

# Quantification of intensity of landscape changes using remote sensing and GIS with special reference to the Bhuj earthquake (26th January, 2001, $M = 7.9$ )

Ketaki Joshi<sup>1</sup> · Deepali Gadkari<sup>2</sup>

Received: 5 September 2014 / Accepted: 17 May 2016 / Published online: 2 June 2016  
© Springer Science+Business Media Dordrecht 2016

**Abstract** Change detection is used to detect changes after the Bhuj earthquake of January 26, 2001 and quantify the intensity of changes using remote sensing and GIS techniques. Changes are generally studied for their locations and spatial distribution, band sensitivity, aerial extent (quantity of changes), nature (permanent change, seasonal/cyclic change) and processes are inferred that may have led to the changes. The present research is an attempt to quantify the intensity of changes using remote sensing and GIS techniques. It may be possible to just visually detect changes in landscape, but to detect the variations in intensity of changes, techniques of image processing need to be employed. In the present study, one of the techniques of change detection, namely ‘temporal band differencing,’ is used to detect changes in landscape and their intensity after the Bhuj earthquake (26th January 2001, magnitude = 7.9 on Richter scale). In this method of change detection, temporal difference between two images is computed by subtracting time 2 image values from time 1 image values (brightness values) of corresponding pixels. Output image contains absolute differences in brightness values of corresponding pixels. This research work attempts to study the change detection technique in which bandwise change detection and areawise change detection is carried out. All the changes are then correlated with the geology and tectonics of the area around Bhuj and epicenter of the Bhuj earthquake.

**Keywords** Intensity of changes · Earthquake · Remote sensing · Bandwise change detection · Temporal image differencing · Liquefaction

---

✉ Deepali Gadkari  
deepaligadkari@gmail.com

<sup>1</sup> Department of Geography, University of Pune, Pune, India

<sup>2</sup> Department of Geography, University of Mumbai, Mumbai, India

## 1 Introduction

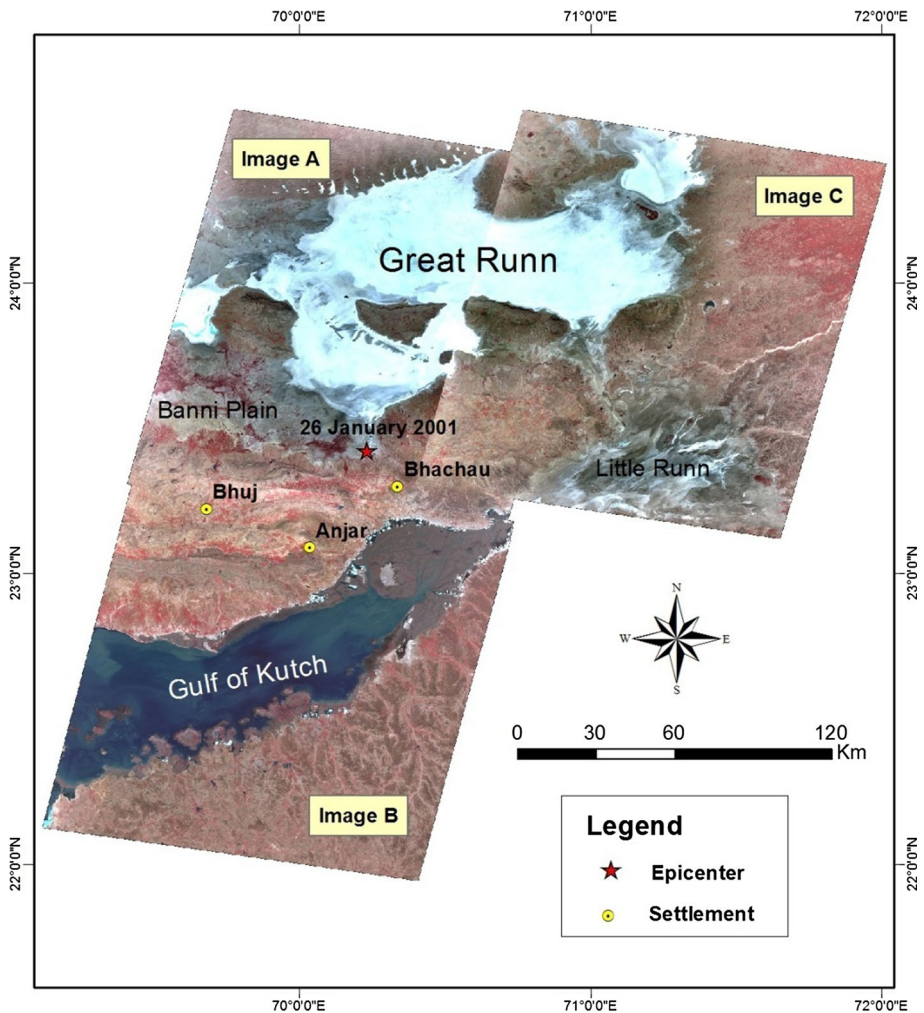
The technique of change detection with remote sensing is employed by many researchers in various fields like forest, urban studies, agriculture, disaster management, landuse–landcover studies, etc. Many scientists have used various image transformation techniques (such as NDVI, Cj index, Tasseled Cap, SAVI) to extract the required information from images and then such transformed images are further used for detecting changes. Here, it is used to detect changes in landscape after the Bhuj earthquake of January 26, 2001 and quantify the intensity of changes using remote sensing and GIS techniques. Changes are generally studied for their locations and spatial distribution, band sensitivity, aerial extent (quantity of changes), nature (permanent change, seasonal/cyclic change) and processes are inferred that may have led to the changes. The quantitative analysis and identifying the characteristics and processes of surface changes involves the type, distribution and quantity of changes that is the ground surface types, boundary changes and trends before and after the changes (Shaoqing and Lu 2008). But there have been a very few attempts to quantify the intensity of changes. The present research aims at quantifying the differences in the DN values of time 1 and time 2 images. Since multispectral data are used, changes detected in every band (of LISS III) throw light on the sensitivity of specific band(s) to the changes in certain type of landcovers.

Earthquake is a hazardous event which can cause changes on the surface of the earth. It is known from literature that this particular Bhuj earthquake ( $M = 7.9$ , dt. January 26th, 2001) has caused a number of changes in the landscape. The literal meaning of earthquake is merely shaking of the ground. The earthquake that struck the Kutch area in Gujarat has been one of the major earthquakes in India. The  $M = 7.9$  quake caused tremendous loss of life and property. Over 18,600 people are reported to be dead and over 1,67,000 injured (Jain et al. 2001). Murty et al. (2005) are of the opinion that the earthquake occurred on the Kutch Mainland Fault. The compressive stresses responsible for the earthquake are related to the collision of India with Asia and the resulting rise of the Himalayas to the northeast. The epicenter of the earthquake was near the remote Little Rann of Kutch, but within 150–200 km of several villages and towns. The proximity to populated areas, coupled with a shallow 17-km focus, resulted in massive destruction and fatalities (Seismo-watch 2001). It is attempted to assess landscape changes within radius of 100 km from the epicenter with technique of change detection using satellite images. The differences found are further categorized to find differences in the intensity of changes over the region. Changes are detected in all the spectral bands of the images, and it is also assessed in which of the band(s) particular changes are clearly detected. The changes so found are classified for their intensity. It is further attempted to correlated the changes that have occurred due to the Gujarat Earthquake with the tectonic setup and the geology of the area.

### 1.1 Geography of the study area

The Rann of Kachchh is a seasonally marshy saline clay desert located in the Thar Desert biogeographic province in Gujarat state in northwestern India and the Sindh province of Pakistan. It is spread over some 30,000 square kilometers between the Gulf of Kachchh and the mouth of the Indus River in southern Pakistan. In India's summer monsoon, the flat desert of salty clay and mudflats, averaging 15 m above sea level, are filled with standing waters, interspersed with sandy islets of thorny scrub.

The part of the Kachchh region which lies to the north of the Kachchh Mainland Fault includes the Banni Plains and the Rann of Kachchh. It is a low, flat basin characterized by salt pans and mud flats. The salt forms in the Rann of Kachchh as mineral-laden waters evaporate. During the earthquake, strong shaking produced liquefaction in the fine silts and sands below the water table in the Rann of Kachchh. Liquefaction is a phenomenon whereby a saturated or partially saturated soil substantially loses strength and stiffness in response to an applied stress usually earthquake shaking or other sudden changes in stress conditions, causing it to behave as a liquid (en.wikipedia.org/wiki). This caused the mineral grains to settle and expel their interstitial water to the surface (Fig. 1).



**Fig. 1** Study area—Bhuj and area around (image details in Table 1)

### 1.2 Tectonic setting and geology of the area

The Indian tectonic plate migrates toward the north at a rate of 55–60 mm per year; likewise, the Asian plate is moving in the same direction at 25–30 mm per year (EERI 2002). The difference in speed is responsible for the formation of the Himalayan Mountains and the 20–25 mm-per-year outward forcing of crustal blocks along the subcontinent’s border with Pakistan. This array of motion speed and direction creates one of the seismically active regions in India, and has been responsible for a number of major and minor earthquakes, including the 26 January, 2001 magnitude 7.9 Bhuj event (EERI 2002).

The rocks belonging to the Precambrian, Mesozoic and Cenozoic eras are exposed in the Gujarat state with absence of Paleozoic era. The hard rock (Precambrian metamorphites and associated intrusives) covers about 49 %, and the rest is covered by Quaternary sediments (sedimentary rocks of Mesozoic and Cenozoic eras and the trap constituting Deccan Volcanics of Cretaceous, Eocene age) (Gujarat Mineral Devt. Corp. report on Geological evolution and mineral resources of Gujarat). The rest being most widespread deposits of the region is the upper Cretaceous Deccan Trap basalt and related intrusive rocks (Fig. 2).

### 1.3 Aim and objectives

The aim of the research work is to assess the suitability of change detection technique for landscape changes with special reference to Bhuj Earthquake. The changes in the landscape which have occurred due to the earthquake are correlated with the geology and tectonic setting of the area. To achieve the above aim, following objectives are set:

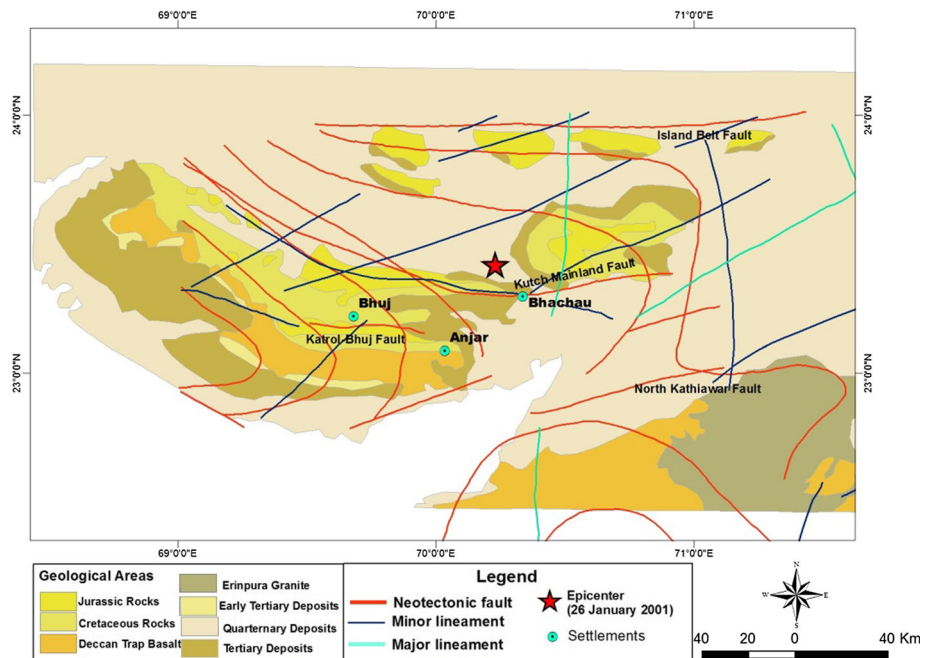


Fig. 2 Geology and Tectonic elements of the study area

**Table 1** Details of data

Sr. no.	Satellite images (Satellite: IRS 1D, Sensor: LISS III, Spatial Resolution: 23.5 m and Spectral Resolution—B1 (green—0.52–0.59), B2 (red: 0.62–0.68), B3 (near-infrared (NIR): 0.77–0.86), B4 (short wave infrared (SWIR): 1.55–1.7)	Time 1 image (before earthquake)	Time 2 image (after earthquake)	Path no.	Row no.
1.	A image	15 November 2000	29 January 2001	90	55
	B image	15 November 2000	29 January 2001	90	56
	C image	7 December 2000	10 February 2001	91	55
2.	Toposheets	Scale = 1:250,000 ( <i>Source</i> Texas University website)			
3.	Seismotectonic map	Scale = 1: 1,000,000 (Dasgupta et al. 2000)			
4.	Geological map	Scale = 1:2,000,000 (EERI 2002)			

- a. To detect the changes in the images of the dates before and immediately after the earthquake by using temporal image differencing technique.
- b. To group the changes according to their intensity.
- c. To correlate the changes with the geology and the tectonic setup so as to find out the correlation between the intensity of changes and the geotectonic conditions.

## 2 Data and methodology

### 2.1 Data

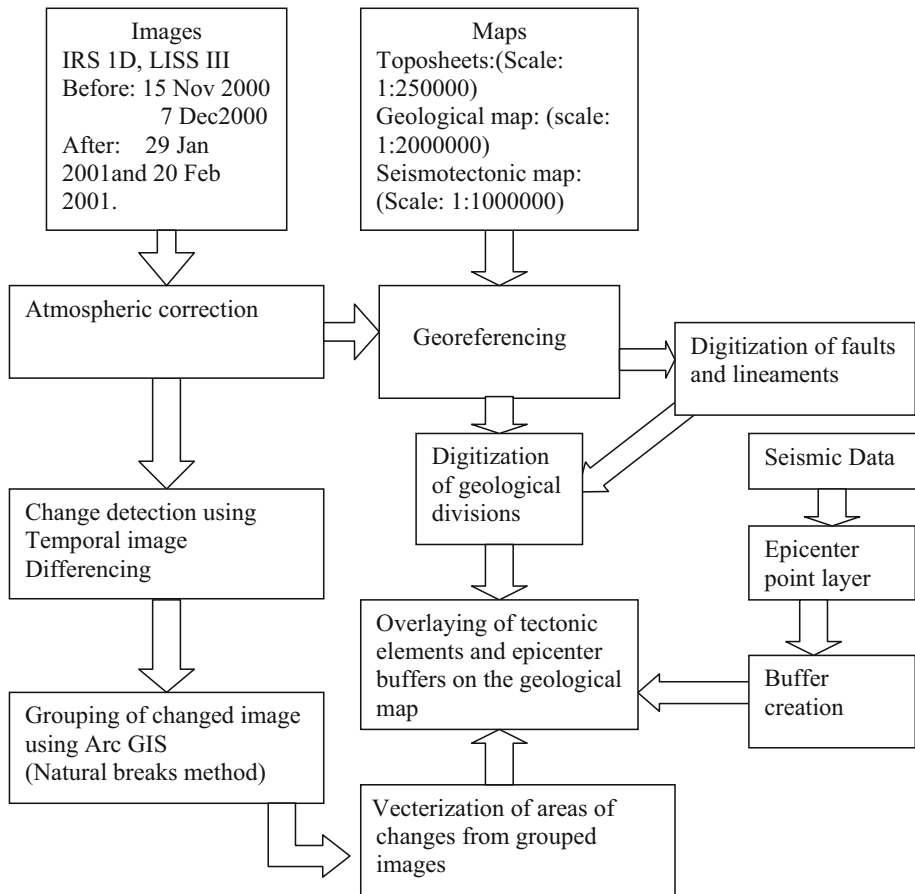
The data used for the research work mainly consist of satellite images, toposheets, seismotectonic and geological maps. Table 1 gives all the details of data used for the present study.

### 2.2 Methodology

The present research is mainly based on analysis of satellite images. So satellite images of two times (before and after the earthquake) are the basic data used. The preprocessing techniques used on images include atmospheric corrections and georeferencing of images with toposheet and with each other. The main technique used here is the temporal image differencing to detect changes those have occurred in the landscape. A subtraction image (differenced image) is gained from the subtracting of the gray value of corresponding pixels of images after image registration (Shaoqing and Lu 2008). The changes detected are then classified into groups as per their intensity and then are correlated with the geologic formations and tectonic setup of the area. All these techniques and methods are described in brief in the following paragraphs (Fig. 3).

#### 2.2.1 Atmospheric correction

For the purpose of change detection, two sets of images are used. The images are of different seasons and every image has some effect of atmosphere. Dark object subtraction



**Fig. 3** Methodology

(DOS) method is used for this research work. This is the simplest, yet most widely used image-based absolute atmospheric correction approach for image classification and change detection applications (Spanner et al. 1990; Ekstrand 1994; Jakubauskas 1996; Huguenin et al. 1997; Song et al. 2001). According to this method, minimum digital number (DN) in the image histogram from the entire scene is thus attributed to the effect of the atmosphere and is subtracted from all the pixels (Chavez 1989). All the images were first corrected for atmospheric effect by DOS and then used for further analysis.

### 2.2.2 Georeferencing

After performing atmospheric correction, the images were georeferenced. Polynomial geometric model is used, with geographic projection for this. Time 1 images are georegistered with toposheets (scale 1:250,000), then time 2 images are georeferenced with time 1 images, and these images are used for further analysis. Similarly seismotectonic maps (scale 1:1,000,000) and geological maps are also georeferenced with toposheet (scale 1:250,000).

### 2.2.3 Change detection technique

There are a number of methods of change detection, like post classification comparison, spectral pattern recognition, principal component analysis, temporal image ratioing (Lillesand and Kiefer 1987), of which ‘temporal image differencing’ has been used for the present study. Alberga (2009) has put the change detection technique into two groups such as those that operate a preliminary feature extraction or classification and the other methods that estimate the differences of radiometric values of image pixels and then establish if a change occurred based on thresholding value. The present work has grouped the changes as low, medium and high category, instead of threshold value. Pixel brightness values of one image are subtracted from corresponding pixel brightness values of the other image. Absolute values of differences are presented in the resultant image. Higher difference values in the resultant image correspond to the areas of high change and lower difference values to the areas of low change. This produces an image with bright and dark areas representing the areas of drastic changes and of minimal changes, respectively.

This is done for each band of the images, i.e., Band 1 of time 1 image–Band 1 of time 2 image, Band 2 of time 1 image–Band 2 of time 2 image, up to the forth band of the LISS III images. Such bandwise change detection helps in knowing the sensitivity of bands to particular type of change(s).

### 2.2.4 Vectorization

Geological divisions are digitized from geological map. Tectonic elements like faults and lineaments are also digitized from seismotectonic map, and they are superimposed on geological map. The areas of changes found after bandwise analysis are also digitized and overlaid on the geological map. This enabled the correlation of the areas of changes with the geology and tectonic elements in the study area. Epicenter is plotted on geological map to know relation of changes according to geology, tectonics and epicenter. Five buffers are created around the epicenter by taking interval of 20 km.

## 3 Data analysis and results

### 3.1 Change detection

The aim of the present research is to use the technique of remote sensing to detect changes that have occurred due to the earthquake. Use of multispectral images allows to assess sensitivity of bands to the type of changes. As mentioned earlier, the images were processed bandwise. This method gives image of difference in gray colors which are difficult to interpret visually. Moreover, this method does not reflect changes in categories (Shaoqing and Lu 2008). So each difference image is then grouped initially into fifteen classes of differences and then into three classes—such as high differences (high change), medium differences (medium change) and low differences (low change), according to the pixel values, using ‘Natural Breaks Method’ (jenks) of reclassification.

The color scheme used to represent the three groups of changes is given below:

i.

Low change: Classes from 1 to 5 (white, pink, dark pink, violet, blue)



ii.

Moderate change: Classes from 6 to 10 (navy blue, cyan, parrot green, leaf green, Citroen green)

iii.

High change: Classes from 11 to 15 classes (yellow, orange, faint orange, brown, dark brown)

The first group, dominated with white color, represents areas of no change or negligible change, whereas the last group, i.e., group three represents areas of high changes.

Areas with high and moderate change are digitized, then the polygons of changed areas are coded, code is given as ‘HL1,’ ‘ML1,’ ‘HS1,’ ‘MA1’ where the first letters, namely H, M and L, represent the three categories of high, moderate and low changes, respectively. The second letters represent the type of landuse/landcover in which the change is found in, e.g., L, A, S represent liquefaction, agriculture and saltpans, respectively. Numbers at the third place in the code represent the location—1, 2, 3 correspond to location 1, location 2, location 3, etc. Here are a couple of examples— (i) HL1—High change, Liquefaction detected location 1; (ii) MA2—Moderate Change in Agriculture at location 2.

### 3.1.1 Nature of detected changes

The changes detected through image analysis are mainly of 3 types—changes related to moisture conditions of the soil (liquefaction), changes in salt pan area, and changes in agricultural fields, waterbodies and sediment conditions. All these changes are plotted on

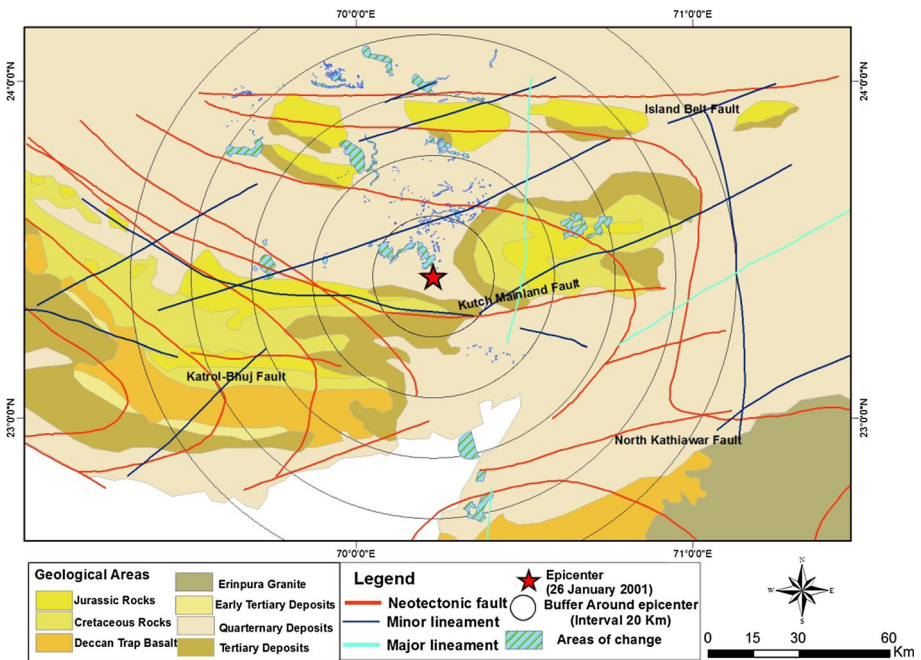


Fig. 4 Changes due to the earthquake



the map of study area (Fig. 4) and are then assessed for their affiliation with the earthquake. The changes are discussed in the following paragraphs.

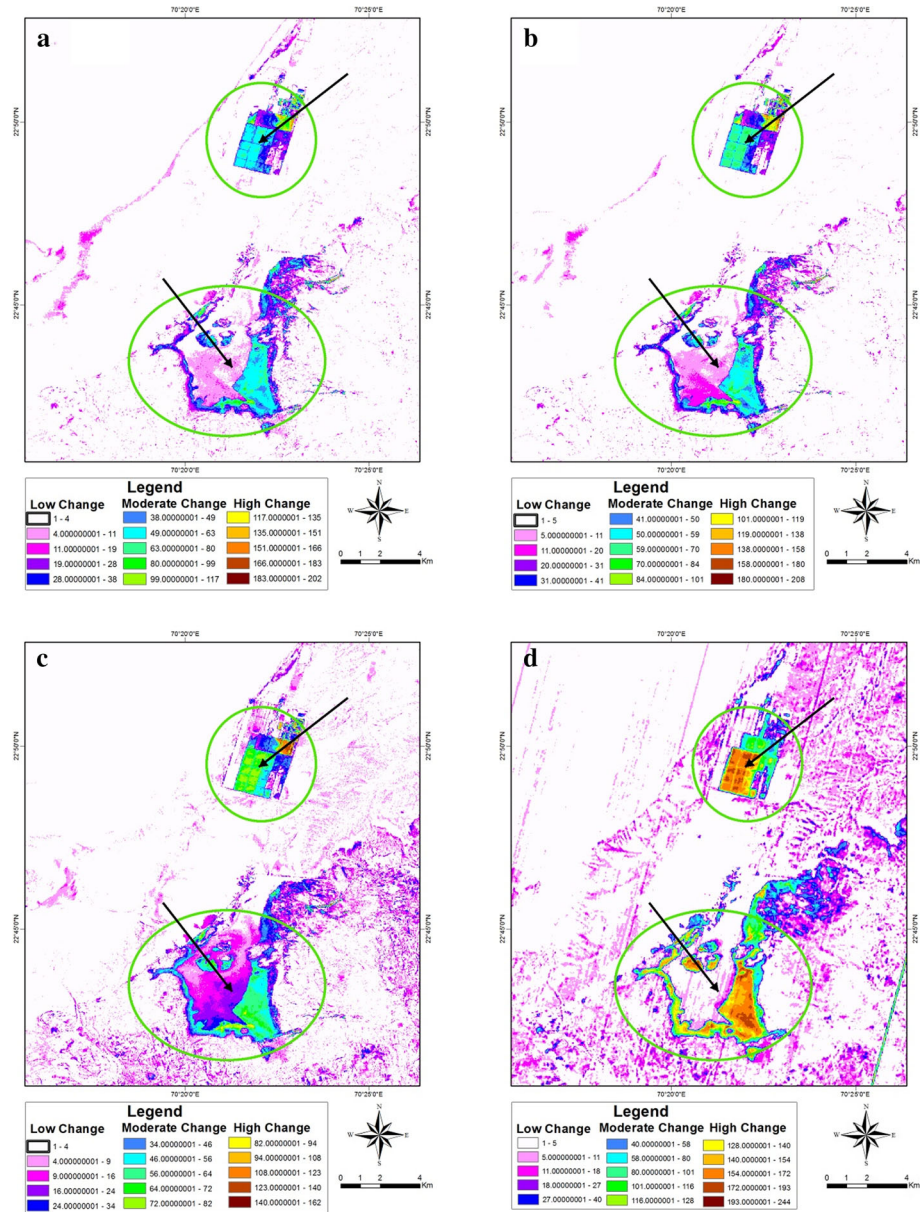
**3.1.1.1 Liquefaction** Liquefaction takes place when loosely packed, water-logged sediments at or near the ground surface lose their strength in response to strong ground shaking. As extensional and compressional movements occur, groundwater is forced upward due to compaction of water-containing subsurface structures. Liquefaction occurring beneath buildings and other structures can cause major damage during earthquakes. The area of liquefaction represents the areas of maximum change in the study area. In the areas of the Banni Plains, the Great Rann, the Gulf of Kutch and Little Rann, soil characteristics and topography cause a high probability of liquefaction during seismic events (McGee 2005) (Fig. 1). Many researchers have observed soil liquefaction in parts of the Rann of Kutch through analysis of remotely sensed images (Singh et al. 2001). It is observed that moisture has come to the surface in the form of small streams after the earthquake in the southern part of the Rann of Kutch. In the differenced images, this change is grouped as high, medium and low change groups. This change is detected in almost all the bands, but the intensity of change is different in every band.

**3.1.1.2 Salt pan areas** Salt pans are seen on both sides of the Gulf of Kutch. These areas produce salt and appear in white or bluish white color on standard false color composite images. These are rectangular in shape. The major change detected in salt pan areas is that of increase of water. Salt pans are filled up with water due to rise in groundwater, after the earthquake (Fig. 5a–d). Changes in moisture content are prominently detected in Band 4 (SWIR)—(Fig. 5d).

This is an effect of liquefaction, widely experienced in the area after the earthquake. It is also noted that the changes in Band 4 (Fig. 5d) are in high change category, whereas changes detected in all the other bands (i.e., Band 1, 2 and 3) are in moderate categories. This is because Band 4 (SWIR) of LISS III is the most sensitive band for moisture. So changes in moisture as an effect of liquefaction could be detected prominently through this band.

**3.1.1.3 Agriculture** Images which are used for this study are of different times. Time 1 images (A & B) are of 15 November, 2000 and time 2 images (A & B) are of 29 January, 2001. Thus, there is time gap difference of approximately 2 months and 14 days. Time 1 image (C) is of 7 December, 2000 and time 2 image (C) is of 20 February, 2001, so these images have time gap of approximately 2 months and 15 days. This span of time is sufficient for crops to be in the next stage of their growth. This is a kind of obvious change due to biological growth and so is not attributed to the earthquake

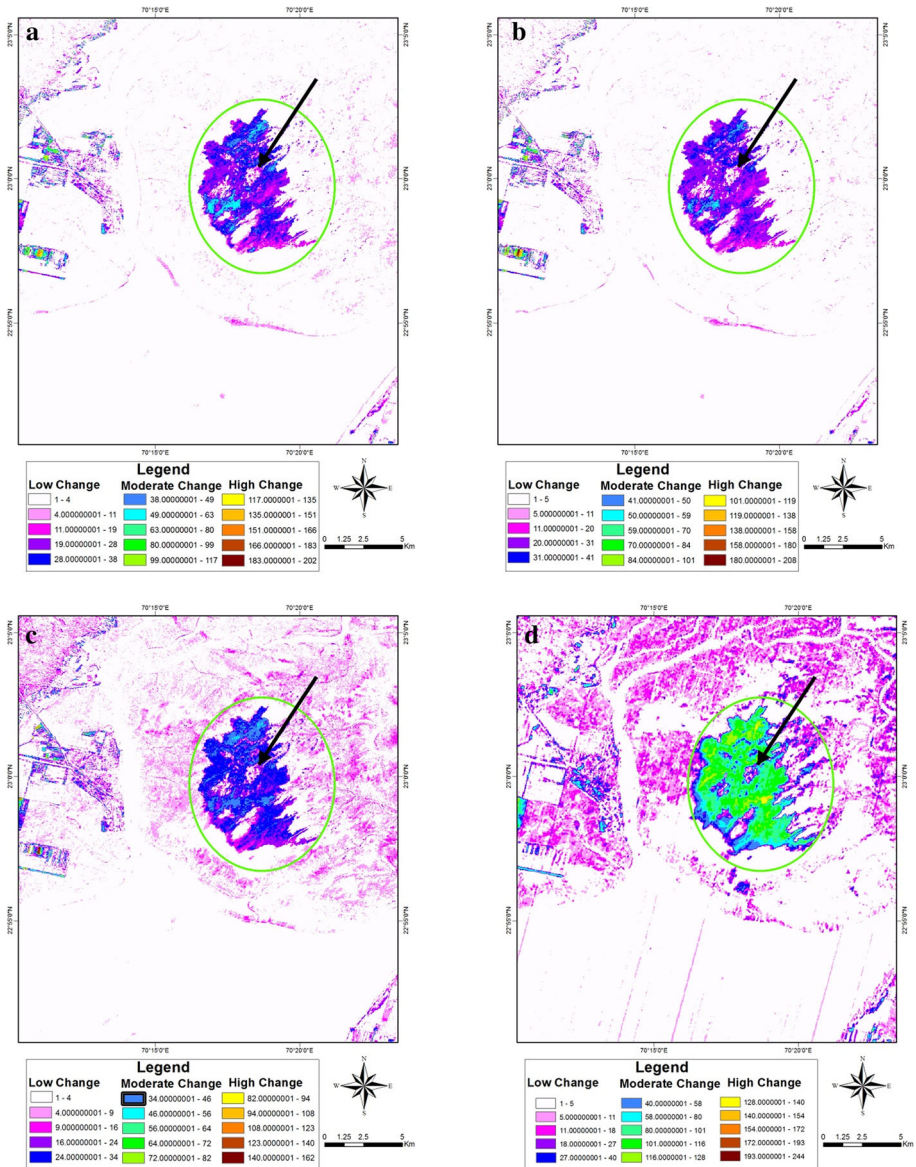
**3.1.1.4 Soil moisture** A prominent change is detected at the tip of the sea arm where there is an increase in moisture on an island and salty area around. The area has undergone a change due to the rise in groundwater level after the earthquake (Fig. 6a–d). Here also it is noted that the change related to moisture content is relatively well detected through Band 4 (SWIR) than the first three bands.



**Fig. 5** Moderate changes in salt pan area—location 1(MS1, ML12); **a** Band 1, **b** Band 2, **c** Band 3, **d** Band 4

### 3.2 Correlation between areas of change and tectonics and geology

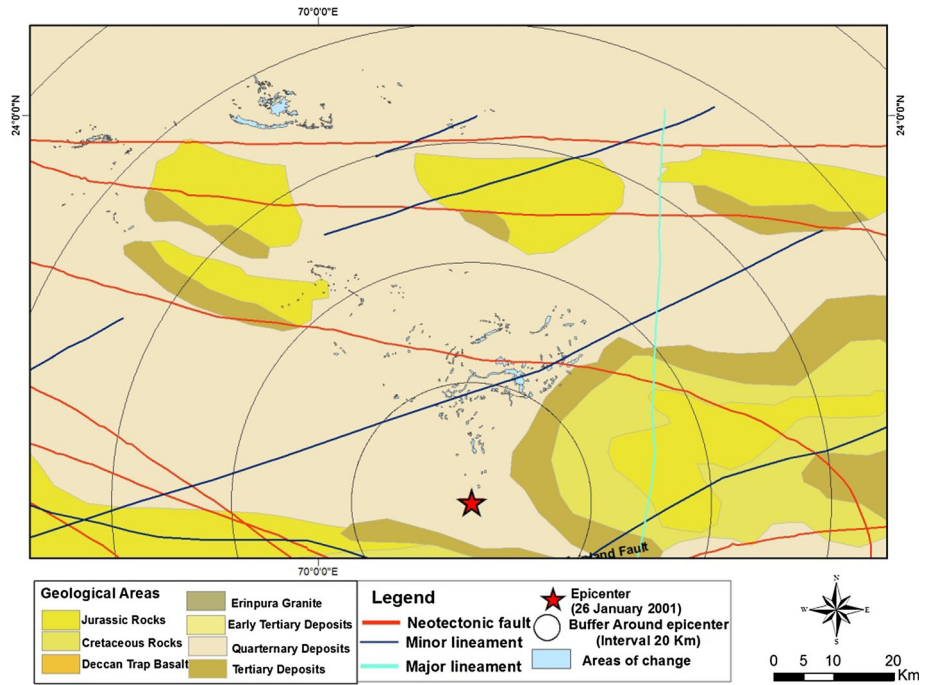
The next step of analysis was to correlate the changes so detected through image analysis with the geology and tectonic setup of the area. The areas of changes were vectorized so as to overlay these on the geological map with tectonic elements and epicenter of the



**Fig. 6** Effect of liquefaction—increased moisture in salty area (ML11). **a** Band 1, **b** Band 2, **c** Band 3, **d** Band 4

earthquake. This enabled to see association between the areas of change and underlying geology and tectonic setup. Buffer zones are created around the epicenter by taking radii of 20, 40, 60, and 100 km. This allowed distance wise comparison of the area of changes from the epicenter (Fig. 7).

Singh et al. (2002) observed in their filed visit after the earthquake to Bhuj and area around many evidences of liquefaction in the form of craters-like structures with salt water,

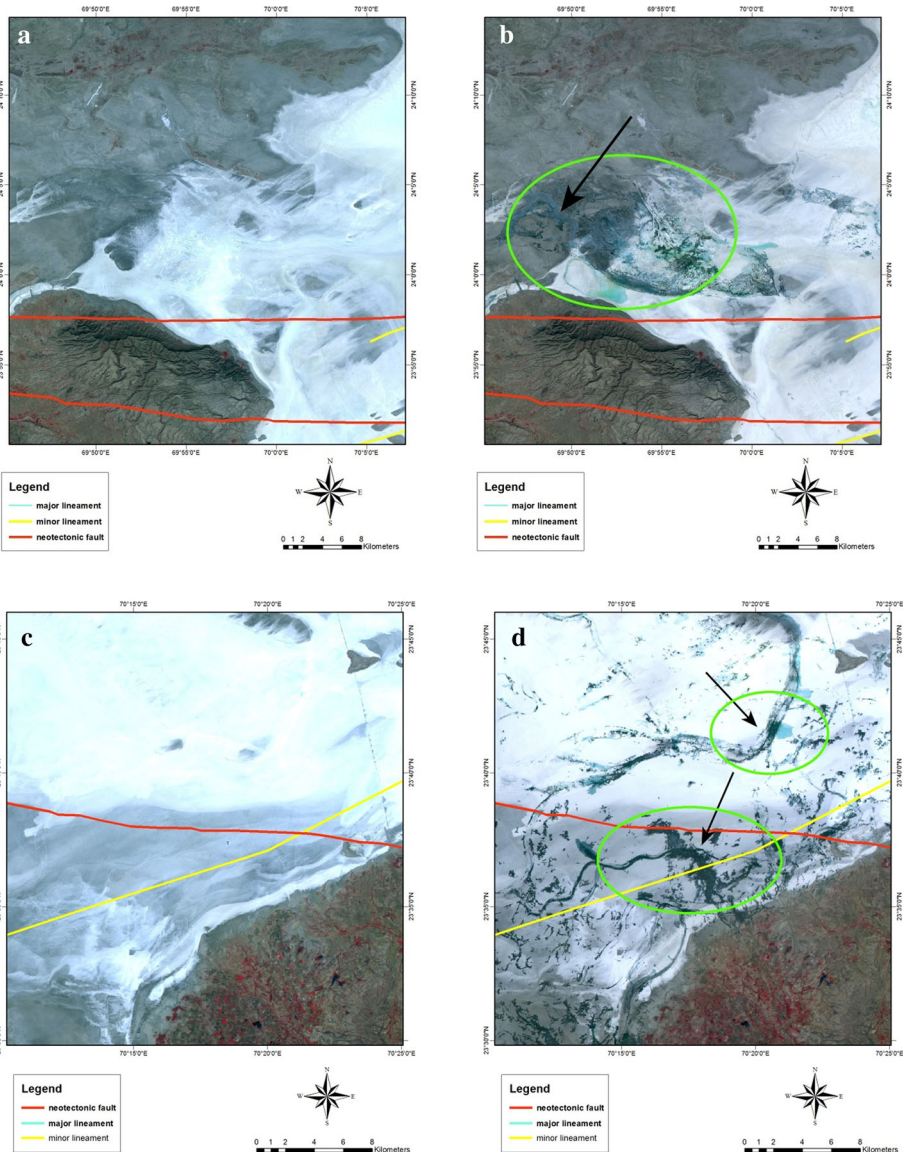


**Fig. 7** Landscape changes with geology and tectonics of the area

**Table 2** Some field observations after the Gujarat Earthquake of January 26, 2001 (After Singh et al. 2002)

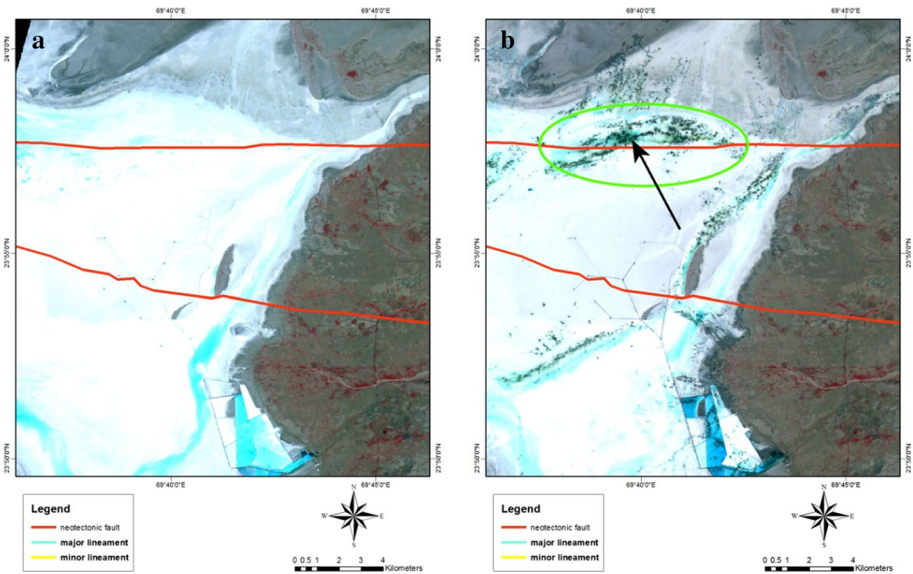
Observation	Longitude (East)	Latitude (North)	Change
1.	70°36'	23°39'	Dome-like structures developed due to liquefaction.
2.	70°30'	23°39'	Liquefaction zone, trend of crack is N235°–N55°
3.	69°57'	23°23'	Extensive salt water field emerged near Lodhai village
4.	69°57'	23°23'	Huge crater-like openings developed near Lodhai village
5.	69°57'	23°23'	Crater-like structures of salt water developed near Lodhai village
6.	69°39'	23°29'	A big tensional crack approximately 30 cm deep, salt water came up to surface due liquefaction
7.	69°39'	23°29'	Extensive salt water field in a nearby field on Bhuj-Khavda road
8.	70°36'	23°40'	Small tensional cracks at the same location as the previous photograph. Salt water on the surface because of the liquefaction through the crack
9.	70°34'	23°34'	Cracks developed on the surface near Barudia village





**Fig. 8** Liquefaction effects on FCC—stream appearance (a, b location 1; c, d location 2)

tensional and compressional cracks of considerable depth and deposits of salt after evaporation of water. Their observations are summarized in Table 2. It is observed that these locations of changes lay in the areas identified as areas of change using remote sensing technique in the present study.



**Fig. 9** **a** Time 1 and **b** time 2: liquefaction in near neotectonic fault (on FCC)

### 3.2.1 Areas of maximum change and geology and tectonics

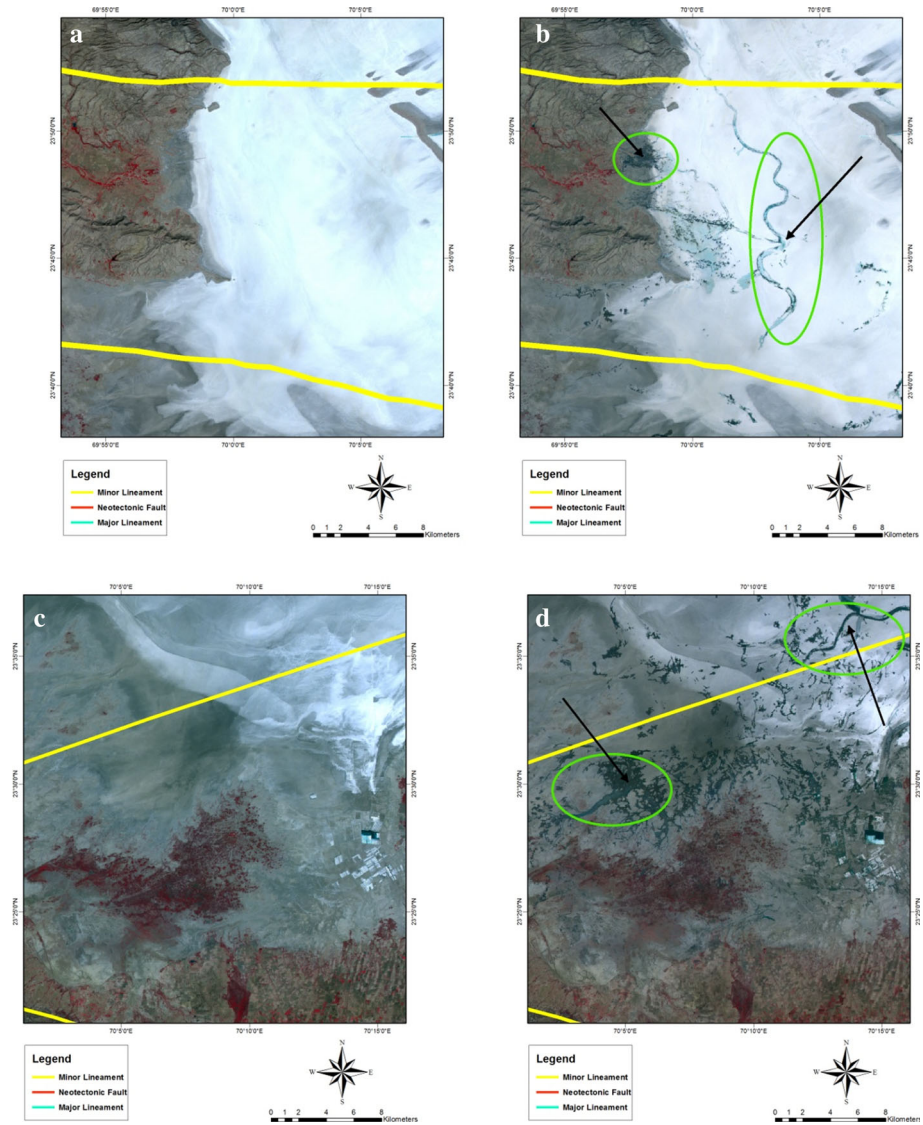
Maximum change has been found in the form of liquefaction and in the areas of salt pans. Five such areas with effect of liquefaction have been identified. Most of the maximum change areas with liquefaction are found to be to the north of the epicenter. Whereas the areas of maximum change in case of salt pans are found to the southwest of the epicenter.

The first location (HL1) of the liquefaction is found between 65 and 80 km from the epicenter. This area has quaternary deposits, and a neotectonic fault is passing through this area (Fig. 8a–d). The second location of liquefaction (HL2) is also found in quaternary deposits and a minor lineament and a neotectonic fault is passing through this area. This area is located in between 10 and 35 km from the epicenter. In this area, new streams are created as an effect of liquefaction (Fig. 9a, b).

### 3.2.2 Areas of moderate change and geology and tectonics

The areas of moderate change are widely spread over the area within 80 km of radius from the epicenter. Moderate change has been observed in the areas of agriculture, salt pan, and in the areas of salt waste in the form of liquefaction. Most of the liquefaction areas are to the north of the epicenter. At the location of ML1, a stream appears (in the time 2 image) in the salt waste area (Fig. 10a, b). In the same way, small streams have appeared as the result of liquefaction at the ML4 location. ML1 and ML8 locations are within 40–60 km of radius from the epicenter. ML4 is within 60–80 km from the epicenter, whereas ML9 location is located within 20 km from epicenter covered large area (Fig. 10c, d).

All these areas of moderate changes in the form of liquefaction are in the quaternary deposits. These locations are also found to be within 7 km from either lineaments or neotectonic faults. Moderate change in case of agriculture either shows harvesting of crop



**Fig. 10** Location ML1 **a** time 1 and **b** time 2; location ML4 **c** time 1 and **d** time 2: liquefaction near neotectonic fault (on FCC)

in time 2 image or healthy growth of crop. Since these changes are due to growth of crops rather than due to the earthquake, these are not considered for analysis.

### 4 Conclusions

The image analysis led us to the following conclusions:



For change detection every band plays an important role and should be considered separately for identifying changes. The changes which may not be visible on a FCC could be detected in single band images. So bandwise change detection is useful and highly recommended for complex landscapes (where there are many landuses and landcovers). Every band of images is showing the same areas of change, but the intensity of change is different from band to band. The highest effect of liquefaction could be detected in near-infrared (SWIR) band. This is because of the fact that due to liquefaction moisture content in soil increases drastically and the SWIR band is very sensitive to moisture changes. Changes in salt pans in the form of increased water content may also be attributed to the earthquake.

Maximum effect of liquefaction is located within the radius of 100 km from the epicenter, beyond which the effect is not much though some areas of liquefaction are found. It is found that liquefaction is prominent (maximum change) in the salt waste areas located to the north of the epicenter. Newly formed stream have been observed in many of the salt waste areas as a result of liquefaction. These salt waste areas which are having liquefaction effect are found in the Quaternary deposits. Every high or moderate effect of liquefaction is within 7 km from neotectonic fault or minor lineaments. This shows clear control of geology and tectonic elements on the pattern of changes. Most of the liquefaction effect is located to the north of the epicenter.

**Acknowledgments** The authors acknowledge here the help and the support extended by the Department of Geography, University of Pune, Pune. The satellite images used for the research are purchased for the funds allotted under Respond programme of the Indian Space Research Organization (ISRO) to the University of Pune. We are thankful to the ISRO for making funds available for research. The corresponding author was working as an assistant professor in the Department of Geography, University of Pune, and recently has joined the Department of Geography, University of Mumbai, Mumbai. Both the authors are thankful to the respective departments of both the Universities.

## References

- Alberga V (2009) Similarity measures of remotely sensed multi-sensor images for change detection applications. *Remote Sens I*. doi:[10.3390/rs1030122](https://doi.org/10.3390/rs1030122)
- Chavez PS Jr (1989) Radiometric calibration of landsat thematic mapper multispectral images. *Photogramm Eng Remote Sens* 55:1285–1294
- Dasgupta S, Pande P, Venkatraman NV, Narula PL, Dasgupta S, Iqbal Z, Banerjee J, Ganguly D, Sanyal K, Acharyya SK (eds) (2000) Seismotectonic atlas of India and its environs. Geological Survey of India
- Earthquake Engineering Research Institute (EERI) (2002) Bhuj, India earthquake of January 26, 2001. Reconnaissance Report Earthquake Spectra, vol 18, no. S1, pp 1–398
- Ekstrand S (1994) Assessment of forest damage with Landsat TM: correction for varying forest stand characteristics. *Remote Sens Environ* 47:291–302
- Huguenin RL, Karaska MA, Blaricom DV, Jensen JR (1997) Subpixel classification of bald cypress and tupelo gum tress in thematic mapper imagery. *Photogramm Eng Remote Sens* 63(6):717–725
- Jain SK, Murty CVR, Dayal U, Arlekar JN, Chaubey SK (2001) The republic day earthquake in the land of M. K. Gandhi, the father of the Nation. NICEE, EERI, IIT, Kanpur, Oakland
- Jakubauskas ME (1996) Thematic mapper characterization of Lodgepole pine seral stages in Yellowstone National Park, USA. *Remote Sens Environ* 56:118–132
- Lillesand TM, Kiefer RW (1987) Remote sensing and image interpretation. Wiley, New York
- McGee CA (2005) Detection of Bhuj earthquake liquefaction. <http://academic.emporia.edu/aberjame/student/mcgee1/finlproj.htm>
- Murty CVR, Greene M, Jain SK, Prasad NP, Mehta V (2005) Earthquake rebuilding in Gujarat, India, an EERI recovery reconnaissance report. Earthquake Engineering Research Institute, Oakland
- Seismo-watch (2001) Special Earthquake Report No: 01-002. <https://www.eeri.org/2001/01/bhuj/>

- Shaoqing Z, Lu X (2008) The comparative study of three methods of remote sensing image change detection. *The Internl. Archv. Of the Photogramm., Remote Sensing and Spatial Informn.Scis.*, Vol. XXXVII, part B7, Beijing
- Singh RP, Bhoi S, Sahoo AK, Kanwar R (2001) Changes in Ocean. *GIS @ Dev* 5:35–36
- Singh RP, Bhoi S, Sahoo AK (2002) Changes observed on land and ocean after Gujarat earthquake of January 26, 2001 using IRS data. *Intern J Remote Sens* 23(16):3123–3128
- Song C, Woodcock CE, Seto KC, Lenney MP, Macomber SA (2001) Classification and change detection using landsat TM data: when and how to correct atmospheric effects? *Remote Sens Environ* 75:230–244
- Spanner MA, Pierce LL, Peterson DL, Running SW (1990) Remote sensing of temperate coniferous forest leaf area index: the influence of canopy closure, understory vegetation and background reflectance. *Int J Remote Sens* 11(1):95–111