Surface manifestations after the Gujarat earthquake

Once again the myth about the Indian shield as a stable shield shattered the Indian geoscientific community after the Gujarat earthquake[1] of January 2001. This earthquake occurred far from the edge of the Indian Plate and quite close to the $M_s = 7.5$ earthquake[2] that occurred in 1819. The Gujarat earthquake caused severe damage and killed tens of thousands and left many more homeless. The Gujarat earthquake of 26 January 2001 generated intense shaking which was felt at about 70% of the region of India. The intense shaking brought out changes in the ocean and land surface. Singh *et al.*[3] have found significant changes in ocean parameters (chlorophyll and suspended sediment concentrations) after the earthquake. The present communication discusses the changes on land surface revealed from IRS-1D LISS-III remote sensing data.

IRS-1D, LISS-III digital data of numerous scenes prior and after the earthquake have been acquired from National Remote Sensing Agency, Hyderabad. Digital analyses of remote sensing data along various paths and rows have been carried out. The maximum surface manifestations have been found in the scene covered by row 90 and path 55, which was taken from detailed surface features extraction. The digital remote sensing data prior (4 January 2001) and after (29 January 2001) the earthquake were geo-referenced using topo-sheets and with the help of ground control points observed in the field using handy Global Positioning System (GPS). The FCC image of bands 4,2,1 prior and after the earthquake is shown in Figures 1 *a* and *b*, respectively. The comparison of two images shows significant surface manifestations. The band ratio of the two data sets (prior and after earthquakes) has been carried out. The band ratio image is shown in Figure 1 *c*. The band ratio image of band 4 (Figure 1 *c*) clearly brought out changes in surface features after the earthquake of 26 January 2001. Prominent surface manifestations, paleo-channel and water bodies are clearly seen in and around Rann of Kutch. The area where these manifestations are seen is covered by saline soil, which looks brighter in both the images (Figures 1 *a* and *b*). During

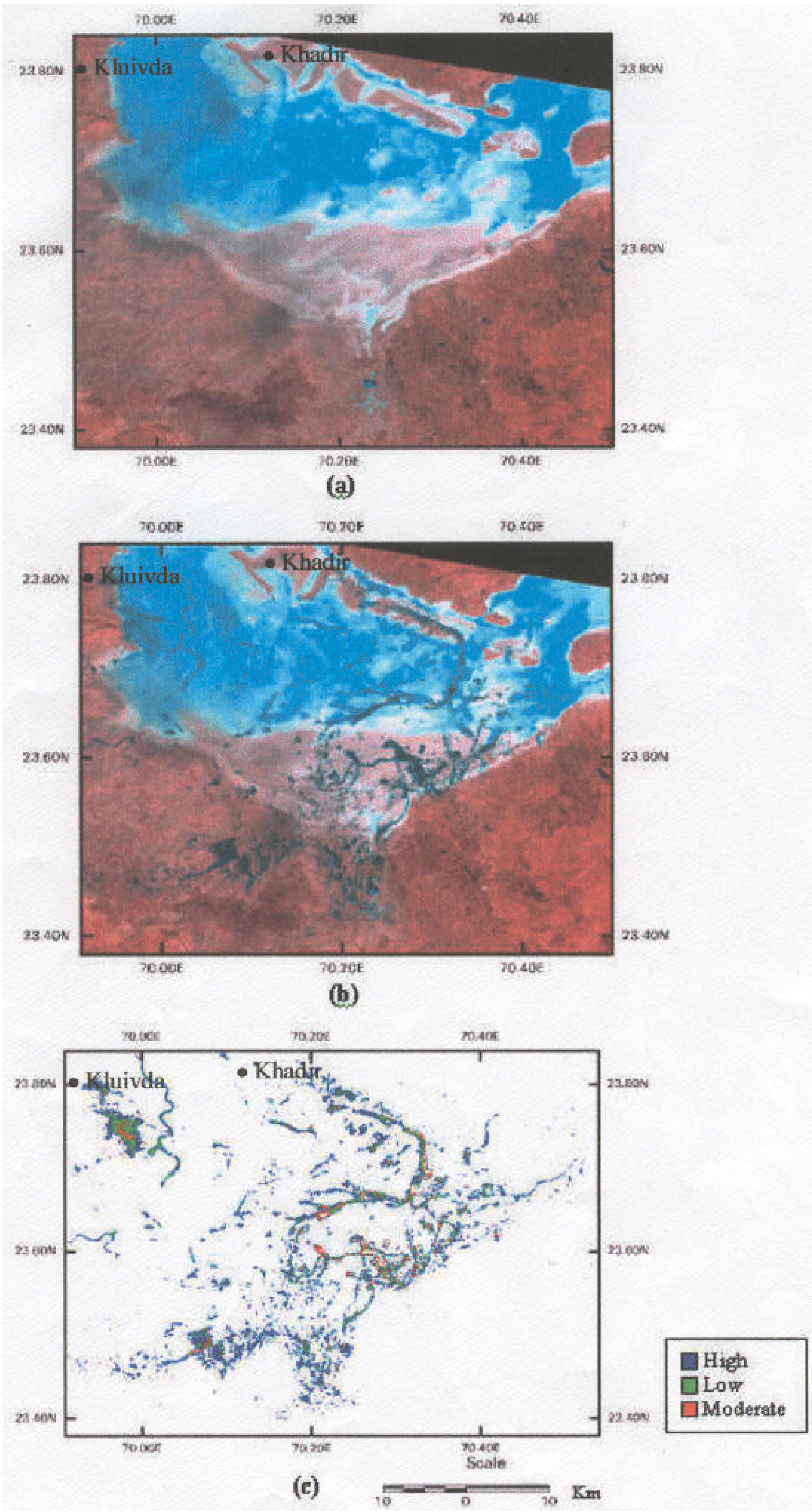

Figure 1. Surface manifestations in and around Rann of Kutch. (***a***), Pre- and (***b***) post-earthquake image of LISS-III FCC 4,2,1. (***c***) Ratio image of band 4 pre- and post-earthquake.

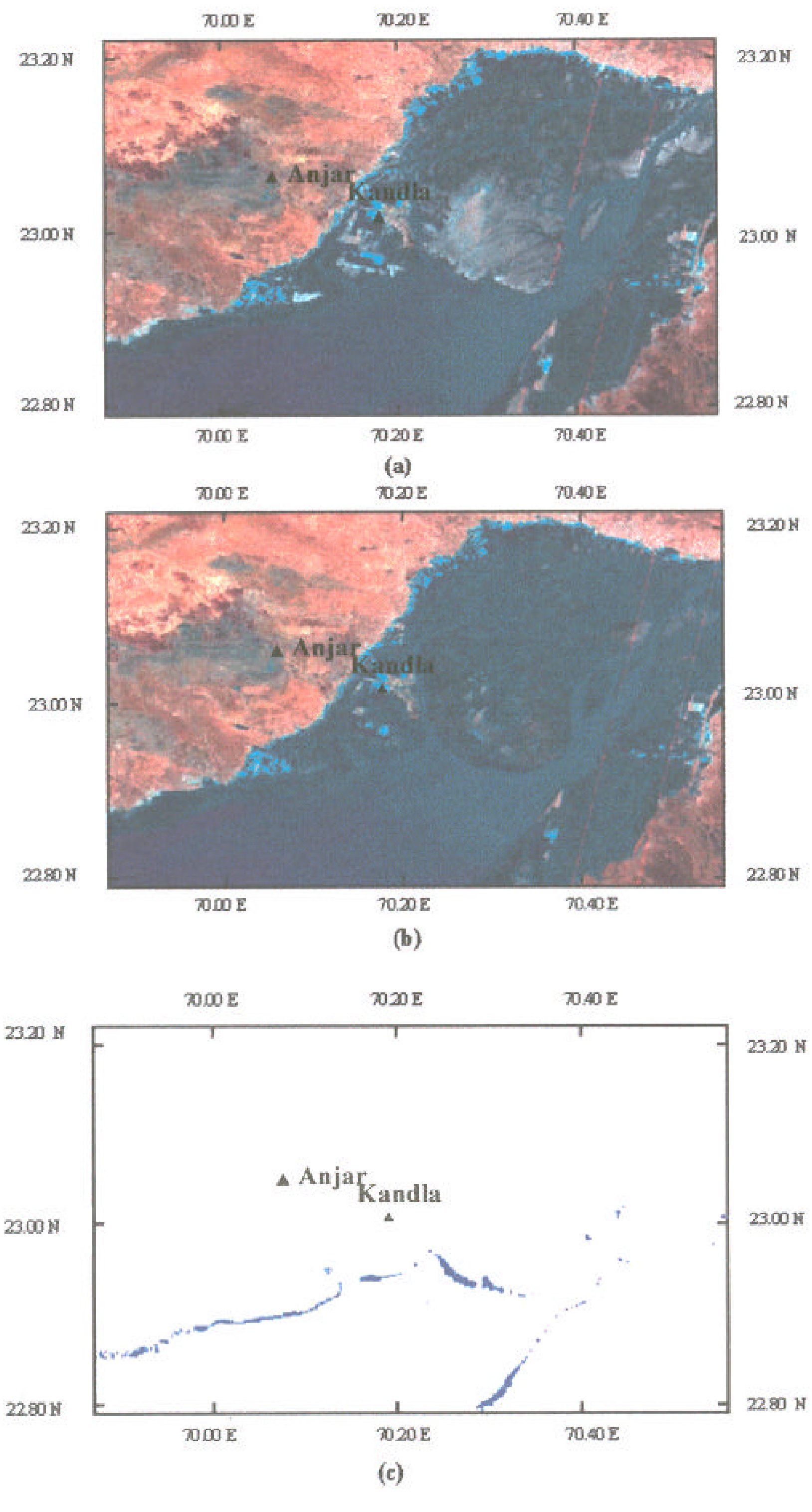

Figure 2. Surface manifestations in coastal region near Kandla port. (***a***) Pre- and (***b***) post-earthquake image of LISS-III FCC 4,2,1. (***c***) Ratio image of band 4 pre- and post-earthquake data.

our field visits after the earthquake, various surface features such as cracks, water logging, liquefaction and sand boils were seen in this region where the surface manifestations are clearly seen in the band ratio image (Figure 1 *c*). From various liquefaction sites, water samples were collected. The laboratory analysis of water samples shows high chloride concentration (more than 14.35 g/l) and salt content (more than 24.7 g/l) which ruled out any hope of potable water. At some sites water emerged as fountain up to 5 feet and remained up to 2 h.

The pre- and post-earthquake images around Kandla port are shown in Figure 2 *a* and *b*, respectively. A comparison of these images shows significant changes along the coastal region (Figure 2 *c*). Figure 2 *c* is the pre- and post-earthquake ratio image of band 4, which shows the changes along the coast (shown with blue colour) after the Gujarat earthquake. The changes show the emergence of land along the coastal region. The decrease in the brightness and tonal variations are also seen which show the increase of moisture in the coastal region. The increase of the moisture content is likely due to liquefaction, whereas the emergence of land along the coast region as shown in blue colour is plausible only when there is significant reduction in the tidal wave soon after the earthquake.

Figures 3 *a* and *b* show the tectonic lineaments, which have been extracted, from pre- and post-earthquake IRS-1D LISS-III remote sensing data. For extracting these lineaments, various image-processing operations have been carried out simultaneously on both the images. Operations include edge enhancement, high pass filtering, etc. With the help of toposheets, we have ignored the lineaments due to railway lines, roads, etc. and extracted only the tectonic lineaments representative of geological structures. The onscreen digitization of lineaments has been carried out, thereafter. The comparison of pre- (Figure 3 *a*) and post- (Figure 3 *b*) earthquake lineaments shows a series of new lineaments where significant surface manifestations are seen. The extensive field visits have revealed that the villages located over the lineaments have suffered either severe damage or total destruction. The comparison of pre- and post-earthquake images shows that in the northern region, the surface manifestations are related to the emergence of water bodies and paleo-channel with high water content. This may be palusible when the area may have subsided which is expected and this may be confirmed once aftershock data are available.

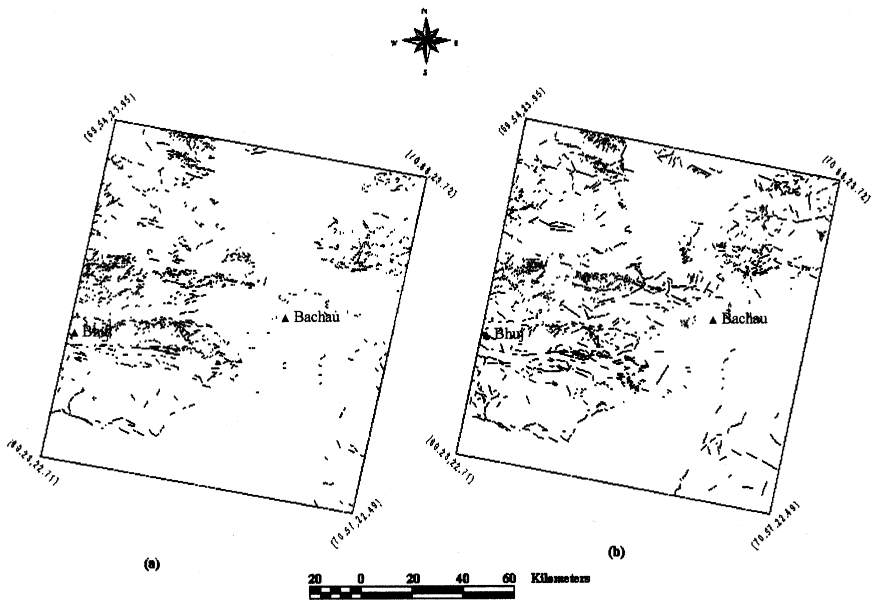

Figure 3. Lineaments map based on (***a***) pre- and (***b***) post-earthquake digital remote sensing LISS-III data after Gujarat earthquake of 26 January 2001.

The present results show the use of IRS-1D LISS III data in revealing changes on land and coastal region after the earthquake. The present results show the importance of the lineament map based on the remote sensing data. Such lineament maps based on remote sensing data should be used in the planning of construction, especially in seismic-prone areas. Such maps will also be useful in the microzonation of any region and also in evaluating highly seismic risk regions of the country.

1. Gaur, V. K., *Curr. Sci.*, 2001, **80**, 338–340.
2. http://cires.colorado.edu/~bilham/Gujarat 2001.html
3. Singh, R. P. *et al.*, *Curr. Sci.*, 2001, **80**, 1376–1377.

ACKNOWLEDGEMENTS. Financial support from DST is thankfully acknowledged. We thank the anonymous reviewers for their comments and suggestions. Our thanks to Dr B. C. Raymahashay for frutiful discussion. The help of Mr M. Girish Kumar in the analysis of water samples is thankfully acknowledged. We are grateful to Shri S. Adiga, Director, NMRMS-RRSC, ISRO Headquarter and Dr P. P. Nageshwara Rao, Head, RRSC Bangalore for their keen interest in this work.

RAMESH P. SINGH*,†
SANJEEB BHOI*
ALOK K. SAHOO*
UDAY RAJ**
SUDHA RAVINDRANATH**

Department of Civil Engineering, Indian Institute of Technology, Kanpur 208 016, India
***Regional Remote Sensing Center, Bangalore, India*
†For correspondence.
e-mail: ramesh@iitk.ac.in