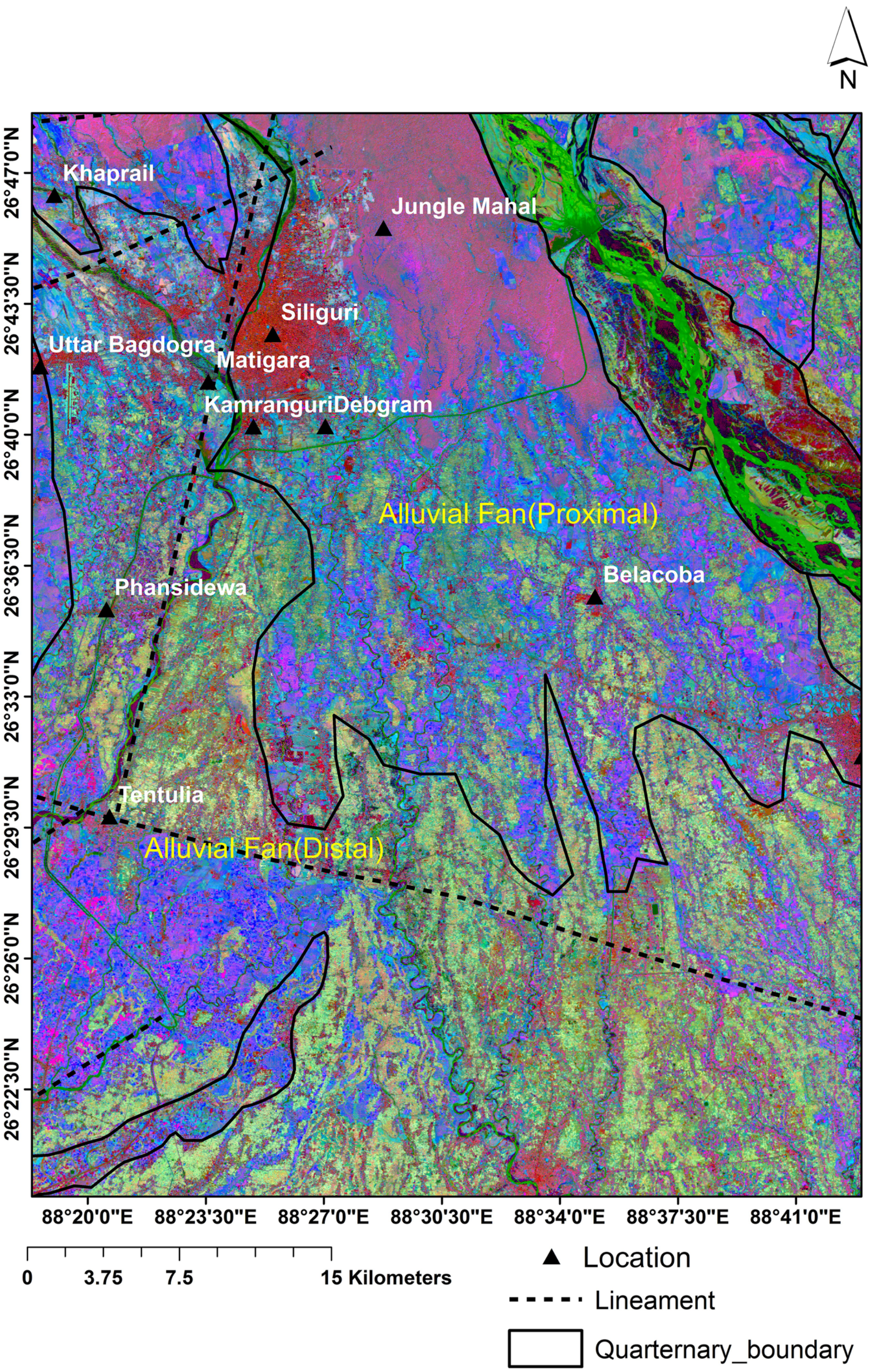
Data

In the present study, we have analysed Landsat 8 data, ALOS (Advanced land imaging satellite)-PALSAR (Phased Array L band SAR) geocoded L band of two polarisation and Shuttle Radar Topography Mission (SRTM) derived digital elevation model with 90 m spatial resolution. Landsat 8 data has two sensors. These are operational land imager (OLI) and thermal infrared sensor (TIRS) (Landsat-8 Handbook). In this study, we have used the visible near infrared and short-wave infrared bands from OLI sensor. L-band Synthetic Aperture Radar (PALSAR) is an active microwave sensor; which is used to acquire microwave image using L-band frequency for day-and-night land observation (Alaska 2016). Landsat -8 data and ALOS-PALSAR data were used to map the different sub-components of alluvial fans of the study area. In addition to above sensors, we also have used field data on depositional sequence from selected geological sections to characterise and clarify the image based delineation of sub-component of fans. Further, ground penetrating radar (GPR) profiles were collected at selected transects in vicinity of image interpreted lineaments to record the displacement in depositional sequence based on variations in radar reflectivity of incident signal across the different layers of deposional sequence. Details of the datasets used in the study have been furnished in the Table 1.

Methodology

The flow chart is used to highlight the major steps followed for deriving different image processing products, analysing

Fig. 3 Principal component (PC) composite prepared using PC bands 6, 4 and 2 of Landsat 8 data. Different sub segments of the fan surfaces (alluvial fan proximal and alluvial fan distal) are delineated over this composite. In this FCC, red = PC band 6, green = PC band 4 and blue = PC band 2. 'PC' is the paleo channel



them based on field data, GPR data and digital elevation data in the present study (Fig. 2).

Processing of Landsat and ALOS Data

We have processed Landsat 8 (VNR-SWIR-TIR) bands, ALOS L band data independently to understand how each data can be used to delineate geomorphological artifacts of the study area. We also have combined microwave and optical data to understand conjugate use of two sensors for enhancing different sub-components of the fan lobes of study area. We derived Principal components (PC) from VNIR-SWIR bands of Landsat sensor (Fig. 3). Principal component analysis (PCA) has been used to delineate different geomorphic elements based on spectral contrast of sediment surface and associated land use practices. Further, we

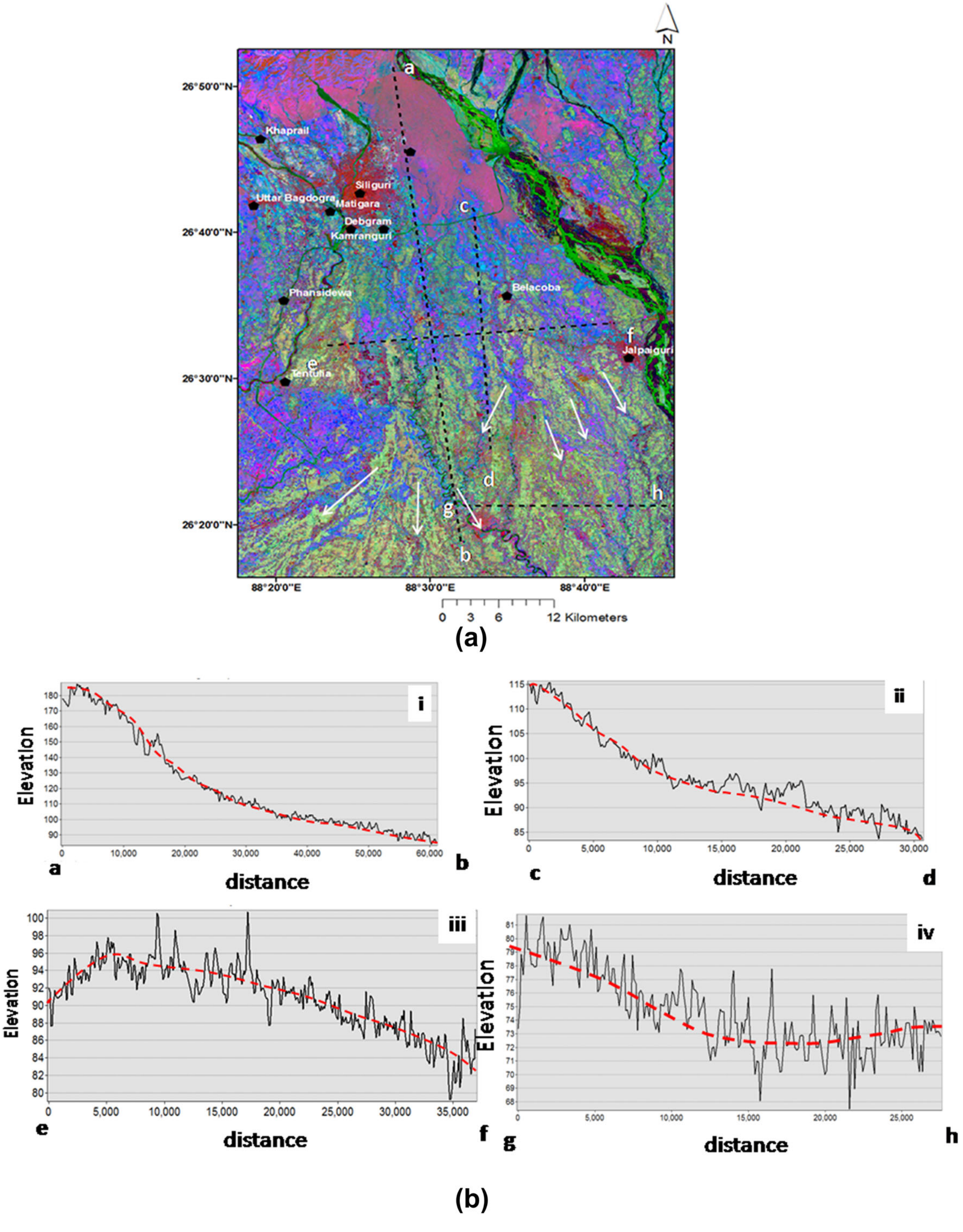


Fig. 4 **a** Topographic profiles lines (along selected traverses) of SRTM image have been demarcated on the PC—composite(topographic profile lines are shown using dashed line and named as '*a*–*b*', '*c*–*d*,' '*e*–*f*', '*g*–*h*'. **b** Profiles '*a*–*b*'(*I*),'*c*–*d*'(*II*) are longitudinal profile drawn along the depositional axis of fan. Profiles, '*e*–*f*'(*III*) and '*g*–*h*'(*IV*) are traverse topographic profiles drawn transverse to the depositional axis

implemented independent component (IC) analysis to transform the input spectral bands to new data spaces; where information of input data bands were decomposed to new data axes; which were not perpendicular to each other. IC transformation is regarded as the image enhancement tool for blind source separation, where no prior information on the mixing was available (Gomez et al. 2007). The transformation was attempted based on the assumptions that the terrain elements are non-Gaussian in this spectral transformation and this would help in delineating smaller targets. Similarly, PCA of the input datasets was also used to enhance the decorrelative information of spectral bands (Gupta 2003). False colour composite (FCC) images were derived by the selected bands of principal components and independent components in red(R), green (G) and blue (B) colour display (Figs. 3, 5). We also have derived several longitudinal profiles on SRTM DEM image to clarify the spectral contrast based delineation fan segments with the topographic changes associated with the different fan segments and the faults (Fig. 4a, b).

In order to use the radar reflectivity variation, FCC Images using HH, HV polarisation channels of ALOS PALSAR data were used to delineate variations in radar amplitude recorded in these channels resulted due to variability of surface roughness and moisture content. Combined use of L band HH channel of ALOS sensor with SWIR bands of Landsat 8 sensor was attempted to delineate different segments of fan system using combined variations of moisture, roughness and spectral reflectance of different fan surfaces (Joseph 2005; Woodouse 2005; Guha et al. 2009) (Fig. 6). ALOS-L band HH channel data is known for its capability in delineating geomorphic features like paleochannels etc. (Khan et al. 2014).

Processing of Digital Elevation Model

SRTM DEM was used to derive topographic profiles (Fig. 4b–f) and also to derive shaded relief image in order to delineate different segments of fans and the structural imprints upon these fans (Fig. 9a). Further topographic profiles were also collected across the lineaments to see how topography was changing across the lineaments (Fig. 9b). Longitudinal and transverse profiles were collected to investigate the changes happened in the conventional longitudinal and transverse profile of alluvial fan due to post depositional changes caused by anthropogenic or other allogenic factors. Profiles were drawn across interpreted lineament and also around the places where abrupt changes in land use were noticed.

GPR Data Collection and Processing

GPR analysis at selected point along and across the interpreted lineament was attempted to see any discernible dislocations were identified in the upper part of depositional sequence. For this purpose, AKULA 2000 GPR system from GeoscannersAB © Sweden in “cartwheel” configuration was used. An odometer connected to the wheel was used to measure the distance of the survey taken. The sampling interval was taken as 64 samples/scan and 16 bits per scan. The data was recorded using a 400 MHz central frequency with shielded monostatic antenna. It was observed that for the measurements in fluvial provinces which are located close to the river with very shallow ground-water tables, a trade-off between depths of penetration versus vertical resolution needs to be adopted. The 400 MHz central frequency antenna optimally suits the requirement of adequate depth of penetration as well as sufficient vertical resolution to delineate the near surface depositional sequences of alluvial fan segments (deposited sequence youngest in terms of age). Attempts were made in examining the upper few meters of depositional sequences as dislocations were expected within this part of the depositional sequence. The GPR survey was carried out in selected transects representing all the sub-segments of alluvial fan.

The profile distance of the survey was in general between 5 and 10 m in length. Surveys of longer distances were not attempted due to disturbances caused by the presence of power lines or underground pipes near vicinity of the places identified important for GPR measurement. The processing steps for this type of sedimentological surveys were elaborated by earlier worker (Neal 2004). The raw data was depth corrected using a 0.1 ns time level. This was done to remove any effect of topographic undulations that may have induced noise in the survey. Dewow correction was carried out to remove any type of very high frequency noise. This was following by filtering of the data. Three types of filtering, namely, Infinite Impulse Response (IIR), finite impulse response (FIR) and 2D fast Fourier transformations (FFT) were carried out independently (Fisher et al. 2000). It was observed that, for the current data, IIR yielded the best results. Therefore, IIR was applied to all the surveyed sections. Once the filtering was carried out, automatic gain control (AGC) was applied to the data to amplify the signal. This rendered better visualisation of the data and made it effective for visual interpretation. Three GPR profiles were collected along lineaments (Fig. 9a). Each GPR profiles were consequently analysed keeping in mind the pattern and variation of depositional sequence of proximal fan (Fig. 10).

Results and Discussions

In this study, our main aim was to evaluate the potential of earth observation data from different sensors for delineating different segments of alluvial fans. In this regard, microwave, optical and digital elevation data were independently analysed to extract the variations in different geophysical parameters of alluvial fan surfaces. These components can be broadly categorised into spectral or tonal variations in the optical data and variations in radar reflectivity in the microwave data. These parameters are sensitive to land use and land cover variation and surface moisture and texture variation of alluvial fan surfaces. Results thus derived from the present work have been discussed in three sub headings.

Analysis of the Observations Made Using Optical Earth Observation Data (In Conjunction of Digital Elevation data)

In order to delineate different components of these fans, few image enhancement products like false colour composite (FCC) of principal components (PC) and independent components (IC) were derived. PC image had added benefit to delineate spectrally different geomorphic surface in fewer bands of PC composite than original image (Gupta 2003; Guha et al. 2013). Here, PC composite was successfully used to delineate river channels and flood plains (Singh et al. 2015). In the FCC image derived using 6, 4 and 2 PC bands, we could delineate proximal and distal fan based on colour contrast of these units in this composite (Fig. 3). This contrast has resulted due to variable land use, soil and drainage patterns developed distinctively in each fan segment. Proximal fan (part of the fan developed near the edge of mountain) was represented with coarser sediments (in depositional sequence). In the study area, proximal fan was characterised by forest covers and large tea gardens on surface and appeared with blue colour in this composite. On the other hand, distal fan (formed at the outward edge of the fan) was made up of relatively finer sediment (sand or pebble rich sand) than the sediment of proximal fan and covered dominantly with agricultural land and sporadic or patchy distribution of tea garden. It was known that older depositional surfaces were often found associated with specific type of vegetation and land use pattern and helps in delineating depositional sequences in surface (Rossetti et al. 2012). Here, we found tea gardens and forest cover were predominant with proximal fan. In Fig. 3, we could delineate seven proximal fan units marked with 1–7. Distal fan units of these fans were coalesced to derive mega fan complex. In the FCC, distal fan was green in colour with development of patchy distributary drainages in blue colour (Fig. 3). Although distal parts of each of the fan were coalesced or merged to derive complex fan; discordant distributaries developed on each distal fan can be identified (Fig. 4a). The directions of the distributaries developed on distal fan segment and their discordant nature (i.e. differential outward flow direction) were shown with arrow (Fig. 4a). Similar observations were also reported in the earlier literatures (Chakraborty and Ghosh 2010).

Two longitudinal (illustrated as “a–b”, “c–d” profiles on Fig. 4a) and two transverse topographic profiles (illustrated as “e–f”, “g–h” profile lines on Fig. 4a) were derived using SRTM DEM to understand whether longitudinal and transverse profiles drawn at different distances from fan apexes could delineate fan surfaces based on its conventional concave upward longitudinal profile and convex upward transverse profile (Blair and Mcpherson 1994). Spatial positions of these profiles are shown in PC composite image (Fig. 4a). In the longitudinal profiles (a–b and c–d), we could see consistent concave upward elevation profiles along depositional axis of the fans even though these profiles were drawn at different distances from the apex of the deposional surface and they were spatially apart from each other. But transverse profiles of the fans had different shapes at different places (Fig. 4b). Profile e–f was identified with convex upward shape while g-h profile has convexo-concavo shape. Therefore, it was assumed that the distal fans (which were at southern extent of the study area) were more reworked and modified after they were coalesced due to post depositional anthropogenic activity, intense agricultural and avulsion processes often noticed in distributaries.

We also derived false colour composite using first three independent component bands (Fig. 5). In this FCC, tea

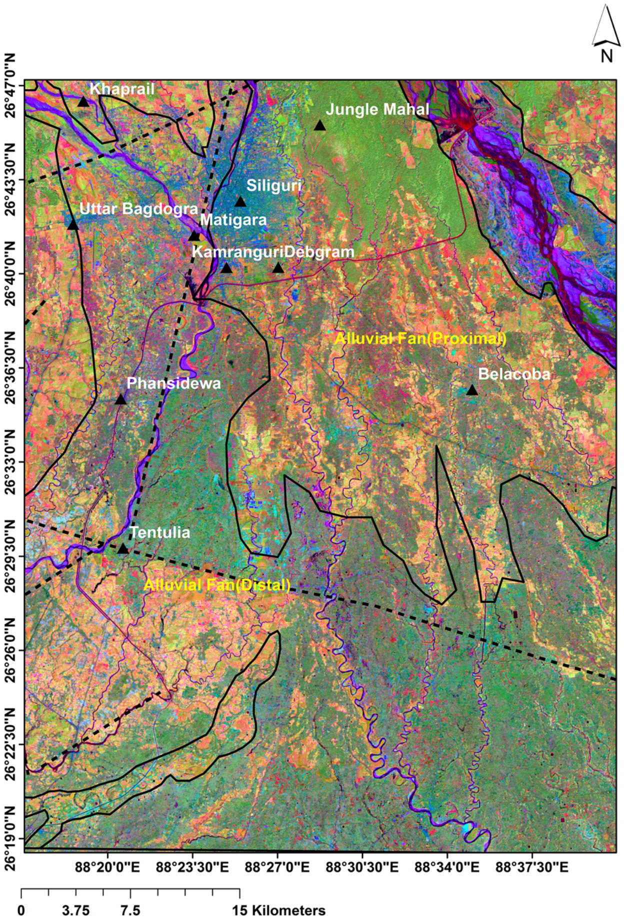


Fig. 5 Independent component (IC) image composite prepared using IC band 3, 2 and 1 of Landsat 8 data. Both proximal and distal fan segment s of the fan surfaces were delineated over this composite. Lineaments are also interpreted on this image (shown with dotted line. In this FCC, red = IC 3, green = IC 2 and blue = IC 1

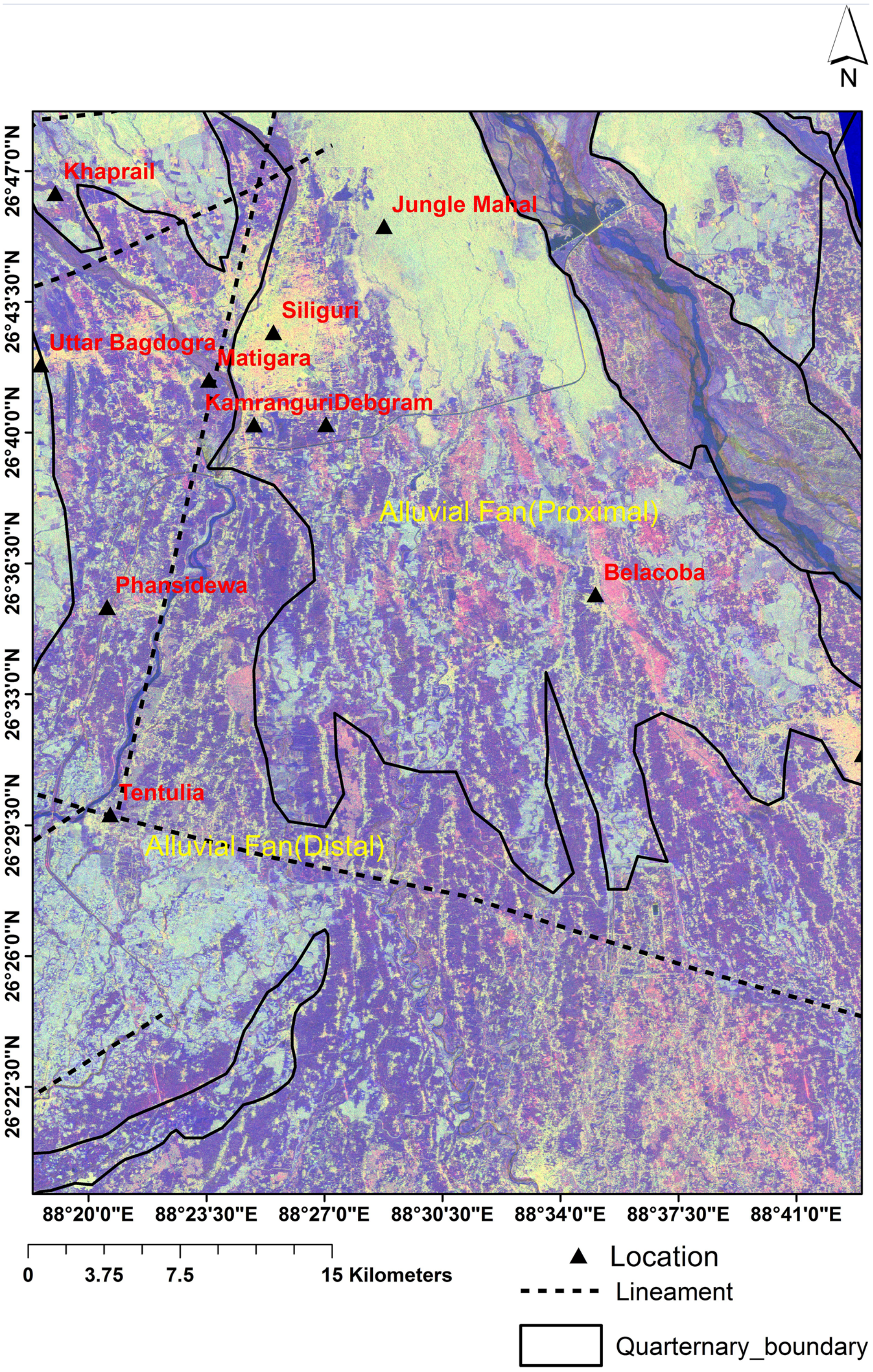
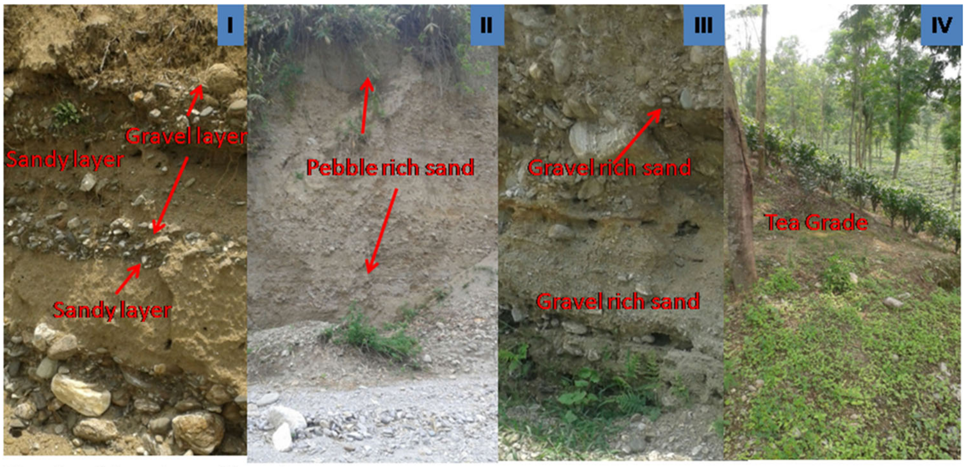


Fig. 6 False colour composite (FCC) prepared using the combination of HH channel of ALOS-PALSAR amplitude data and band 5 and 7 of Landsat 8 data. In this image composite, Red = HH polarisation channel, Green = Band 5, Blue = Band 7 of Landsat 8 data

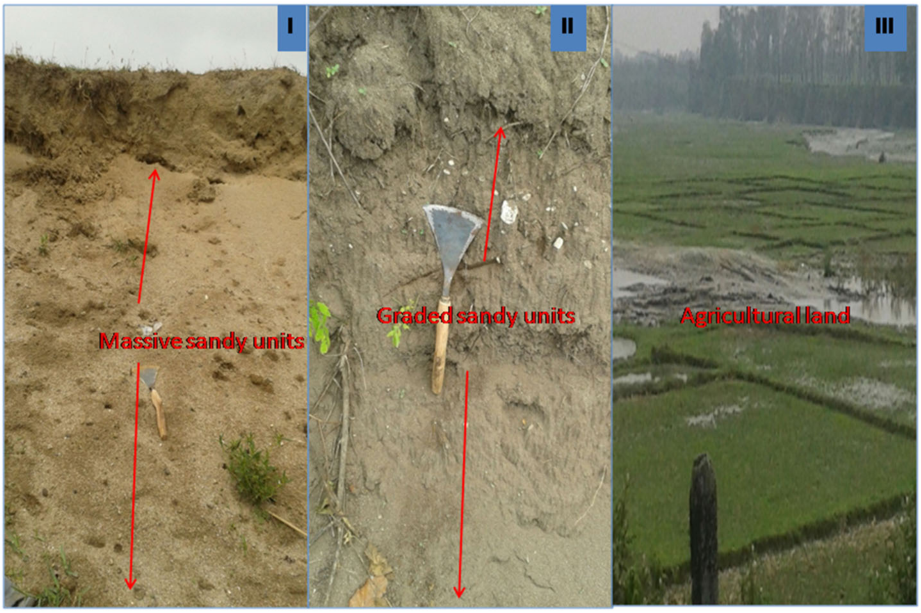
gardens, forest covers were enhanced (Fig. 5). Further drainages were also enhanced in this composite. The image composite was also better for delineating the sharp land use discontinuity (Fig. 5). Few lineaments were also enhanced in this composite based on drainage pattern, discontinuity in land use. PC and IC composites derived in this study, had complementary information on delineation of different components of fans (i.e. distal and proximal fan). In these composites, paleochannels and distributaries developed at the base of proximal fan were also highlighted (Figs. 3, 5).

Analysis of the Observations Made Using Microwave Earth Observation Data

We used L band radar data to enhance the geomorphological contrast of different components of alluvial fans of



Proximal fan depositional sequence (a)



Distal fan depositional sequence (b)

Fig. 7 **a** (*I*) Quaternary sequences with alternating boulder rich and sand rich horizon of proximal fan near Khaprail area. **a** (*II*) Inversely graded pebble rich sandy sequence at south of Pankhabari. **a** (*III*) Gravel rich sand (inverse graded) in Mahananda river section near Saluguda. **a** (*IV*) Sloping surface of a proximal fan; which is being used for tea-production. **b** (*I*) Massive sandy bed of distal fan near Siliguri. **b** (*II*) Inversely graded sandy unit of distal fan near Belecoba. **b** (*III*) Agricultural land at the junction of distal fan and flood plain, south east of Belecoba

the study area. Polarisation of composite of L band radar image was used to enhance moisture and roughness contrast of fan surface. Roughness of terrain elements is dependent on the differences between root-mean square of surface height and wavelength of radar signal. Heights of forested land or tea gardens were larger than the wavelength of L band. Therefore, these land covers will be rougher to L band microwave signal and return signal will be depolarised more from these land covers. Forest covers and tea gardens were characterised with higher return in HV channel (Woodouse 2005; Guha et al. 2009). False colour composite prepared using L band microwave polarisation channels could delineate proximal fans by the presence of forest cover, tea garden. On the other hand, moisture rich zones were characterised with larger backscatter in HH channel (Woodouse 2005; Guha et al. 2009). We integrated (stacked) HH channel of ALOS-PALSAR with SWIR bands of Landsat-8 data to enhance moisture variations of fan surfaces (Fig. 6). We found that the distributaries incising the edge of proximal fan were enhanced in this image. This information was important as degree of incision can be related to the structural control on the development of alluvial fan as incision was attributed to tectonic control on fan deposition (Bahramai 2013).

Field Based Observations

We found the synergy between surface boundaries of different segments delineated in the image enhanced products with the depositional sequences identified in geological

Fig. 8 **a** Hill shade image of SRTM DEM is used to delineate elevated proximal fan surface and interpreted lineaments are draped. We have taken some transeverse profiles on these lineaments for GPR related studies. **b** ‘P1-P1’, ‘P2-P2’ are two of such profiles drawn along the depositional axis of fan

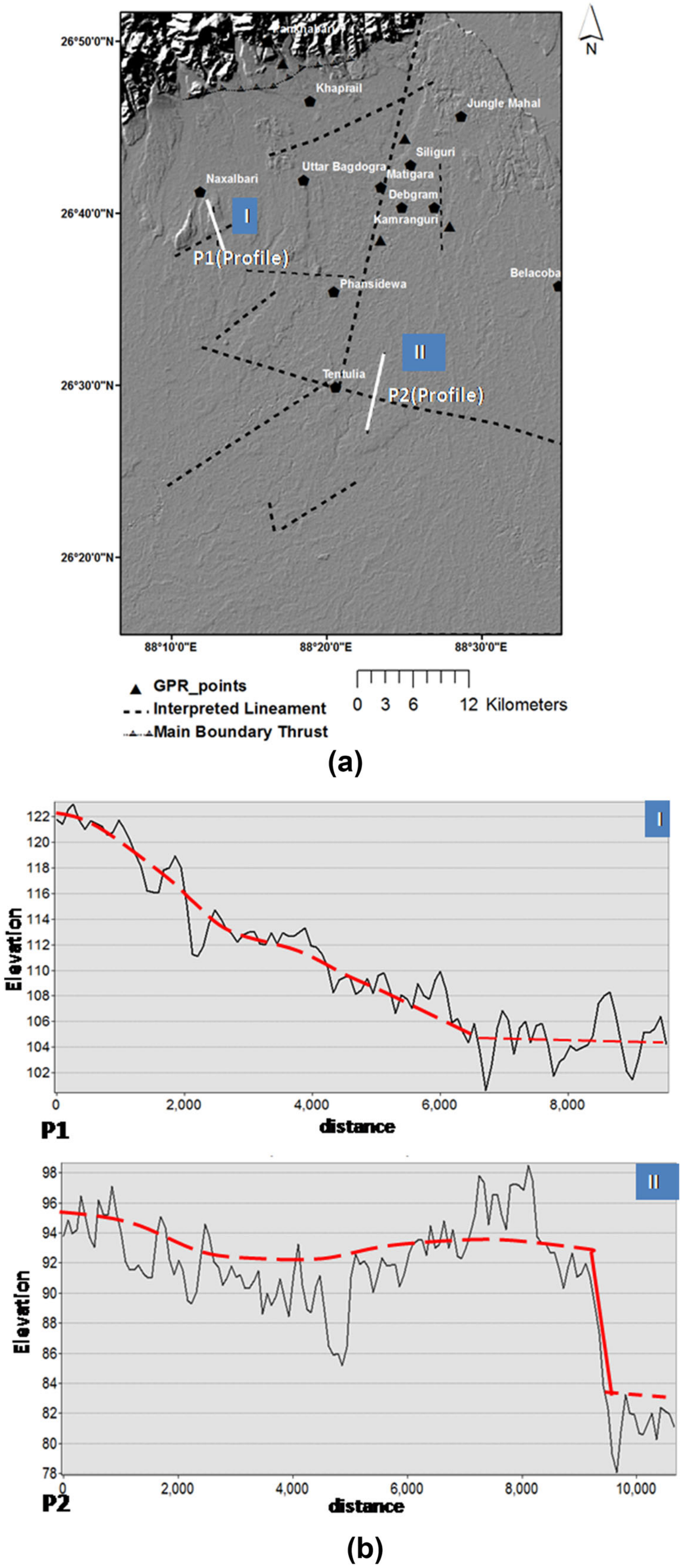


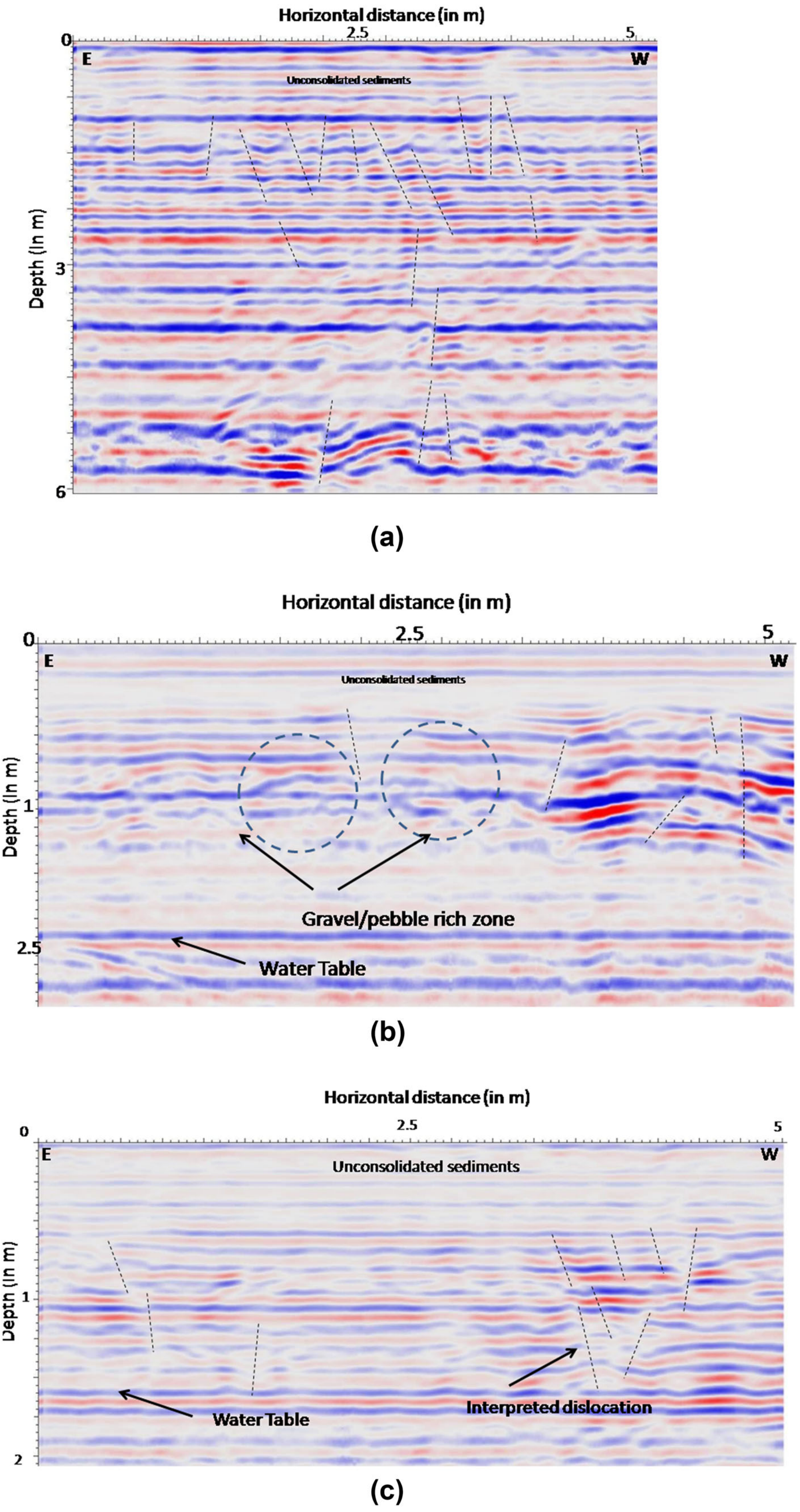
Fig. 9 **a** River terraces near Siliguri. **b** Boulder/gravel bed at the top of the geological section on the river terrace in Siliguri. **c** Abandoned channel at east of Jungle Mahal. **d.** Large incised gulley at south-east of Jungle Mahal

sections during field work. Both proximal and distal fan depositional sequences were distinct from each other in terms of texture and layer wise disposition of depositional units. We identified upper part of proximal facies either as alternating sequence of pebble/gravel rich sand and fine sand or pebble/gravel rich graded sand sequence Fig. 7a-I, III. Tea garden (Fig. 7a-IV) was the main land use class; which was predominant above the proximal fan surface along with the forest cover. On the other hand, massive sandy or fine pebble rich sand units were identified as the dominant depositional unit of distal fan depositional facies (Fig. 7b-I and II). Paedological and agricultural activities were also found more intense above distal fan depositional sequence (Fig. 7b-III).

Additional Topographic Observations

Digital elevation model (DEM) derived from Shuttle Radar Terrain Mission (SRTM) sensor was used to highlight the topographic variations across few of such interpreted lineaments (Fig. 8a). Shaded relief image derived from DEM was used for delineating sharp topographic break at the edge of some of proximal surface; which were corroborating well with the interpreted lineaments from IC and PC image composites. On this image, profiles lines were shown; which were collected across the interpreted lineaments (Fig. 8a). We could find sharp break along these profiles; which were drawn across these lineaments. Three profile lines showing topographic breaks were drawn across the interpreted lineaments (marked as P1, P2) in the shaded relief image (Fig. 9a). In addition this observation, we have noticed few unpaired terrace, incised gullies, abandoned channels along these lineaments in spatial vicinity of drawn topographic profiles during field work. These signatures could be due to post depositional disturbances (Fig. 10a–d). It was well known fan features can be modified by endogenous and exogenous processes and similar instances were also discussed in the literature (Sánchez-Núñez et al. 2015). Fluvial terraces often reported with alluvial fans; were generally formed by rapid deposition of sediments during flood events along fluvial valleys in which intense precipitation triggers debris remobilization driven by water. On the other hand, overhanging terraces were reported with tectonic activity (Sánchez-Núñez et al. 2015). However, fluvial terrace with depositional sequence capped by boulder bed also were delineated in deposional sequences where terraces were moved laterally with removal of upper unit due to incision. Therefore, there could be both neotectonic and long term tectonic reasons for such terraces.

Fig. 10 **a** GPR section of distal fan of Ambari area. **b** GPR section of distal fan at the South of Pakhanbarii. **c** GPR section of proximal fan sequence near Kamranguri area (GPR locations are given in the Fig. 8)



Observations from GPR Transects

GPR surveys carried out around interpreted lineaments were helpful for identifying displacements in the deposited strata as radar signals (reflected at the boundary of two layers) helped in reconstructing shape of the deposited sedimentary layers. GPR analysis of deposited sequences points toward certain tectonic disturbance at places like Ambari, Pakhanbari and Kamranguri area (Fig. 9a). These disturbances were shown with dashed lines. However, pinches, wrinkles in the bounding surfaces of depositional layers in GPR section were attributed to reflection of GPR signal from the boulders/gravels in depositional sequence; which had disturbed the horizontal layering of lower sedimentary strata. Development of variability in gravel rich sandy sequence was attributed to changes in discharge condition, variation in sediment supply due to monsoon fluctuation and provenance (in rainy season land slide in upstream may add sediment from new provenance). However, role of tectonic activity in supplying sediments has been ruled out by the workers (Kar et al. 2014) who have earlier studied Tista and adjacent fans.

Conclusions

We have made few important observations on parameters like spectral contrast, moisture and roughness variation delineated by optical and microwave sensors with reference to delineation of different component of alluvial fans and associated fluvial units. The analytical results of these observations were complimentary in nature. It was found that IC and FC composite were effective in delineating proximal and distal fan from each other. These products also could enhance associated fluvial units. Image based delineation of fan segments were also substantiated by delineating distinct depositional sequences for proximal and distal fans in the field. Fan-profiles from SRTM DEM data were useful in delineating cross-sectional characteristics of fans and also indicated the post depositional changes. For example, convex up transverse sequence of fan was modified at the southern edge of the study area. Lineaments were enhanced in IC image products; which were further substantiated by the presence of break in topographic profiles. GPR surveys highlighted the presence of considerable vertical dislocations in recently deposited sequence in few places. The study suggest that the integrated use of satellite image products of different sensors can be used to delineate different component of alluvial fans, their process of evolution and post depositional changes effectively.

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