Potential of RISAT-1 SAR data in detecting palaeochannels in parts of the Thar Desert, India

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In the present study, we have demonstrated the potential of RISAT-1 Synthetic Aperture Radar (SAR) data to detect palaeochannels in parts of Thar Desert, India, which may be utilized as one of the guides of geoarchaeological exploration, besides forming groundwater prospective zones. Palaeochannels have been detected using RISAT-1 SAR MRS datasets in the southern parts of Jaisalmer and northeastern parts of Barmer districts, Rajasthan. These palaeochannels of length varying between 14 and 36 km and width varying between 20 and 65 m are present within parabolic sand dune complexes. Palaeochannels have been detected as distinct dark tone on RISAT-1 SAR data compared to feeble expression on corresponding LANDSAT-OLI FCC datasets. This is due to sand-filled valleys, acting as radar smooth surface and absorbing the radar energy with negligible backscatter and enhanced topography due to side-looking capability of RISAT-1 SAR. High-resolution Cartosat DEM has been utilized to prepare topographical profiles, supporting the geomorphological interpretation. Merging of RISAT-1 SAR and LANDSAT ETM datasets using PCA techniques led to enhancements of palaeochannels on merged FCC data products. Like polarization of RISAT-1, SAR data could further enhance and aid in detecting palaeochannels. The entire region was flooded in August 2006 and water had flown through these palaeochannels, which subsequently dried up and facilitated their easy detection; they are otherwise difficult to interpret using pre-flood images. Analysis of sequential post-flood images has been taken up for detailed study of the area, as there is scope to detect additional hitherto unknown palaeochannels.

Keywords: Desert, geoarchaeological exploration, palaeochannels, synthetic aperture radar data.

Introduction

REMOTE sensing due to its synoptic view and capability to provide information in different parts of the electromagnetic spectrum has been accepted as a useful tool for geoarchaeological exploration. Radar data are capable of penetrating up to a few metres in dry, fine-grained sediments in arid regions and provide subsurface information[1–3]. Imaging radar has led to the discovery of many previously unknown paleodrainage channels buried beneath the sand sheets in eastern Sahara Desert[4–7]. Radar imageries have been used by archaeologists to study the ruins of Angkor, Combodia[8]; detailed investigations and study of agricultural and drainage canals of Maya Lowlands[9–12] to detect locations of Palaeolithic sites in the Gobi Desert, Mongolia[13] and to identify sites associated with Pleistocene/Holocene human occupation in desertic landscape of Egypt and Sudan[13]. Radar data have also been used for locating the lost city of Ubar[14].

Useful reviews of work carried out in India related to search of the lost Vedic river Saraswati and the associated civilization using remote sensing and GIS techniques are available[15–19]. Gupta *et al.*[20] have traced the courses of the Saraswati river in the Great Indian Desert, i.e. Thar Desert spread over modern India and Pakistan using optical remote sensing and GIS techniques followed by detailed field validation. Limited work has been carried out using radar data. Digital enhancements were carried out using the ERS-1 SAR and IRS LISS-III data for the region covering parts of western Rajasthan and palaeo/buried channels/relict valleys were identified in eight areas on the basis of synergistic use of optical and SAR data followed by detailed field validation[21]. Digital image processing of JERS-1 SAR data covering parts of the Pali, Jodhpur and Nagaur districts in western Rajasthan was carried out and hitherto unknown paleovalleys of the Luni in the alluvial plains between Jodhpur and Pali were interpreted[22]. Paleodrainage network of western Rajasthan has been reconstructed using multi-sensor satellite data (radar as well optical sensors) and GIS techniques[23]. A buried channel near the archeological site of Talakadu, Mysore, Karnataka situated on banks of River Cauvery was revealed by analysis of RADARSAT-1 C band VV polarization data[24]. These studies demonstrated the potential of radar data in detecting hitherto unknown features of geoarchaeological significance. Recently, Singh *et al.*[25] demonstrated the potential of RISAT-1 SAR data in detecting glacier lakes buried under snow in the Himalayan terrain. In this study we have analysed RISAT-1 SAR data in conjunction with optical datasets

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covering parts of the Thar Desert (Figure 1) and report detection of hitherto unknown palaeochannels.

Data used and methodology

In the present study, RISAT-1 C band SAR data acquired in MRS mode (spatial resolution:18 m, swath: 115 km, polarization: HH and HV, incidence angle: 36°) have been primarily used. Details about RISAT-1 SAR are provided by Misra *et al.*[26]. In addition, LANDSAT ETM and OLI images (spatial resolution 30 m) and high-resolution Cartosat DEM (10 m spatial and 4 m vertical) have been used.

Radar image contains variation of radar amplitude. Conversion of radar intensity to radar backscatter coefficient is necessary for quantitative information extraction as well as interpretation. Calibration of HH and HV polarization amplitudes was carried out using values of calibration constant provided in product.xml file using the equation[27]

$$\sigma_0 \text{ (value in d}B) = 20\log_{10}(\text{DN}) - \text{calibration constant},$$

where σ_0 is the radar backscatter coefficient and *DN* is the radar amplitude.

Speckle suppression

Speckles appear in the SAR images as granular noise giving salt and pepper appearance to these images. This complicates the image interpretation, reduces the effectiveness of image segmentation[28], classification and other information extraction techniques. Several filters like Lee[29], Kuan[30] gamma map[31], Frost[32], mean and median filter exist and their choice is dependent upon the targeted scientific application. To suppress the speckle in SAR images, enhanced Lee filter[30] was used. The filter size of 5×5 was selected as it is an adaptive filter which suppresses the noise while preserving the edges or shape features in images. Efficient suppression of speckles in the images along with preservation of the shape of the feature is critical for detection of palaeochannels.

Sensor merging and digital image enhancement

Radar image backscatter variations are sensitive to physical properties of target such as surface roughness, dielectric constant and geometrical orientation, while optical sensors provide information on target chemistry. Thus, data from both the sensors are complementary in nature. Combination of optical and radar data, therefore, may improve the feature detection and mapping. Sensor merging of radar and optical data was performed using principal component analysis (PCA)[33–35]. This approach integrates the disparate information content of multisensor data in one image by combining image channels of different sensors in one image and then calculates PCA. Histogram equalization was performed on the merged image to enhance the appearance of paleo/buried channels.

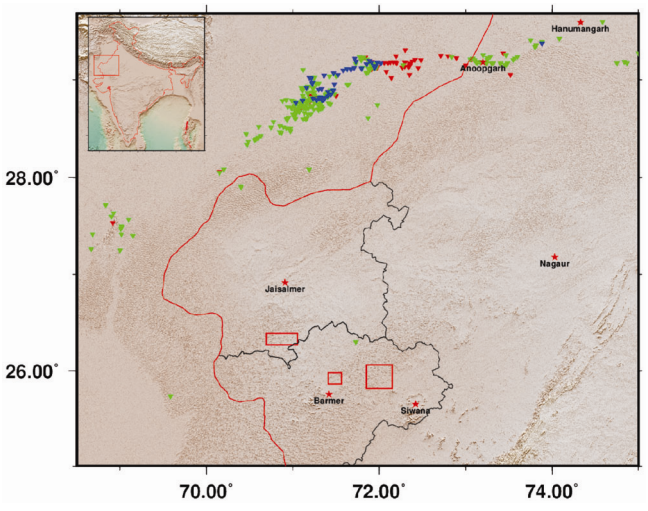

Figure 1. SRTM DEM showing location and physiography of the study area. Three study sites, located south of Jaisalmer town and northeast of Barmer town, Rajasthan, India are shown in red-coloured boxes. Sites of early Harappan, mature Harappan and late Harappan are shown in red, green and blue triangles respectively. Locations of archaeological sites are taken from Mughal[38] and Joshi[39].

Results and discussion

Palaeochannels in the southern parts of Jaisalmer district, Rajasthan

Paleochannels could be detected in the southern parts of Jaisalmer district on RISAT-1 SAR image acquired on 20 May 2013 (Figure 2 *a*) in vicinity of Gajhunki Basti, Hemjiki Dhani, Isarki Dhani, Kassuka Tala, Tejmalta and Morha covering SOI topographical map 40J/15, A3, B3 and C3 quadrants on 1 : 50,000 scale (surveyed in 1957–58). This topographical map does not show any current drainage in the region. Corresponding LANDSAT OLI images acquired during 15 May 2015 show feeble expression of this channel (Figure 2 *b*). Paleochannel could be enhanced by merging RISAT-1 SAR and LANDSAT OLI images using PCA technique (Figure 2 *c*). This channel is ~36 km in length and in ~20 m in width. The entire region is a parabolic sand-dune complex trending NE–SW and the paleochannel trends W–E following interdunal flats/depressions and at places cutting across parabolic sand dunes.

Cartosat DEM with 10 m resolution of the region (Figure 3 *a*) shows dune complex comprising parabolic sand dunes and interdunal flats. Topographic profiles A1–A2 (Figure 3 *b*) and B1–B2 (Figure 3 *c*) prepared using

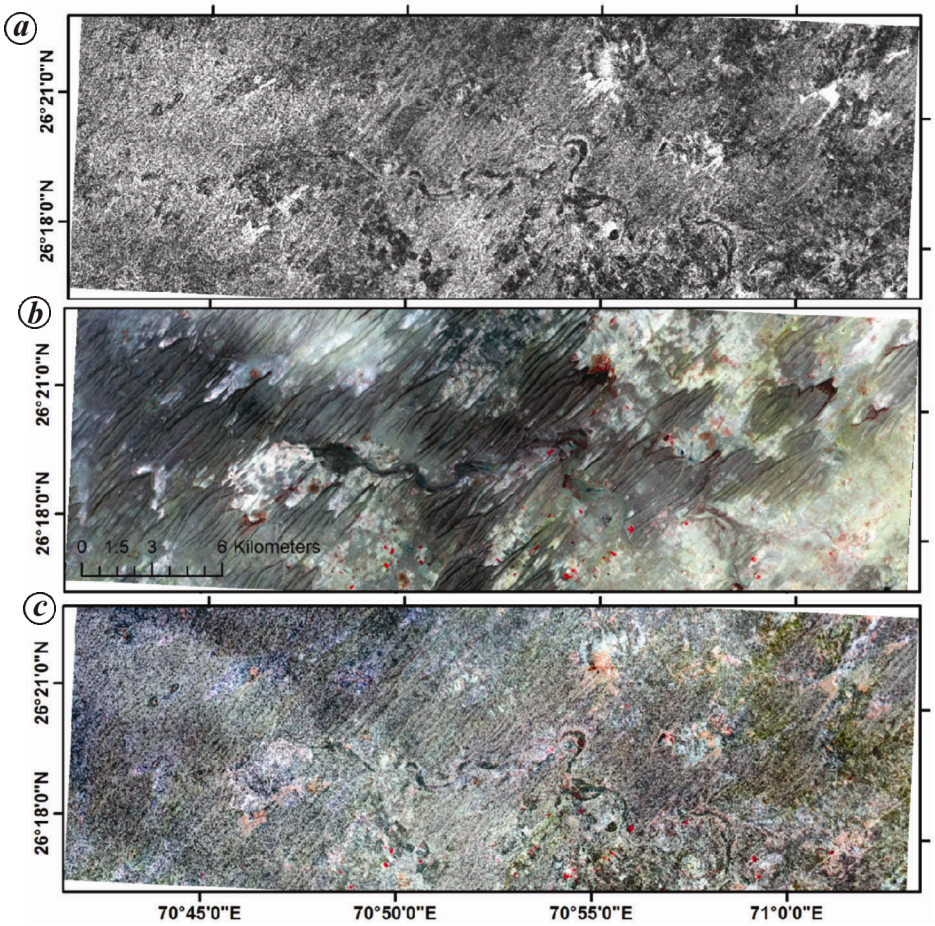

Figure 2. ***a***, Palaeochannels detected on RISAT-1 image in the southern parts of Jaisalmer district, Rajasthan. ***b***, Corresponding Landsat OLI FCC; ***c***, Optical and SAR-merged FCC. In optical and merged images, FCC is generated using combinations of bands 5, 4, 3.

Cartosat DEM show that the paleochannel region is within interdunal flat region at an elevation of ~150 m amsl. Sand dunes in the surrounding area are at 15–35 m height from the interdunal flat surfaces.

The paleochannel is observed as dark tone on radar images. This is due to sand-filled valleys, acting as radar smooth surface and absorbing the radar energy with negligible backscatter and enhanced topography due to side-looking capability of SAR.

Palaeochannels in parts of Barmer district, Rajasthan

Paleochannels could be detected in the region northeast of Barmer district on RISAT-1 SAR image acquired on 20 May 2013 (Figure 4 *a*) in the vicinity of Rohli to Kawas and Chokhla to Kawas, covering SOI topographical maps 40O/5, B1, C1, C2 quadrants and 45O/9 A1 and A2 quadrants on 1 : 50,000 scale (surveyed in 1958–59). These topographical maps show parts as undefined stream, while other parts do not show any current drainage in this region. Corresponding LANDSAT OLI images of 15 May 2015 show feeble expression of this channel (Figure 4 *b*). Palaeochannels could be enhanced by merging RISAT-1 SAR and LANDSAT OLI using PCA technique (Figure 4 *c*). These palaeochannels are ~15 km in length and ~60 m in width and truncate ~3–4 km NW of Kawas. The entire region is a parabolic sand-dune complex trending NE–SW with large interdunal flats. Palaeochannels trend NW–SE following interdunal flats/depressions.

Cartosat DEM with 10 m resolution of the region (Figure 5 *a*) distinctly shows patterns of these palaeochannels as sand-filled valleys within sand-dune complex comprising parabolic sand dunes and interdunal flats. Topographic profiles A1–A2 (Figure 5 *b*) and B1–B2 (Figure 5 *c*) prepared using Cartosat DEM show that palaeochannels are within interdunal flat region at elevation ~120–130 m amsl. Sand dunes in the surrounding area are at 25–35 m height from the interdunal flat surfaces. In this region also palaeochannels are observed as dark tone on radar images. This is due to sand-filled valleys, acting as radar smooth surface and absorbing the radar energy with negligible backscatter and enhancement of the topography due to side-looking capability of SAR.

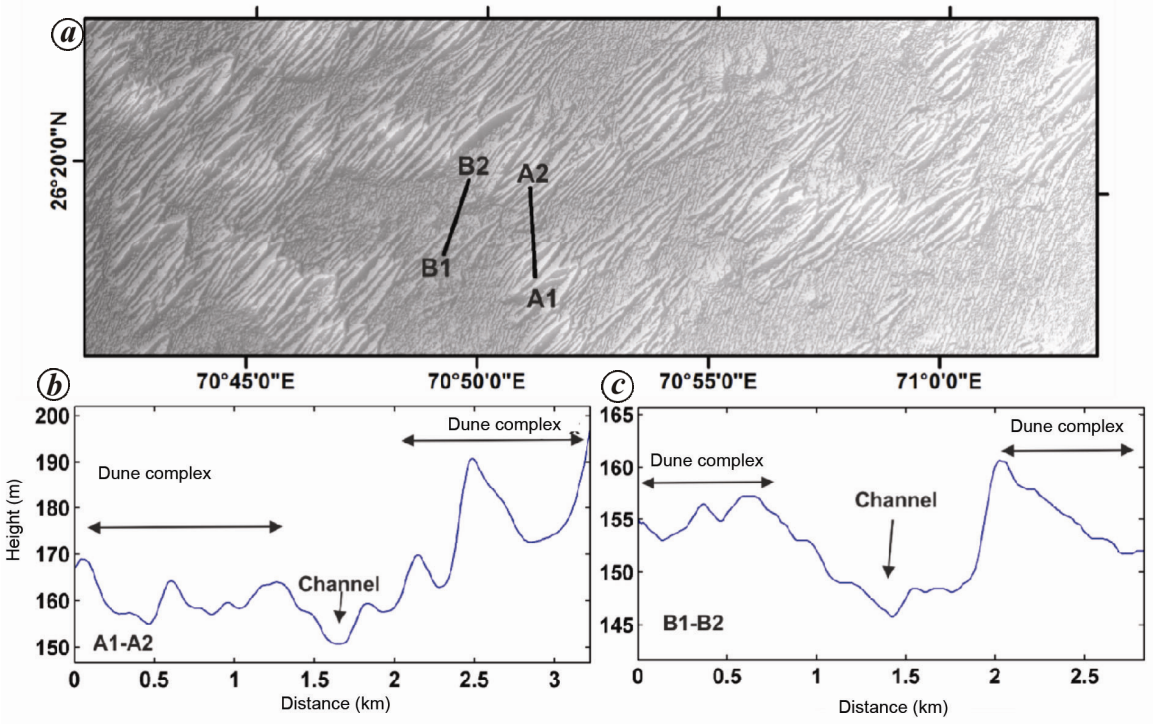

Figure 3. (***a***) Cartosat DEM covering southern parts of Jaisalmer district, Rajasthan and topographic profiles A1–A2 (***b***), and B1–B2 (***c***).

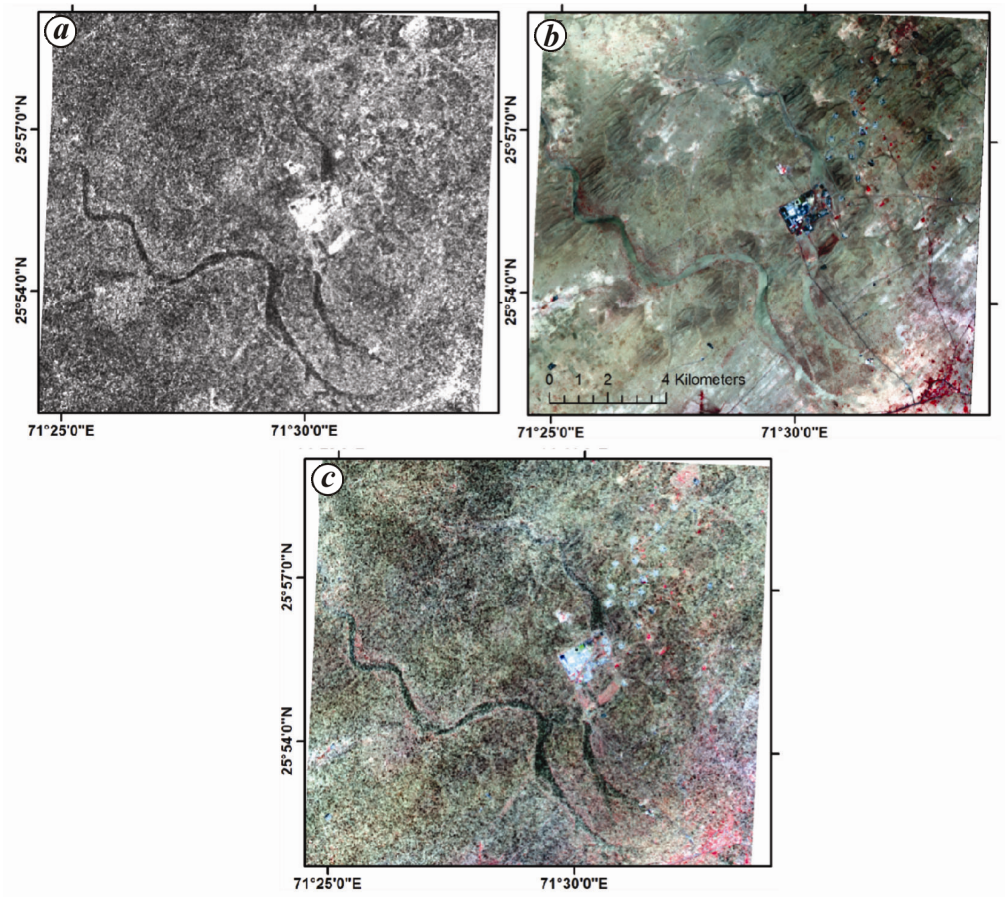

Figure 4. (***a***) Palaeochannels detected on RISAT-1 image in parts of Barmer, Rajasthan. (***b***) Corresponding Landsat OLI FCC image, and (***c***) optical and SAR-merged FCC. In optical and merged images, FCC is generated using combinations of bands 5, 4 and 3.

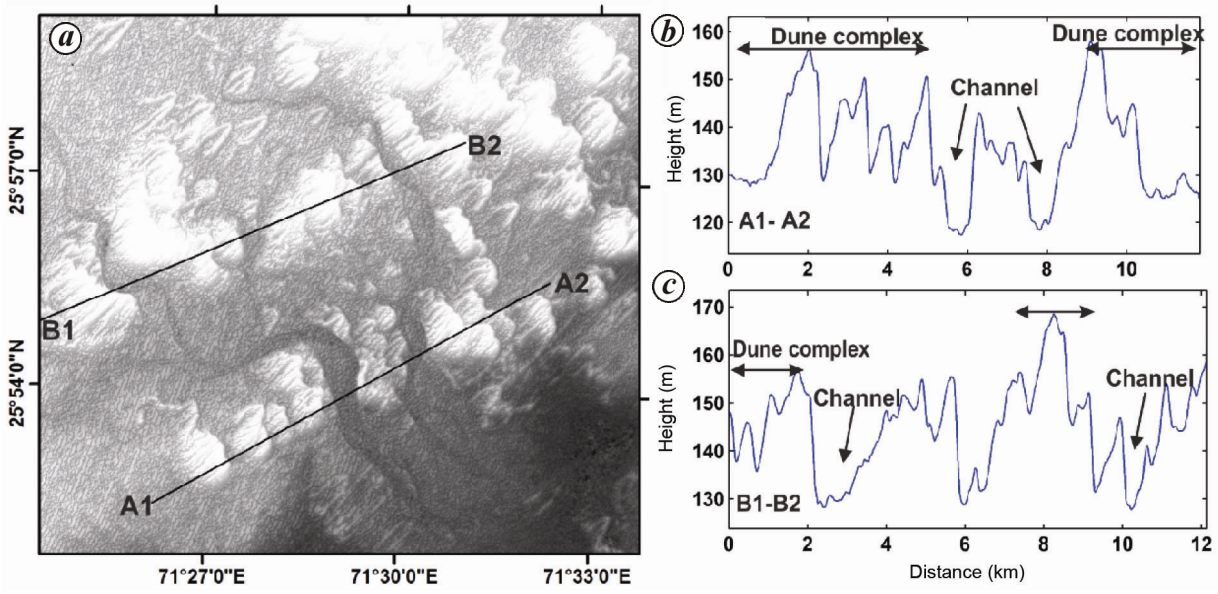

Figure 5. ***a***, Cartosat DEM covering parts of Barmer district, Rajasthan. Topographic profiles A1–A2 (***b***) and B1–B2 (***c***).

Laul and Laul[36] have reported that the August 2006 floods in Barmer area affected around 8 lakh people (ca. 30% of the population of Barmer district) as well as livestock. Floods in the area have taken a few hundred human lives and a few thousand cattle have also lost their lives. Heavy rains (601 mm against the normal annual rainfall of 227 mm) in Barmer area flooded the depressions and plains particularly underlain by clays – bentonite and fullers earth (Tertiary) and gypsite (Quaternary), which acted as impervious layers. The most affected villages include Malwa, Kavas and Bhadaka[36]. It was observed that the detected palaeochannels acted as pathways to the flood waters. A sequential analysis of pre- and post-flood SAR datasets may help in detecting additional hitherto unknown palaeochannels in this region.

Palaeochannels around Pachpadra playa, Barmer district, Rajasthan

This region is located in the NW part of the Luni basin covered with parabolic sand dunes trending NE–SW, inter-dunal depressions, north-to-south-flowing ephemeral Lik river, east-to-west flowing-ephemeral Luni river and ENE–WSW trending Pachpadra playa as observed on topographical maps and LANDSAT ETM imagery. Luni River takes an E–W to N–S abrupt turn, following the N–S trend of the Lik river. Luni river in this part is controlled by the Luni–Sukri lineament system (ENE–WSW trending) and N–S trending lineaments. The region is just north of Jaisalmer–Barwani lineament system, which is NNW–SSE trending.

In this region, several palaeochannels flowing north to south adjoining Lik river, west of Pachpadra playa have been detected on RISAT-1 HV image of 31 August 2012 (Figure 6 *a*). These palaeochannels are enhanced on RISAT-1 HH image of 31 August 2012 (Figure 6 *b*), providing the pattern of a bird foot-shaped delta of small dimension or indicating shifting pattern of these river channels. Corresponding LANDSAT ETM FCC acquired on 29 October 2010 of same region (Figure 6 *c*) does not show such patterns, and only feeble pattern of main channel of Likriver is seen. Merged product of SAR and optical data using PCA technique has enhanced the pattern of these palaeochannels (Figure 6 *d*).

Cartosat DEM with 10 m resolution of the region (Figure 7 *a*) shows dune complex comprising parabolic sand dunes and interdunal flats around Lik river and the region north of Pachpadra playa. Topographic profile A1–A2 (Figure 7 *b*) prepared using Cartosat DEM shows that the paleochannel region is within interdunal flat region at elevation ~80 m amsl. In the absence of any topographic expression of a valley, these palaeochannels are buried by shallow alluvial/aeolian sand cover. Sand dunes in the surrounding area are at 35–40 m height from the interdunal flat surfaces.

Possible causes of their darker appearance are (i) presence of alluvial/aeolian sand in abandoned channel-like depressions, which changes the polarization state thereby causing reduction in intensity of backscatter as observed in HH polarization image and (ii) finer grain size of channel-filled alluvial sand causes attenuation of radar waves more than the relatively coarse-grained aeolian sand.

The name Pachpadra denotes confluence of five rivers and their tributaries. Presence of major lineaments controlling the Luni and Lik river courses also support that the area has been under the influence of Neotectonic activities, leading to possible shifting of river channels.

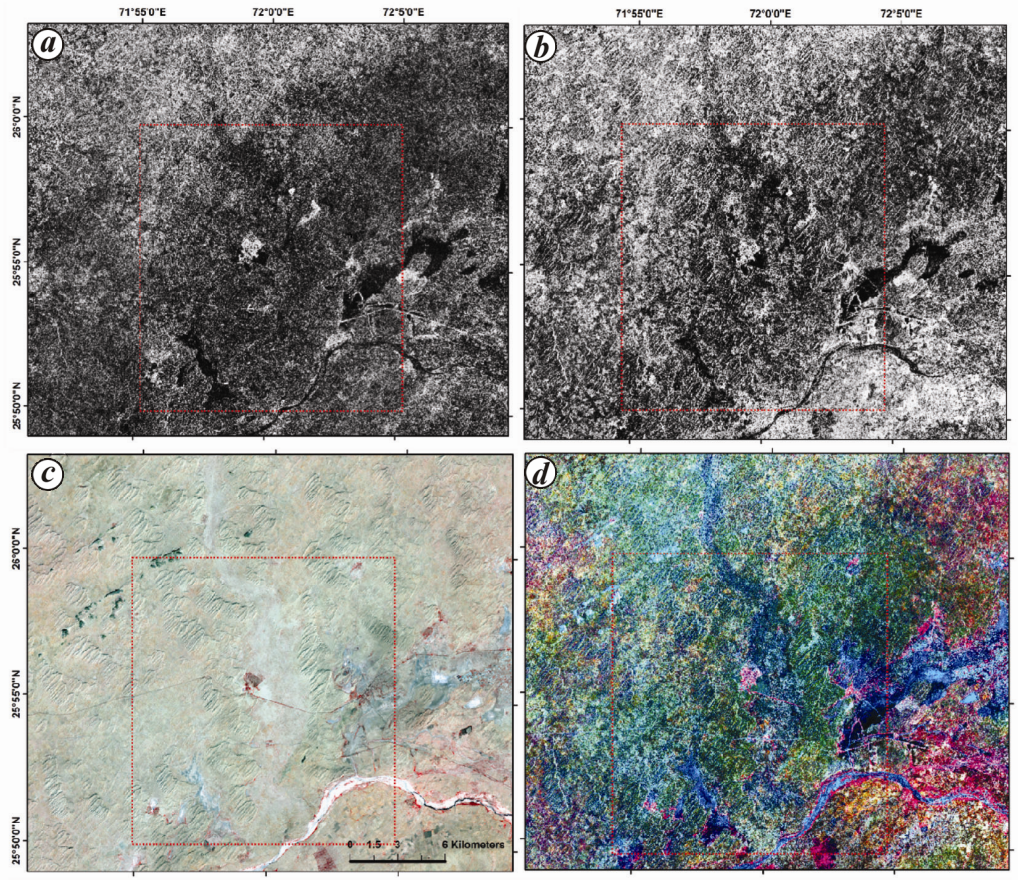

Figure 6. ***a***, Feeble pattern of palaeochannels seen on RISAT-1 HV image, west of Pachpadra playa, Barmer district. ***b***, Enhanced palaeochannels in RISAT-1 HH image. ***c***, Corresponding Landsat ETM FCC showing feeble pattern of main channel only. ***d***, Radar and optical merged image using PCA technique enhances the palaeochannels.

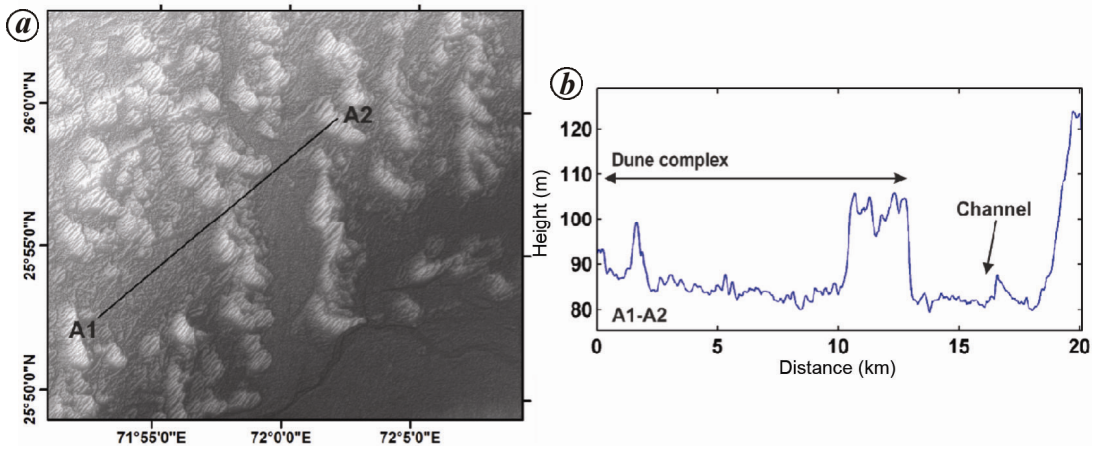

Figure 7. (***a***) Cartosat DEM covering the region west of Pachpadra playa, Barmer district and (***b***) topographic profile A1–A2.

These palaeochannels are hitherto unknown and have not been reported earlier and are in addition to eight paleo/buried channels reported by Rajawat *et al.*[21].

A large number of archaeological sites have been explored (Figure 1) in the Indus basin of Pakistan and India[37–39]. Many of the sites are in parts of the Thar desert. Palaeo/buried channels detected using RISAT-1 SAR data can act as guides for geoarchaeological exploration. A detailed analysis of RISAT-1 SAR data for the entire Indus basin is suggested to detect and map geoarchaeological features. These channels need to be investigated using GPR and sedimentological studies for validation.

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