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Cover

Changes observed in land and ocean after Gujarat earthquake of 26 January 2001 using IRS data

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The Gujarat earthquake of 1819 in north-west India is considered, with magnitude $M = 7.5$, as a major intraplate event, ranking second in magnitude only to the 1811–12 New Madrid earthquakes (Rajendran and Rajendran 2001). The 1819 earthquake resulted in the formation of a 6–9 m high alluvial scarp (with gentle northward dip) trending approximately east–west for about 80–90 km, known as Allah Bund (Mallik *et al.* 2000). The earthquake of similar magnitude (7.1 body wave magnitude, 7.5 on the surface wave) which occurred on 26 January 2001 in this region killed 19 727 people, injured 166 000, made 600 000 homeless, destroyed 348 000 houses, damaged 844 000 houses, and people living in 70% of India felt intense shaking.

Multisensors (IRS-P4-Ocean Colour Monitor (OCM) and IRS-1D-LISS-III) and multidate remote sensing data of Indian satellites were acquired from the National Remote Sensing Agency, Hyderabad, India. Using multisensors and multidate data, changes in ocean parameters and land features have been studied after the Gujarat earthquake.

Figure 1 and cover shows the FCC image of bands 3, 2 and 1 of IRS-1D-LISS-III data after the earthquake of 26 January 2001 with the epicentres determined by IMD, New Delhi, US Geological Survey (USGS) and ERI, Japan. A maximum intensity (EERI 2001) of MSK X (shown by dotted line) has been estimated over an east–northwesterly elongated zone of approximately 2100 km^2. In this elongated zone most of the villages are found to have suffered total destruction. Numerous ground deformations representing the presence of fissures, fractures and ruptures and also excessive liquefaction after the earthquake are seen in the satellite image and have also been observed in this field. In the image, the brighter white features represent Runn of Kutch where prominent surface manifestations, palaeo-channel (blue) and waterbodies (blue patches) are clearly seen after the earthquake (figure 1). The area where these manifestations are seen is covered by saline soil, which looks brighter. The water samples were collected from intense liquefaction sites. The

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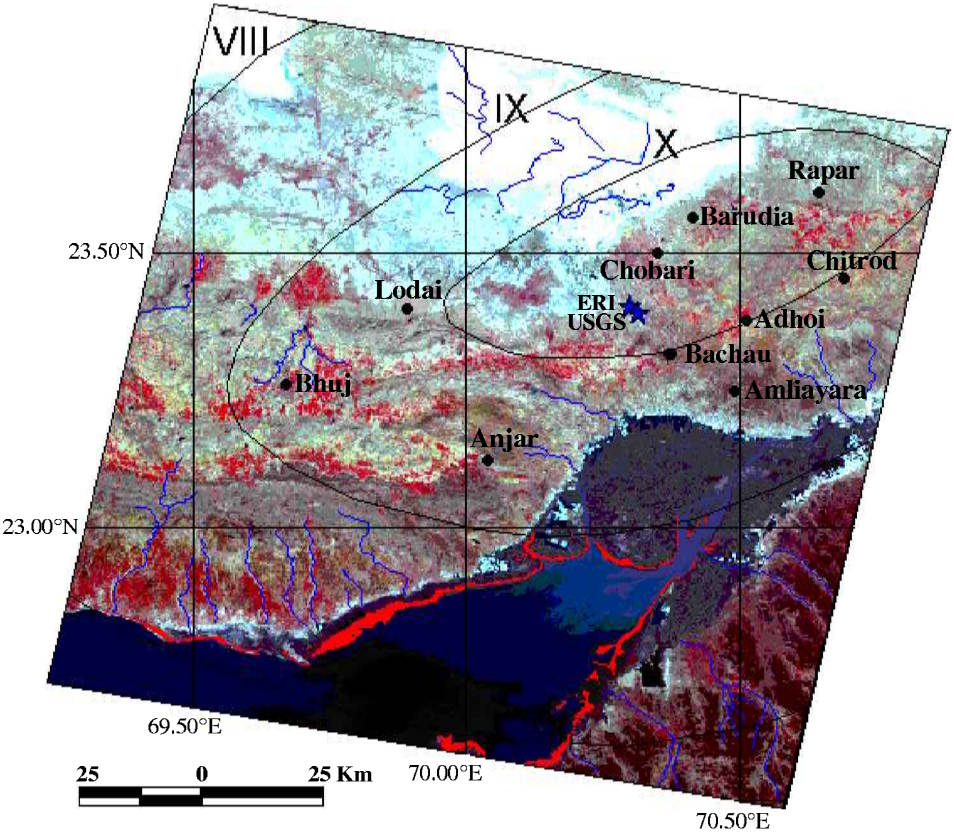

Figure 1. IRS-1D-LISS-III image after Gujarat earthquake showing the changes in land features, MSK isoseismals and epicentres determined by IMD, New Delhi, USGS and ERI, Japan.

laboratory analysis of water samples is found to be highly saline. In the FCC image of IRS-1D-LISS-III data after the earthquake, the emergence of a palaeo-channel is seen in the northern part of the Runn of Kutch (figure 1). A comparison of pre- and post-earthquake images around Kandla port shows significant changes along the coastal region. The emergence of land after the earthquake is shown by a thick red line along the coast (in the creek area of figure 1). This phenomenon occurs only when there is significant reduction in the tidal wave soon after the earthquake, which was not possible to confirm since the tidal height data measured at Kandla port were not available after the earthquake.

The maximum changes in land features have been found in the scene covered by row 90 path 55, which was taken for detailed surface features extraction. The digital remote sensing data prior to (4 January 2001) and after (29 January 2001) the earthquake were georeferenced using toposheets and with the help of ground control points observed in the field using hand-held Global Positioning System (GPS) apparatus. The FCC image of bands 3, 2 and 1 prior to and after the earthquake are shown in figure 2(*a*) and (*b*), respectively. Comparison of the two images shows changes in land features. The band ratioing image of the two datasets (pre- and post-earthquake)

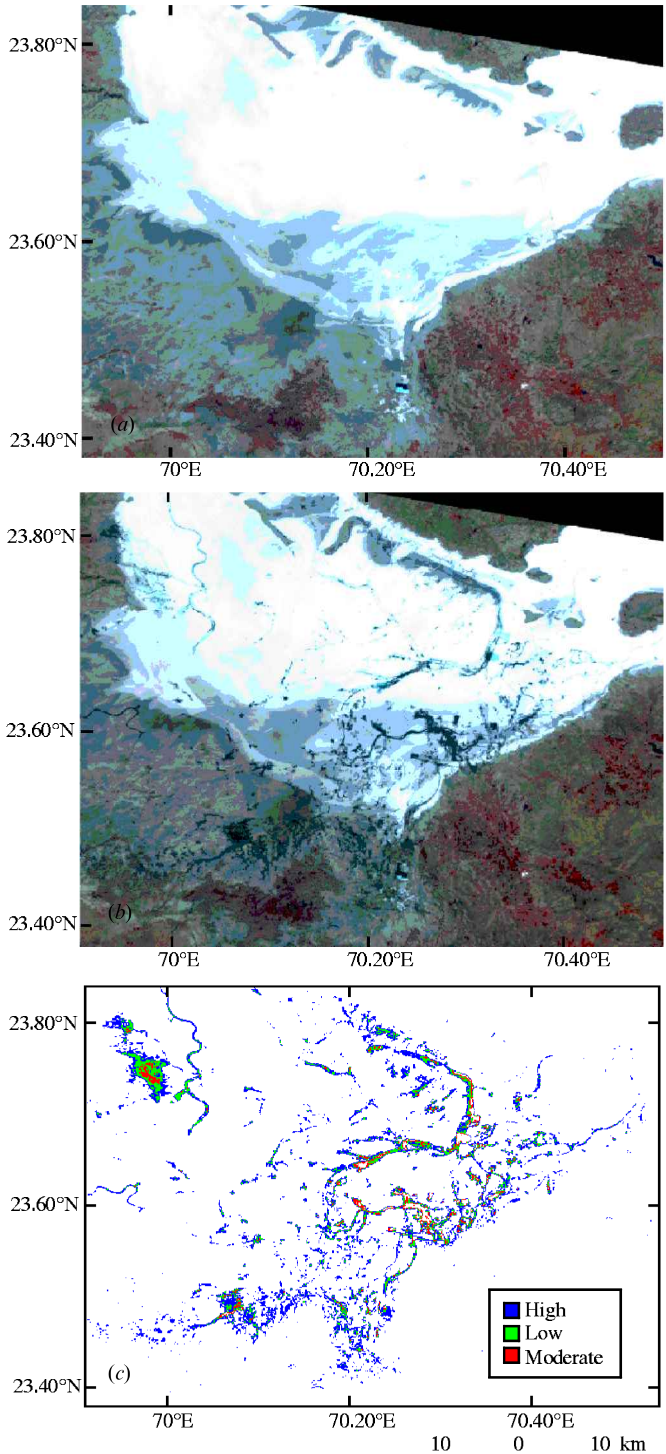

Figure 2. FCC image of bands 3, 2 and 1 of IRS-1D-LISS-III: (*a*) prior to Gujarat earthquake (4 January 2001); (*b*) after Gujarat earthquake (29 January 2001). (*c*) Band ratioing image of band 4.

is shown in figure 2(*c*). The band ratioing image of band 4 (figure 2(*c*) clearly shows changes in land features after the earthquake of 26 January 2001. During our field visits to this after the earthquake, various land features such as cracks, waterlogging, liquefaction and sand boils were seen corresponding to the features depicted in the band ratioing image (figure 2(*c*). From various liquefaction sites water samples were collected, analysis of which showed highly saline water. At some sites water emerged as a fountain for about 2 h to a maximum height of 150 cm.

The chlorophyll (Ch1) and suspended sediment concentrations have been estimated using IRS-P4-OCM digital data. IRS-P4 Oceansat, the first in a series of operational ocean remote satellites, was launched on 26 May 1999. The OCM sensor records in eight bands at visible and near-infrared wavelengths. The field of view of the optics is 43°, providing a swathe of 1420 km from an altitude of 720 km (Chauhan *et al.* 2000). The digital data for IRS-P4 OCM of path 9 row 13 for 18 January 2001 (prior to the earthquake) and for the same path for 26 January 2001 (a few hours after the earthquake) and 3 February 2001 (about a week after the earthquake) have been analysed. The three datasets were corrected for atmospheric effects using an approach suggested by Doerffer (1992). From the atmospheric corrected images, Chl and suspended concentrations were estimated for ocean water. The details of the algorithms used and the processing of data are discussed by Kundu *et al.* (2001). Chlorophyll distribution in the ocean adjoining Gujarat prior to (figure 3(*a*), soon after (figure 3(*b*) and about a week after (figure 3(*c*) the Gujarat earthquake is shown. Comparison of these images shows significant increase in Chl concentration just after the earthquake (figure 3(*b*), and one week after the earthquake the Chl concentration is found to be similar. A similar increase is also found in suspended sediment concentrations. The significant change in Chl (figure 3(*b*) and suspended sediment concentrations are clearly seen in the creek regions of the Gujarat coast and along the west coast. The significant increase in Chl suspended sediment concentrations after the earthquake can be attributed to the upwelling of subsurface water and vertical mixing (Singh *et al.* 2001). The upwelling of subsurface water is generally observed to result from an increase in ocean surface temperature; however, the sudden upwelling of the ocean is probably due to the intense ground-shaking after the Gujarat earthquake, leading to ocean waves and coastal surf. An increase in the ocean's productivity is well known to result from upwelling and productivity therefore increases from January to February as the temperature increases. The increase of suspended sediments may be due to the intense shaking. The high concentration of Chl, together with high ocean surface temperature, are favourable conditions for fish catch. The ocean surface temperature pre- and post-earthquake was not available; however, the fish catch data available from the Fisheries Department of Daman (Union Territory) showed a sudden increase in the fish catch soon after the earthquake. Upwelling caused by the increase in temperature from December to January and February normally increases the fish catch by 20%. However, the significant increase in the fish catch in February after the earthquake is found to be double that figure, which supports our results showing an increase of Chl concentration around the Gujarat coast and along the western coast of India after the earthquake of 26 January 2001 (Singh *et al.* 2001).

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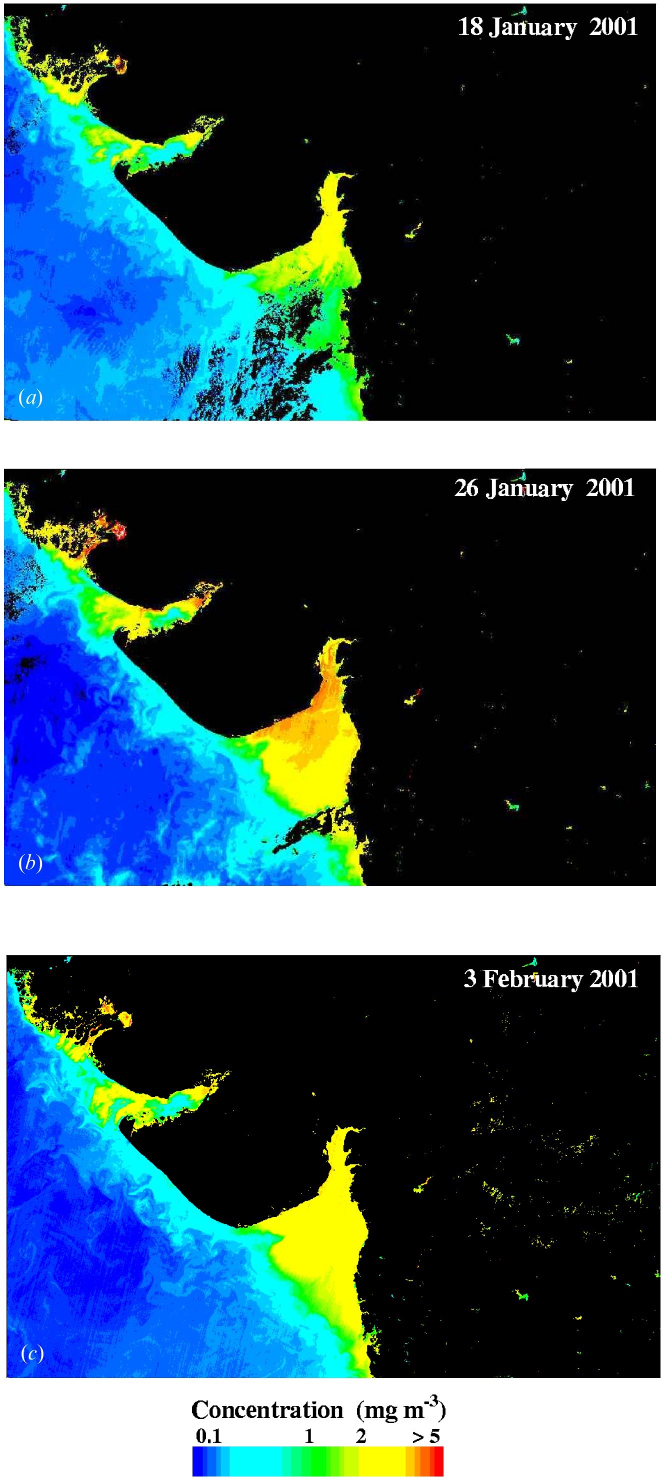

Figure 3. Chlorophyll distribution image around the Gujarat coast: (*a*) 18 January 2001; (*b*) 26 January 2001; and (*c*) 3 February 2001.

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