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Kachchh (India) earthquake 2001—causes, severity and impact on groundwater resources

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Abstract: Earthquake 2001 in Bhuj region of Kachchh district of Gujarat (India) was one of the most devastating earthquakes in the Indian history. This earthquake has caused severe damage to human life and properties. The impact of earthquake on groundwater resources at many locations was significant. Steep rise in static water level due to earthquake was observed at Bhachau and Chandarani. At other location groundwater followed the declining trend.

Keywords: earthquake; geology; groundwater; Bhuj, Kachchh

Introduction

Well authenticated generalization is that the majority of the Indian earthquakes have originated from the Great Plains of India or from the peripheral mountain range to their north, west and east. Kachchh region falls within the great earthquake belt which traverses the earth from east to west extending approximately 250 km and 150 km (north-south) and is flanked by Nagar Parkar Fault in the north and Kathiawar fault in the south (Fig. 1). Portion bounded between these two faults is the reflection of movements along the major E-W longitudinal faults viz. Katrol hill fault, Kachchh mainland fault, Banni fault, Island fault and the Allah bund fault (Biswas, 1987). Due to these faults the Kachchh region has experienced several episodes of earth movements comprising an assemblage of various techtogenitic geomorphic features.

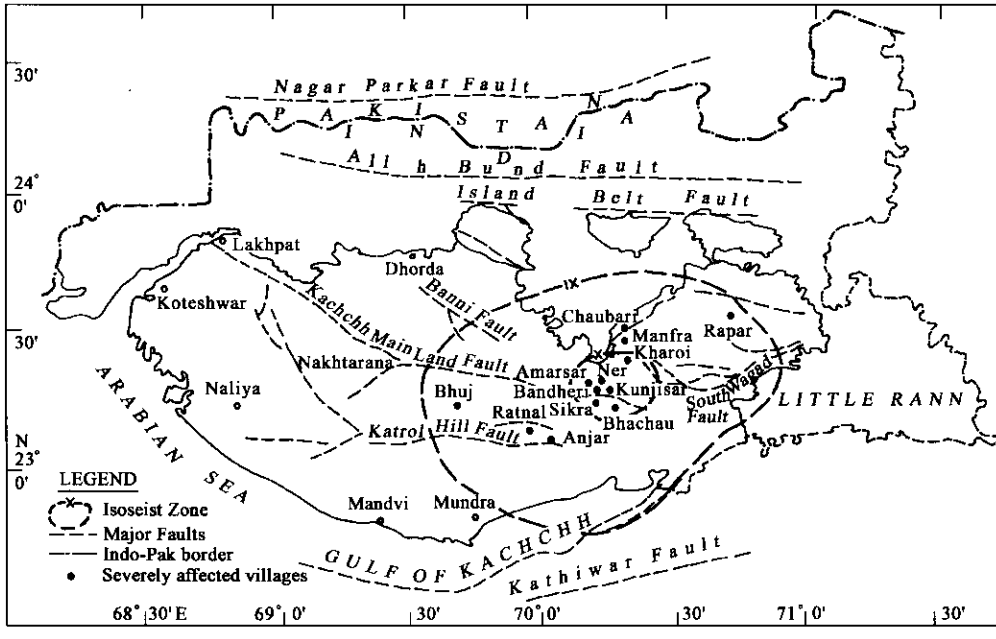


Fig. 1 Area affected by earthquake 2001, Kachchh district

Kachchh region along with the Himalaya and northeast India are seismically the most active regions in

India. About 74 earthquakes have been recorded in last 200 years in India, out of which 18 earthquakes have occurred in the Kachchh region. Among these the Allah bund fault earthquake of June 16, 1819 and the Anjar earthquake of July 21, 1956 were the major having the magnitude as 7.7 and 7, respectively. The other major earthquakes in India in the past are: 1897 Shillong earthquake(M 8.7), 1905 Kangra earthquake(M 8.6), 1934 Bihar-Nepal earthquake(M 8.3) and 1950 India-China border(i.e. Assam) earthquake(M 8.7)—all falling along the Himalayan belt and in north-east India(Gupta, 2001).

After a period of relative quiescence lasting almost 45 years a large portion of Gujarat State was shocked by severe earthquake during the morning hours of January 26, 2001, the very first republic day of the twenty first century. This episode was affected by a renewal of seismic activity in Bhuj area of Kachchh district along the Kachchh main land fault that has been identified as one of the active faults of the region and is said to be a reverse fault having structural displacement of about 2 - 3 km(Karanth, 2001). In continuation to this fault another fault in the eastern fringe is the south wagad fault that has also the main role of deformation in this region. This episode was the most devasting natural calamity affecting vast area of Gujarat with severe destruction in Bhuj, Anjar, Bhachau and Rapar talukas of Kachchh district causing great loss of life, extensive damage to the property, leaving thousands of the people maimed, battered and broken. The present paper discusses the causes, severity of this earthquake and its impact on groundwater resources.

1 Location and environment

Kachchh is the largest district having a crescent shaped landmass located in the north-western parts of Gujarat State with an area of 45652 km^2 covering 24 percent area of the state. It stretches between longitudes 68°09′46″E to 71°54′47″E with its width between latitudes 22°14′11″N to 24°41′25″N. The major part is barren, rocky and devoid of vegetation, having hill ranges and isolated peaks, rugged and deeply cut river beds, cultivated valleys and rich pasture lands. The great Rann of Kachchh and the little Rann, occupying 60 percent of the district area have marshy tidal flats and the saline waste composed of salts and sand with clay. The landmass is sloping towards the great Rann in the north and the little Rann, the gulf of Kachchh and the Arabian Sea in the southeastern, south and western sides.

The environment is very fragile and the resources are scarce and are in degraded state. The normal annual rainfall varies from 342.4 mm at Bhuj in the central part to 451.9 mm at Naliya in the western part. The mean annual rainfall is relatively higher along the eastern fringe following southwestern and southern coastal belt from where it decreases gradually inland. The rainfall is erratic with extreme temperature upto 47.8℃ in summers while the winter temperature drops to 0℃. It has an arid climate with a mean moisture index of -79.0 and high rates of evaporation.

Due to the setting of faults and environment of the Kachchh district, natural calamities like droughts and earthquakes are regular and enormous which tends the situation more precarious. The district had 36 droughts during the last 90 years of which 13 were severe and experienced at least 18 episodes of earth movement. The 2001 earthquake is the second major earthquake after June 1819, which created an 80 km long fault scrap on Allah Bund fault uplifted at its crest by 6.5 m. Known as the first major intercontinental earthquake for which crystal deformation was quantified(Oldham, 1898).

2 Geology

The basement rocks of Kachchh area include the Precambrian granite and ryolite which are overlain by a cobble-conglomerate containing cobbles of granite and arkoses in the great Rann of Kachchh and the probable source of disturbance lay in the fractured zone of the crust underneath a geosynclinal depression towards the great Rann following the pre-Mesozoic basinal configuration producing the Primordial fault pattern in the Precambrian basement(Biswas, 1968). As such the sedimentary sequence of Jurassic to

cretaceous formation developed under marine to estuarine condition during early Mesozoic period are witnessed in Kachchh mainland area.

The Mesozoics includes the rocks of Pachham, Chari, Katrol, Umia, Bhuj and Wagad series(Fig. 2). The Pachham series were deposited in a transgress shallow area and are exposed in Patcham, Bela and Khadir islands, whereas the Umia, Katrol and Chari series were deposited under brackish environment with marine incursions followed by Bhuj series. The Chari and the Katrol series are the oldest and are composed of yellow-greenish-calcareous sandstone with gypseous shale whereas the Umia and Bhuj series are composed of coarse grained sandstone, silty shale and siltstone. These are overlain by Deccan Trap Basalt of upper cretaceous period. The earthquake area is covered by Umia and Bhuj series composed of variegated soft sandstone with minor sandy shales and clays. In Bhachau and Rapar area Wagad series equivalent to Bhuj series consist of coarse grained friable, cross-bedded sandstone with shale were noticed. The semi consolidated Pleistocene sediments composed of alluvium usually occupy the southern coastal belt of Mandvi and Mundra area. However, area covered by villages Amarsar, Ner and Bandheri along with the agricultural fields of Chobari, Manfra, Kharoi and Kunjisar are adjoining the marshy tidal flats and saline waste of alluvium with the basement rocks of Umia, Bhuj and Wagad series which produce the lateritised incurstation spouting the lateritic water(Surendra, 1996).

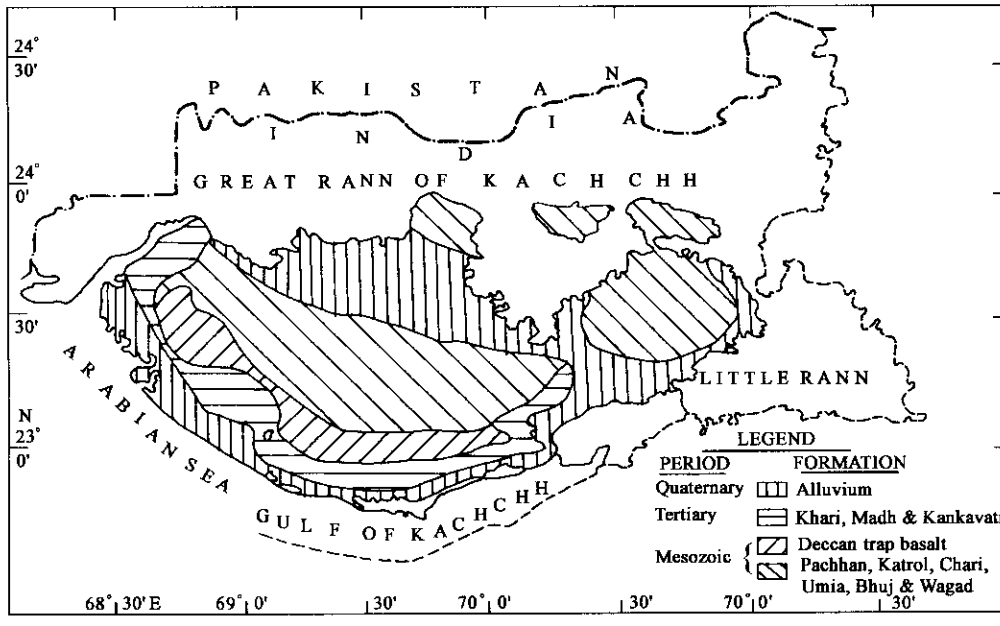


Fig.2 Geology, Kachchh district

3 Results and discussion

3.1 Severity of earthquake

The shocks were felt with exceptional violence along Chobari-Kunjsar-Bhachau-Ratnal-Anjar track on the epifocal tract falling in isoseist intensity X of Medvedev-Sponheuer Karnik sacle(MSK-64) and lies in zone V of Seismic zonation map of India(Jai, 1992) having the magnitude of 7.6(Yagi, 2001) computing depth of origin(i.e. focus) at 10 km with the velocity of the earth waves as about 3 km per second.

The epicenter was at about 30 km northeast of Bhuj in Lodai Village. However, after conducting observations of ground deformation ruptures, fissures and cracks along the Kachchh main land faults and

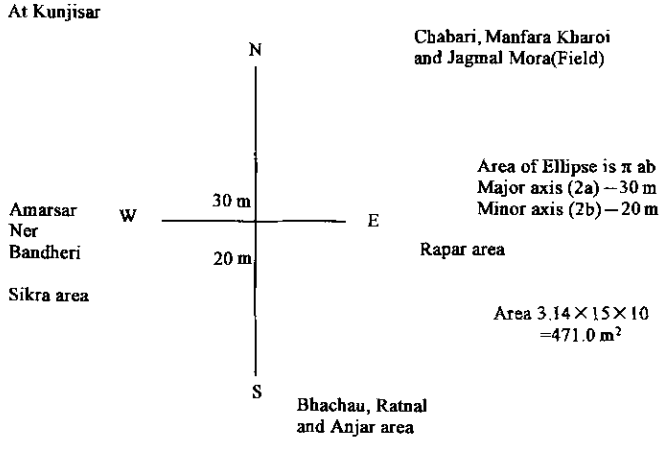
south wagad fault numerous foci or centers of disturbances have been observed at Amarsar, Ner, Bandheri, Kunjisar, Bhachau and Chobari villages extending upto Adhoi and Rapar in the east within the zone of 20 km. N-S following the approach roads towards Bhuj, Bhachau and Rapar. Large craters, cone shaped vents have been observed which have been formed due to gushing fluids through intense shaking giving rise to the liquification and saltincrustation of underground sediments with lateritic water in the agricultural fields as well as in the Rann areas of Lakhara and Lakhaba.

The main shock was sudden followed by after shocks of moderate to slight intensity which succeeded for weeks and months. Geological effects were not very marked out but number of landslips and rock falls were noticed and the villages Chobari, Kharoi, Manfra, Kunjisar, Bhachau, Amarsar, Ner, Bhanderi, Sikra, Rapar, Anjar and Ratnal were in ruins within a short while. According to government of Gujarat report of March 2001, this episode took a total of 20072 human lives, killed 21551 cattles and inflicted various grades of damage to about 10.8 lakh houses in 7904 villages(Shankar, 2001). Ground deformity, ruptures and damage to infrastructures are more severe in eastern side of Bhuj than towards the western side.

3.2 Impact on ground surface and ground water

The area shaken encompassed over 45652 km^2 in an ellipse stretching N-S from Chobari to Anjar through Bhachau. The main shock was followed by a large number of after shocks. These shocks originated in a large number of shifting foci scattered over the main epicentral tract in a fitful manner(Fig. 1). Geologically the area witnessed the concomitant structural changes on the ground surface viz. fractures and cracks, wide gapping earth fissures opened out in particular directions in the alluvial plains from which innumerable jets of yellow lateritic water with sand like fountains spouting upto 1 - 3 metres in the air through cone shaped vents, open wells were ridged up and filled by the outpouring sand collapsing the dug/dug-cum-bore wells/tube wells.

During the course of investigations at Kunjisar in a field located at 23°22′33″/70°20′40″ (GPS reading) the signature of earthquake have been noticed in the elliptical shape with major axis(N-S) as 30 m and minor axis(E.W) as 20 m, covering an area of 471.0 m^2.



At the elliptical circumference the cracks with craters and cone shaped vents were observed from which saline water as well as lateritic water spread out showing salt and lateritised incrustation. Craters and cone shaped vents have 15 to 30 cm depth and 5 to 8 cm width. Continued cracks are seen in the adjoining fields toward W-NW direction upto Amarsar, Ner and Bandheri villages having 17 to 20 m length 20 to 75 cm wide and 1 to 2 m deep in the saline alluvial plain area. Severe impact of earthquake on settlement and

infrastructure has been observed in Kunjisar Village. It is continued north of Kunjisar covering Kharoi, Manfra and Chobari villages. In west Amarsar, Ner, Bandheri, Sikra, Amarpur, Dhudhai, Lakhara villages in south Bhachau, Ratnal, Anjar villages and in east Rapar area upto Adhoi are affected severely.

At Chobari in Jagmalmora i.e. field 7 km west of Chobari Village widespread range of cracks were seen 100 to 112 m long, 15 to 20 cm wide and 1 to 2.20 m deep in about one km^2 area. One 112 m long fissure was observed trendy W-E from which lateritic water spread out in the field. Cone shaped vents and craters with 15 cm subsidence have been noticed. In SE of Kunjisar i.e. Bhachau, Adhoi area upto Ratnal and Anjar villages are totally smashed out effecting the damage to agriculture too.

In all 16 dug wells as well as dug cum bore wells were observed for ground water conditions/variation from different hydrogeological units i.e. acquifer comprising sandstone and alluvium(Table 1).

Table 1 Variation on depth to water and EC in earthquake affected area

Village	Depth to water, m			EC, dSm^{-1}		Aquifer
	2001	1988—89	Variation	2001	1988—89	
Chobari	81—84	34.40	Fall	1.09	4.90	Sandstone
Manfara	84	18.30	Fall	2.80	1.90	-do-
Kharoi	14.20	12.30	Fall	0.92	1.75	-do-
Kunjisar	7.60	-		2.54	-	-do-
Sikra	25.40	20.5	Fall	2.41	-	-do-
Bhachau	11.40	24.0	Rise	5.19	3.50	-do-
Dudhai	74.50		-	3.12	-	-do-
Ratnal	61.20	37.8	Fall	0.94		-do-
Chandrani	26.20	35.4	Rise	2.22	-	-do-
Naranpur	90.00	17.69	Fall	1.08	-	-do-
Sarli	45.00	21.60	Fall	1.14	6.90	-do-
Jhura	32.80			6.70		-do-
Nainchirai	11.20	9.00	Fall	5.39	6.90	Alluvium
Mithi Rohar	11.60	6.50	Fall	4.43	9.90	-do-
Kotri	21.5	-		2.30	-	-do-
Bara	59.5	-		6.70		-do-
Bandheri*	1.6	-	-	11.80		-do-

* Well is situated at the periphery of Nadi.

In the sandstone aquifer the depth to water ranges between 7.6 (Kunjisar) to 84.0 m (Manfra-Chobari) covering severely damaged area in northeast of Bhuj with electrical conductivity varying from 0.9 dSm^{-1} (Kharoi) to 5.18 dSm^{-1} (Bachau). Whereas, at partly damaged Jhura Village located in northwest of Bhuj, the depth to water has been observed at 32.80 m having EC 6.7 dSm^{-1}. Besides, a spring has been noticed 2.5 km south of Jhura at sodacamp situated in intermontain valley at 23°24′06″/69°36′25″ (GPS reading). The water was still coming out having EC 6 dSm^{-1}. The area is covered by ferruginous sandstone exposures. South of Bhuj on Mandvi road the depth to water varies from 45.00 m (Sarli) to 90.00 m(Naranpur) with EC ranging 1 to 1.14 dSm^{-1}. This area is covered by ferruginous sandstone exposures. In alluvium aquifer depth to water varies from 11.20 m(Nanichirai) to 59.5 m(Bara) with EC ranging 2.3 dSm^{-1} to 6.7 dSm^{-1} except at Bandheri where EC has been observed 11.80 dSm^{-1} with depth to water 1.60 m.

The depth to water during 1988(Anonymous, 1996) has been compared with data collected after the earthquake 2001 in severely affected area covering Kunjisar, Kharoi, Manfra, Chobari, Sikra, Bhachau and Dudhai villages in north-eastern part of Bhuj. It has been observed that the fall in depth to water between 1988 and 2001 has ranged to the order of 2 m to 45 m bgl except at Bhachau where rise in depth

to water of about 13 m bgl is observed. At another location covering Amredi-Chandrani area rise in depth to water is 9 m bgl. In south the fall in depth to water ranges between 23—72 m bgl.

While comparing the quality of groundwater the electrical conductivity ranges between 1.75 to 6.90 dSm^{-1} (1988—1989) whereas in 2001 it varies from 0.92 to 6.70 dSm^{-1} in sandstone aquifer. In alluvium aquifer quality of groundwater is ranging between 6.90 to 9.90 dSm^{-1} (1988—1989) than 2.30 to 6.7 dSm^{-1} (2001) except at Bandheri where it is 11.80 dSm^{-1}.

Due to wide scale eruption of salty water major part of the Great Rann area have been covered with sheet of saltincrustation in Lakhara Rann and between Umedpur to Lakhaba Rann which is at 9 km north of Lodai Village. At Lakhara Rann craters and cone shaped holes along the cracks are observed. Cracks are seen in meander shape with one feet subsidence. The salty water spouted at Lakhaba rann and spread over towards Khangarpur to Dharampura area as surface water has the EC ranging 32 to 377 dSm^{-1} which is just brine solution.

4 Conclusions

Based on intensive ground deformation as well as damage to the infrastructure, life and property it is inferred that the seismic activity was more severe in isoseist intensity zone X on Kachchh main land fault stretching upto Bhachau. Therefore, epicentre consist of bunching of foci covering Amarsar, Ner, Bhanderi, Bhachau and Sikra villages followed by isoseist intensity zone IX covering Bhuj, Ratnal, Anjar, Rapar, Chobari and Lodai villages of Kachchh district. At many locations groundwater has been severely effected due to devastating earthquakes.

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