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Geophysical Evidences for Palaeochannels and Possible Sources of Groundwater: A Case Study from Kachchh Region, Western Peninsular India

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Abstract

Palaeochannels are potential source of groundwater and mineral deposits. To exploit such resources, identification and mapping of palaeochannels using multi-disciplinary techniques are needed. In present study high resolution satellite data, geological investigation, rainfall/humidity/discharge data analysis, time domain electromagnetic methods (TDEM) and multichannel analysis of surface waves (MASW) have been used to investigate possible source of ground water. Satellite data (LANDSAT and ASTER) were also analysed visually and digitally to recognize the exposed and buried palaeochannels. Image processing techniques such as linear enhancements, fusion, and hill shading of the DEM have been used for better identification of palaeochannels. Existence of the identified palaeochannels was verified by field checks. Integrated geophysical investigation through TDEM and MASW in the paleochannel of Khari River shows presence of water saturated rocks below 20 m near Bhuj. Rainfall/humidity and discharge data of 1991 to 2013 show increase of surface discharge and subsurface water level. From the well log analysis it is inferred that the possible ground water depth of central Kachchh is ~ 50 m near Nakhatrana; ~40 m (near Bhuj), ~20 m near Anjar, whereas stations in the eastern Kachchh show ground water depth ~30 m for Gandhidham, Bhachau and Rapar areas. However the coastal region shows possibility of ground water at ~ 9 m. The depth of potable water in a few paleochannels has been estimated through the TDEM surveys.

Keywords: Palaeochannels, rainfall, Kachchh, electromagnetic surveys, seismic surveys

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1. Introduction

The word palaeochannel comes from the word "Palaeo" means "old", so palaeochannel means old channel (Sinha et al. 2006). Palaeochannels appear as linear or curvilinear on Remote Sensing data products. Palaeochannels can store and transmit ground water. So, it can be a source of water and can be used to trace the ground water flow.

Water is distributed over two-third part of the earth's surface, but non-uniformly. It is in the form of solid (ice), liquid (water) or gas (vapour). With the progress of civilization human community have tried to utilize the surface and ground water resources whenever and wherever available. Over time, for use in domestic, industrial and agricultural requirements there has been heavy reliance on groundwater resources to supplement surface freshwater supplies. Groundwater resources are preferable to surface water resources for less pollution and dependability during drought periods. Further, arid or semi-arid regions and dessert areas like Rann of Kachchh in Gujarat don't have enough surface water sources. In these regions people have to depend on ground water sources, so the rate of extraction of water increases, which lowers the ground water table. In such regions the palaeochannels can be used as drought proofing measure.

Depending upon the nature and shape, the palaeochannels are grouped into three catagories viz. (a) older river channels which were buried due to sedimentation. (b) remnant scars of shifting rivers, and (c) the streams or rivers which were flowing either ephemeral or perennial during past but now are lost either due to tectonic activities, climatic changes or geomorphic activities. Paleochannels developed during climatic changes such as heavy rains will generate huge sediment flux in the form of hyper concentrated sediment flow during high energy condition. These sediments contain huge amount of angular to sub-angular and sub-rounded gravels deposited in the course of channel and allow migration of a river. In case of tectonic forcing (uplift) in hard rock area if a river migrates from one place to another, a bedrock spur may form between the paleochannel and main river course.

2. Generalized Geology of Kachchh

Kachchh basin is in intraplate region of rifted Precambrian craton in northwestern India. The basin is characterized by a thick succession of sedimentary rocks of middle Jurassic to Holocene that overlie the Precambrian basement. Jurassic rocks are richly fossiliferous (Merh, 1995). There are 2 to 3 km of Mesozoic and 1 km of Tertiary sediments (Chopra et al., 2010). The main structural features that have played vital role in the geological evolution of Kachchh include a group of E-W trending 'uplifts' (highland and 'island') surrounded by a residual depression (plains of the great and the little Rann). Six major uplifts namely Pachcham, Khadir and Bela islands, Chorar hills, Wagad highland and Kachchh Mainland occur along three sub-parallel E-W fault lines (Fig. 1). All the major uplifts are bounded at least on one side by a fault and monoclinal flexures on the other side by gently dipping peripheral plains (Merh, 1995). The E-W faults from north to south are: (1) Nagar Parkar fault (NPF) (2) Island Belt fault (IBF) to the north of the Pachcham - Khadir- Bela islands and (3) Kachchh mainland fault (KMF) in the middle of the basin. The Mesozoic rocks ranging from Middle Jurassic to Lower Cretaceous occur conspicuously in various major uplifts, and exposed extensively in the Kachchh Mainland, Wagad, the islands of Pachcham, Bela and Khadir and the Chorar hills. The Tertiary rocks are exposed along the coastal belt of southern and western Kachchh bordering the Mesozoic rocks. These also occur in the periphery of 'islands' of Pachcham, Khadir, Bela and Wagad surrounding the Tertiary rocks (Merh 1995).

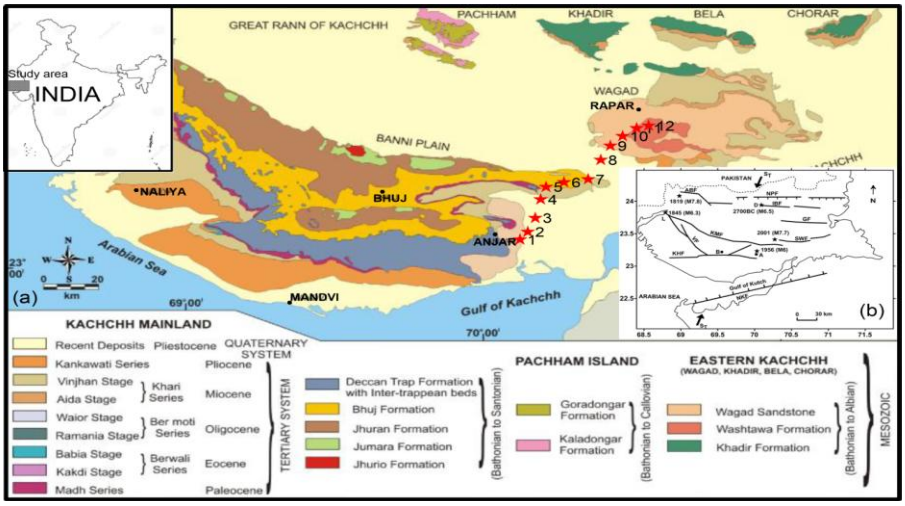

Figure 1. Geological map of the Kachchh region showing major geological formations (modified after Biswas and Deshpande, 1970) Note: red stars indicates locations of the TDEM sites, inset shows major faults in the Kachchh region.

Kachchh district of Gujarat is a water scarce region and ground water has become one of the important sources to meet the water requirements of various sectors. However, Tertiary and Mesozoic formations, present in the area, in general do not form promising aquifer, mainly because of the clayey nature and poor groundwater quality. Additionally, the areas close to the sea-coast suffer from the problem of sea water intrusion. The upper Bhuj (Mesozoic) and Kankawathi (Tertiary) series constitute a relatively good aquifer because it has in general low salinity. The objective of present work is to identify paleochannels in Kachchh region for possible location of potable ground water.

2.1 Major Rivers

The Kachchh peninsula is characterized mostly by ephemeral streams which carry water during monsoon only (Merh, 1995**)**. The entral high land forms the main watershed with numerous streams draining the slopes in the radial pattern. Most of the rivers are of small length and having low sediment carrying capacity. The south flowing streams are Naira, Kankawati, Choke, Sai, Vengadi, Kharod, Rukmavati, Khari, Nagwanati, Phot, Bhukhi, Mitti, Sakra, and Lerakh (Fig. 2). Streams flowing southwestward from the western part of the high land are Rakhdi and Mitti that flow into the Arabian Sea (Merh, 1995**)**. Rivers Nara, Panjorwali, Chhari, Bhukhi, Tramdo, Kaila, Pur, and Kaswali originated from the northern hill slope and flows towards Rann of Kachchh. The east flowing rivers viz. Sang and Sakra disappear into Gulf of Kachchh near the mouth of little Rann.

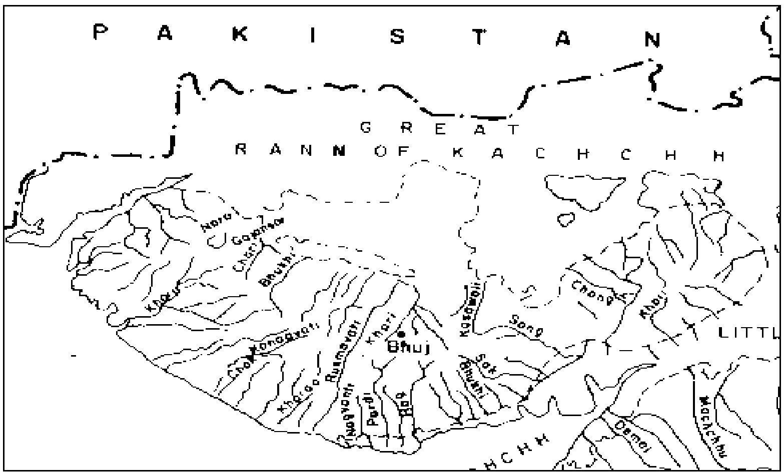

Figure 2. Major rivers in Kachchh region (After Merh, 1995)

3. Data and Field Investigations

Identification and demarcation of palaeochannels in Kachchh region of western peninsular India has been done using multi-disciplinary studies, which include satellite data investigation; geological and geophysical investigations of palasochannels. Hydrology of the Kachchh basin has been assessed for the period of last few decades from the data of humidity, annual discharge and rainfall. Fig. 3 shows flowchart of different geological and geophysical methodologies adopted for the present study.

3.1 Satellite Data Investigations

We have used ASTER 1.5 arc-second (45 m resolution), LANDSAT satellite data and Survey of India (SoI) topographic sheet 1:50,000 scale of 1966 and 1973. We prepared a digital elevation model with the help of ASTER satellite data in GIS platform to extract the drainage network and palaeochannels. All the data have been processed in WGS-84 geodetic system in GIS platform and final maps have been generated using Surfer-11 software. To define spectrally anomalous region the LANDSAT imageries have been draped over an ASTER generated DEM. We used different spectral bands to distinguish surficial features related to palaeochannels viz. sand, clay, carbonate, calcrete, and gypsum rich soil. These features can be differentiated from surrounding lithologies by enhancing the spectral resolution of imagery.

3.2 Meteorological Data and Well Logs

Rainfall, humidity and discharge data of Kachchh region have been collected from S.W.D.C. (State Water Data Centre), Gandhinagar and Ground water data was collected from G.W.R.D.C. (Gujarat Water Resources Development Corporation), Rajkot. The data have been plotted using Microsoft Excel and Surfer 11 software. The well log data have been collected from Gujarat Water Resources Development Corporation (GWRDC), Rajkot. From all these data sets, hydrology of the Kachchh basin has been assessed for the period of last few decades.

3.3 Electromagnetic Surveys

Time-Domain Electromagnetic (TDEM) methods are based on the principle of using electromagnetic induction to generate measurable responses from sub-surface features. When a steady current in a cable loop is terminated a time varying magnetic field is generated. As a result of this magnetic field, eddy currents are induced in underground conductive materials. The decay of the eddy currents is directly related to the conductive properties of rocks, and may be measured by a suitable receiver coil on the surface.

Resistivity methods particularly DC-electrical resistivity survey as well as TDEM investigations are successfully employed in mapping groundwater level in different geological terrains (Yadav et al., 2010; Sinha et al., 2013; Kumar et al., 2014, Goldman & Neubauer, 1994; Tayler et al., 1964, Tayler et al., 1992; Subash Chandra et al., 2011). In the present study we carried out TDEM investigations near Bhuj and eastern part of the Kachchh basin.

The time domain electromagnetic method employs a transmitter that drives an alternating current through a square loop of insulated electrical cable laid on the ground. The current consists of equal periods of time-on and time-off, with base frequencies that range from 3 to 75 Hz, producing an electromagnetic field. Termination of the current flow is not instantaneous, but occurs over a very brief period of time (a few microseconds) known as the ramp time, during which the magnetic field is time-variant. The time-variant nature of the primary electromagnetic field creates a secondary electromagnetic field in the ground beneath the loop, in accordance with Faraday's Law, that is a precise image of the transmitter loop itself. This secondary field immediately begins to decay, in the process generating additional eddy currents that propagate downward and outward into the subsurface like a series of smoke rings. Measurements of the secondary currents are made only during the time-off period by a receiver located in the center of the transmitter loop. Depth of investigation depends on the time interval after shutoff of the current, since at later times the receiver is sensing eddy currents at progressively greater depths. The intensity of the eddy currents at specific times and depths is determined by the bulk conductivity of subsurface rock units and their contained fluids.

The TDEM method in our case gives subsurface information to about 250m depth. TDEM measurements were carried out at 14 sites along four short profiles across Khari river 5km west of Bhuj. At 15-30 km east of Bhuj, TDEM measurements were carried out at 5 locations along a 15km long profile. TDEM measurements were also carried out at 12 locations along a 100km long profile from Anjar to Rapar crossing several paleochannels.

3.4 Seismic Surveys

ISR has carried out the Multichannel Analysis of Surface waves (MASW) test at fourteen sites to delineate the paleochannels near the Bhuj city. The seismic data was acquired following standard CMP roll-along technique with forty-eight channels seismograph. Vertically stacked impact of a 30 kg hammer at 4 m offset from the first geophone is used as a seismic source. For each shot, seismic data were recorded by twenty-four vertical geophones of 4.5 Hz, planted at 2 m intervals along the profile line. Total deployment of 48 geophones makes a geophone spread of about 100m. Finally, the seismic data was processed using the MASW technique to obtain two dimensional shear-wave velocity model for a profile length of 50m.

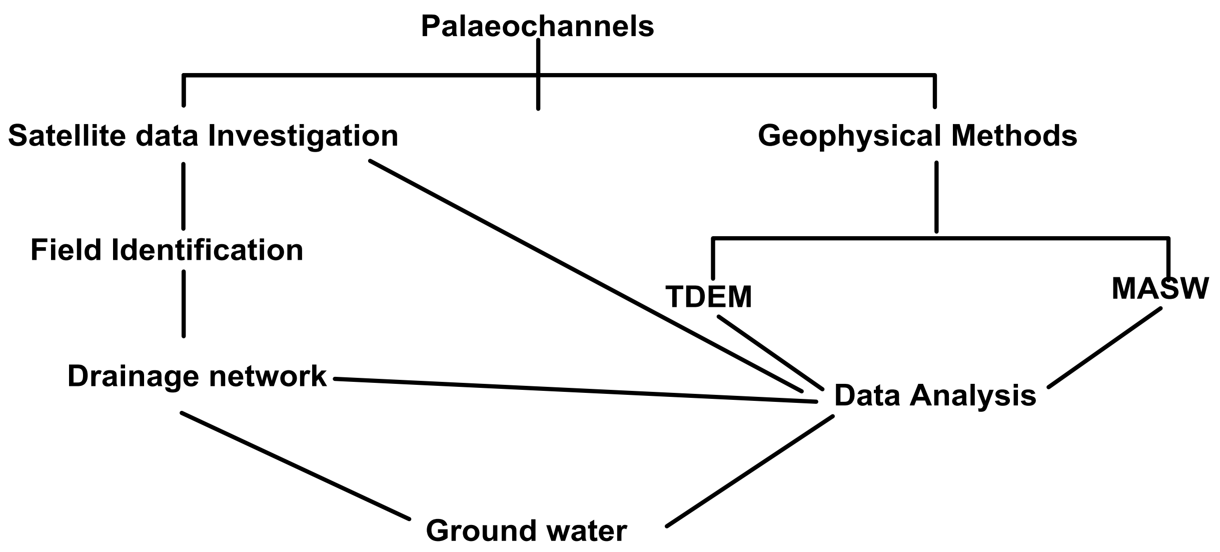

Figure 3: Flow chart of data acquisition and analysis for identification of Paleochannels

4. Results and Discussion

4.1 Rainfall data

We analyzed rainfall data of the period 1991-2013 for geographically well distributed ten sites viz. Abdasa, Anjar, Bhachau, Gandhidham, Lakhpat, Bhuj, Mandvi, Mundra, Nakhatrana, and Rapar, respectively, covering the entire part of Kachchh. All these sites show gradual increase of rainfall pattern from 1994, much higher since 2001 and highest during 2006 – 2011, with maximum of 1600 mm and minimum of 300 mm. Rainfall station located at Lakhpat shows least rainfall. The rainfall data are given in Table1.

4.2 Borehole Litholog Data

We investigated litholog data of eight boreholes. Geographically the sites Rajda (Mundra) and Dhokda (Mandvi) are located in southern Kachchh; sites Mathal (Nakhtrana) and Bhuj are located in the central part of Kachchh; Varsamedi (Anjar), Sinay (Gandhidham) represent lithology of south eastern part of Kachchh; and the site Vandh (Bhachau) represents subsurface geology of Wagad (Fig. 1). The litholog sections of the eight sites are illustrated in Fig. 4.

The litholog data show the inferred ground water depth at 49 m at Mathal (Nakhatrana) with sand deposits, at 45 m at Bhuj with fluvial sandstone deposits, at 20 m at Varsamedi (Anjar) with sand deposits. Similarly at 30 m depth at Sinay (Gandhidham), at 30 m at Vandh (Bhachau), and at 35 m depth at Rapar (Rapar) with sand deposits (Fig. 4).

Table 1: Rainfall data

Year	Abdasa	Anjar	Bhachu	Bhuj	Gandhidham	Lakhpat	Mandvi	Mundra	Nakhatrana	Rapar
	Rainfall in mm									
1991	37	118	203	82		18	1071	148	40	134
1992	720	455	366	750		943	178	846	872	390
1993	37	148	112	72		131	135	46	71	253
1994	630	1001	1016	779		1185	511	1170	1058	652
1995	360	210	230	152		282	453	205	170	215
1996	149	189	282	87		29	84	135	80	382
1997	271	677	669	317		233	180	861	440	829
1998	346	366	375	416	335	230	301	491	461	486
1999	187	86	273	123	103	65	168	120	100	189
2000	272	230	184	219	239	322	503	345	223	194
2001	572	331	382	243	259	294	301	411	456	339
2002	125	136	160	78	195	58	168	103	100	231
2003	443	771	599	712	852	843	503	785	922	679
2004	142	285	275	223	333	25	283	417	201	416
2005	187	382	403	188	383	98	243	490	174	491
2006	634	466	378	596	599	656	547	645	655	532
2007	459	558	588	663	556	442	536	580	560	570
2008	186	402	289	247	376	198	594	438	319	333
2009	849	372	381	419	256	383	559	620	432	462
2010	789	889	968	896	604	375	1689	776	691	942
2011	623	455	881	742	613	415	673	565	634	1056
2012	388	194	182	140	274	290	170	142	380	277
2013	349	796	951	472	765	187	625	942	330	865

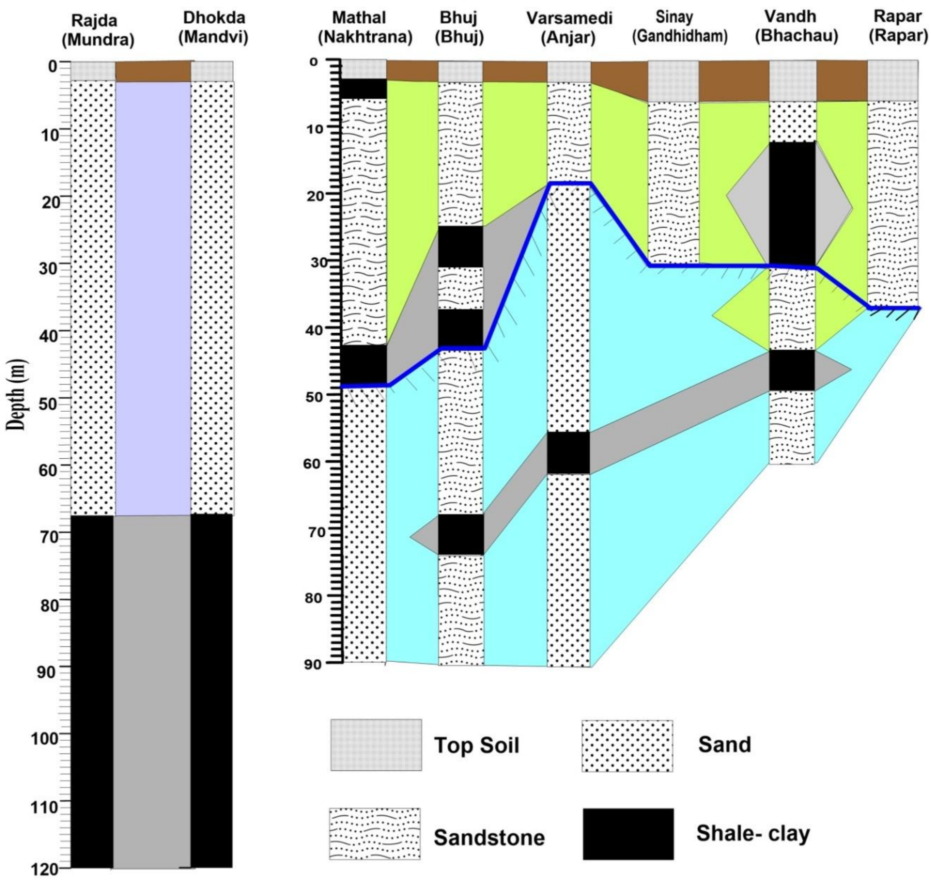

Figure 4. Litholog sections of the boreholes at Mundra, Mandvi, Nakhtrana, Bhuj, Anjar, Gandhidham Bhachau and Rapar are shown. Note: solid blue line represents possible depth of ground water

4.3 Identification of Paleochannels from Remote Sensing

This study has demonstrated use of remote sensing as a tool to identify palaeochannels in Kachchh region of western peninsular India. To map the palaeochannels in the Kachchh region, LANDSAT, ASTER images are used, and Digital Elevation Model (DEM) is prepared from ASTER image. This study has helped to have a better understanding of image characters of palaeochannels. Various image enhancement techniques have been applied in a GIS platform. We identified ~50 paleochannels in the mainland zone of Kachchh and ~40 palaeochannels in great rann of Kachchh region. These channels are of various shapes and sizes; length of channels ranges from 500 m to 10 km and width between 50 and 200 m. The main river courses are in different directions and the paleochannels are sub-parallel to them (Fig. 5). These paleochannels are physically verified during extensive field work on the basis of their lateral continuity, connection with present day river channel, sediment architecture and clast composition (Fig. 6).

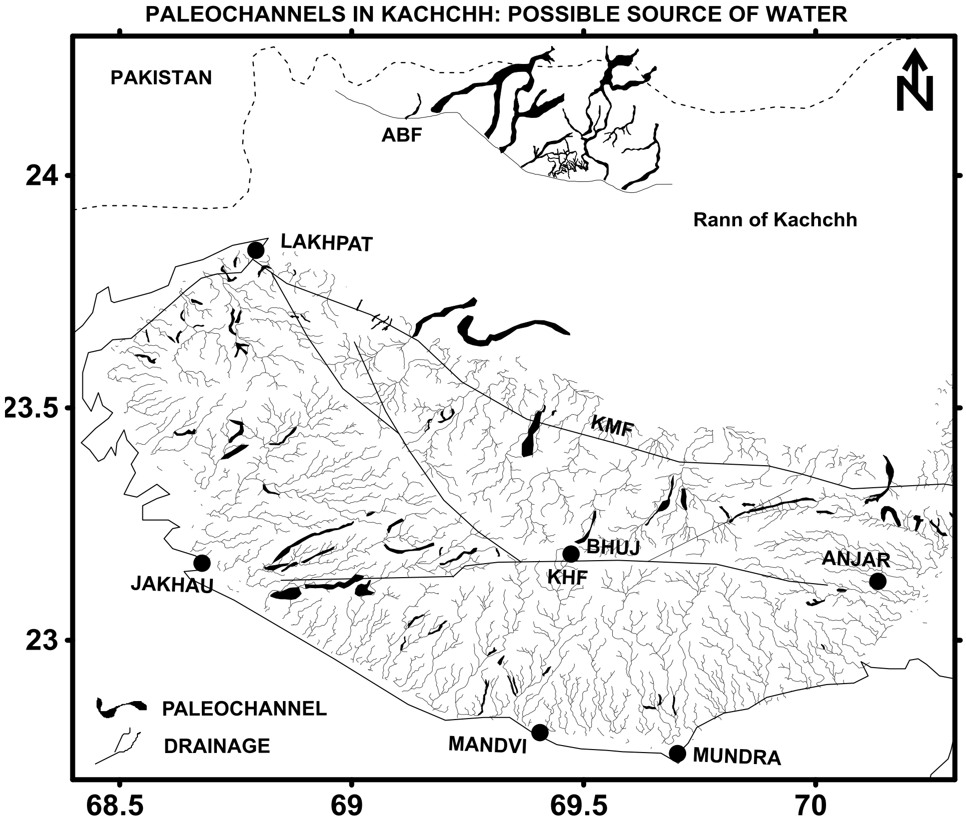

Figure 5. Drainage map of Kachchh shows presence of possible palaeochannels.

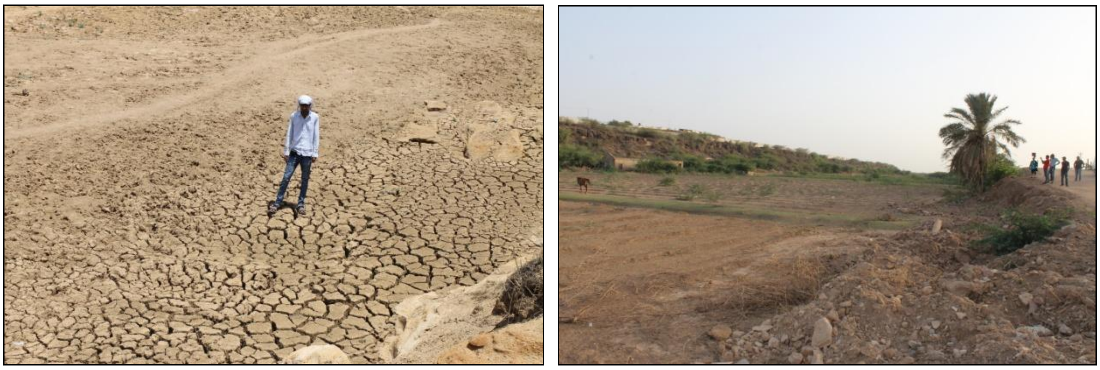

Figure 6. Field photograph of Palaeochannels located near Nirona and Khari Rivers. These channels have been identified based on clast texture and composition of the sediments resting over the palaeo-course of channel

4.4 Multichannel Analysis of Surface Waves (MASW)

Figure 8 shows locations of the MASW and TDEM surveys carried out in Khari River area. Eight MASW test profiles (PA-5, PA-13, PA-3, PA-12, PA-14, PA-10, PA-11 and PA-09) were collected from the current river channel of Khari River (Fig. 7). These test profiles clearly show presence of low shear velocity layers below 20 m depth. The low velocity ~400-600 m/second below 20 m indicates possible water saturated zone. After taking test profiles we have collected six profiles (PA- 4, PA-6, PA-7, PA-8, PA-1 and PA-

2) across the 3.89 km long palaeochannel of the Khari River (Fig. 7). These profiles show consistent low and high velocity layers without any local break. All six profiles show low velocity (100-500 m/second) layer down to 10 m depth, reflecting presence of highly saturated weathered rock layer (Fig. 8). Profile P-13 shows a high velocity layer (600-1200 m/second) between 10 m and 20 m, that corresponds to a hard and compact impermeable layer. The profile shows an undulating pattern of low velocity layer (~400-600m/second) below 20 m which may be a highly saturated layer. The profiles P-5 and P-6, however, do not show such signature (Fig. 8).

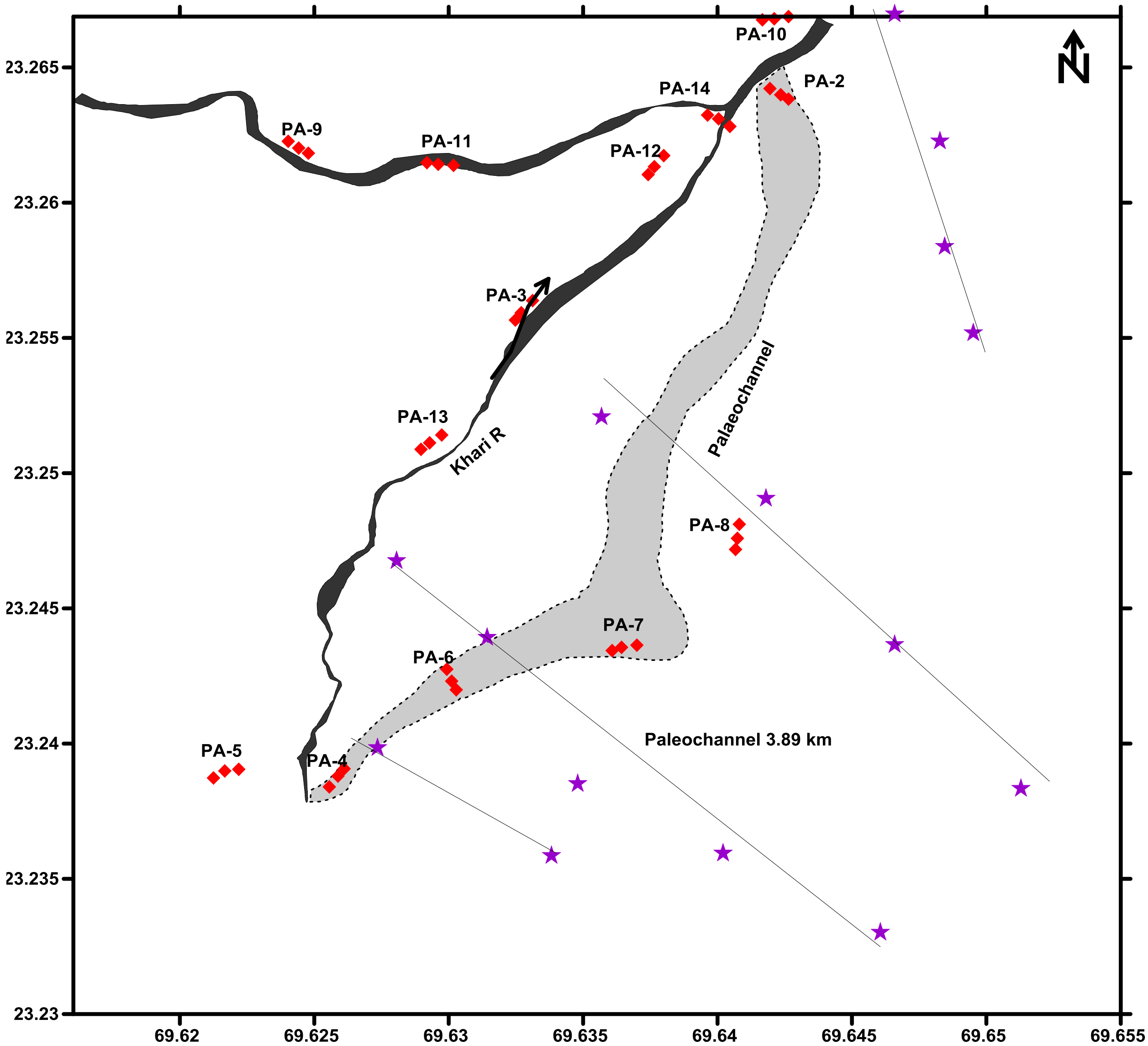

Figure 7. Location map of Khari river paleochannel, 3-5 km west of Bhuj. Solid red squares across the paleochannels indicate locations of MASW survey, stars indicate the locations of TDEM measurements and black lines indicate the profile lines defined by stars.

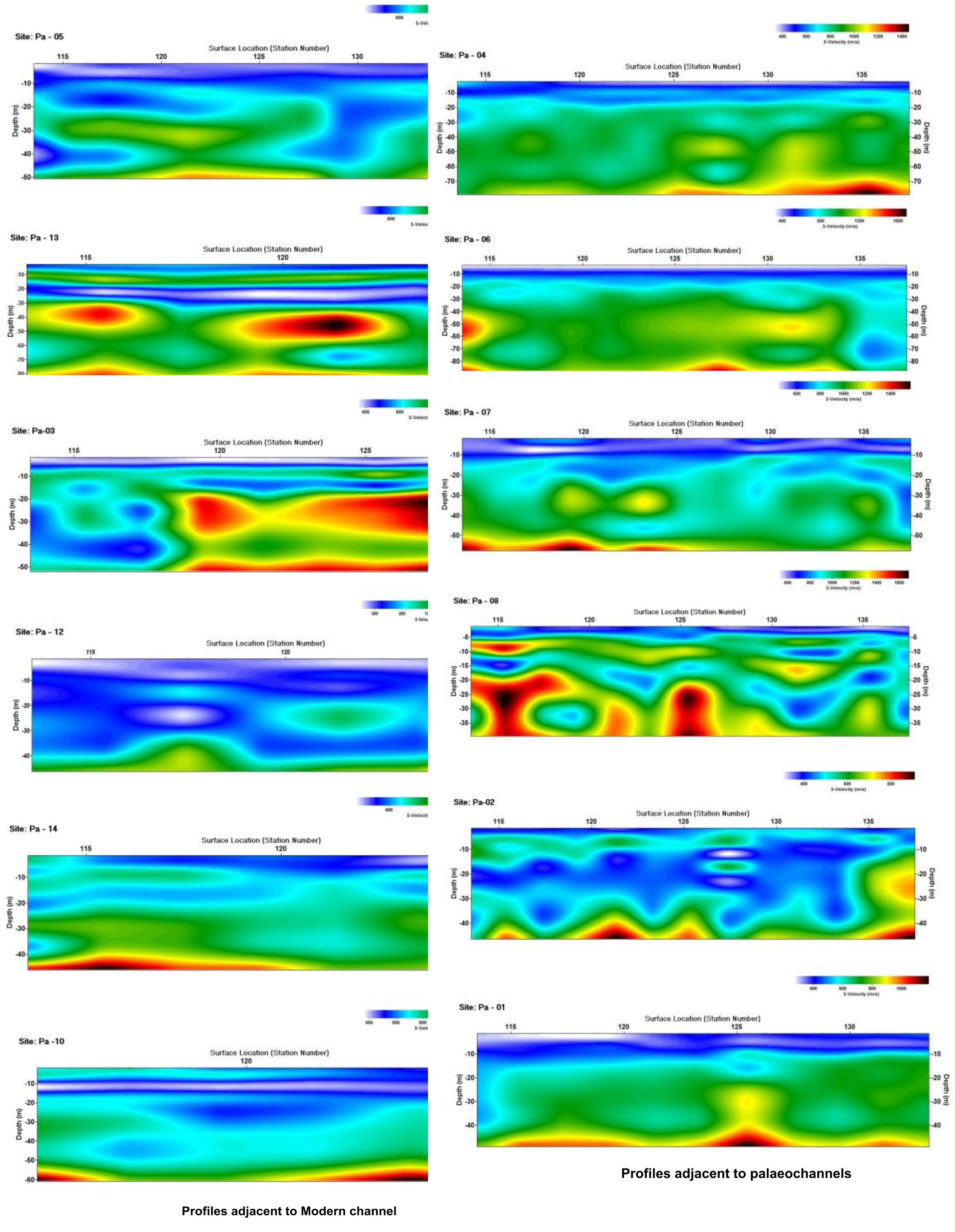

Figure 8. The first six 2D depth plots of MASW survey are along Khari River while the later six over the palaeochannels. (Note: low shear velocity 400-600 m/s below 20 m depth for 2D sections over the palaeochannels indicates possible water saturated layer. Numbers on top of each profile gives geophone position. Distance between two geophones is 2m giving Profile lengths of 50m in all the profiles except for P10 which has profile length of 25m)

4.5 Time Domain Electromagnetic Survey (TDEM)

TDEM investigations near Bhuj

Fifteen TDEM soundings with 100 m loop size were undertaken along four ~1 to 2.5 km long profiles across Khari river paleochannel, 5 km west of Bhuj. About 70 m thick Bhuj sandstone layer starting at depths 30-40m with about 15 Ohm.m resistivity is inferred to be a possible aquifer (Fig. 7). The aquifer below the paleochannel appears to be at shallow depth as compared to depth of 90 m east of Bhuj and 150 to 250 depth in Anjar - Rapar belt as described below:

The one dimensional resistivity structure obtained for a 15 km long TDEM profile, 15-30 km east of Bhuj, is illustrated in Figure 1. It shows a 35-38 m thick sandstone layer of resistivity ~10 ohm.m overlying a thicker ~50 m conductive layer with resistivity <10 Ω.m (Fig. 9). The top sandstone may be having saline water. Another sandstone layer with resistivity ≥10 Ω.m at depth from 90 to 140 m is identified (Fig. 9). It could be a potential aquifer in the region.

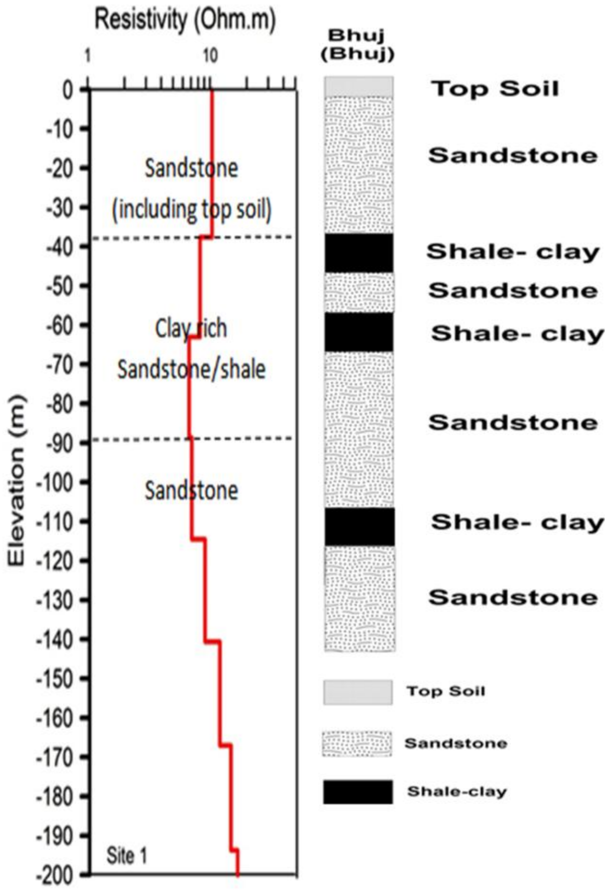

Figure 9. One-dimensional resistivity structure at a site close to Bhuj. Different layers are well correlated with lithology of the area

TDEM investigations between Anjar and Rapar, Kachchh

A time domain electromagnetic (TDEM) survey along the Anjar - Rapar (A-R) corridor covering a length of 80 km in the eastern part of the Kachchh basin was also carried out to map potential aquifer layer in the region. Twelve fixed in-loop TDEM soundings with 100 m sided transmitter loop were carried out at regular interval (Fig. 1). The measured transient decay curves are used to model the depth and subsurface resistivity of the underlying structure. The modelled 1-D section reveals a 20 to 50 m thick conductive layer of 10-15 Ω.m resistivity with its top surface at 10-15 m depth. We infer this conductive layer as a probable aquifer comprising of saturated sandstone with moderate to low salinity. At some places along the corridor, we have also obtained another aquifer layer at deeper depth (150-250 m) overlying a relatively low resistive layer comprising of clay and/or clayey sand (Fig. 10). The layers at 200-250 m appear to be heterogeneous in nature and are inferred to be composed of clay (>5 Ω.m), clayey sand/sandy clay / sandstone with saline water (5-10 Ω.m) and shale (20-50 Ω.m). The results are correlated with the litholog data.

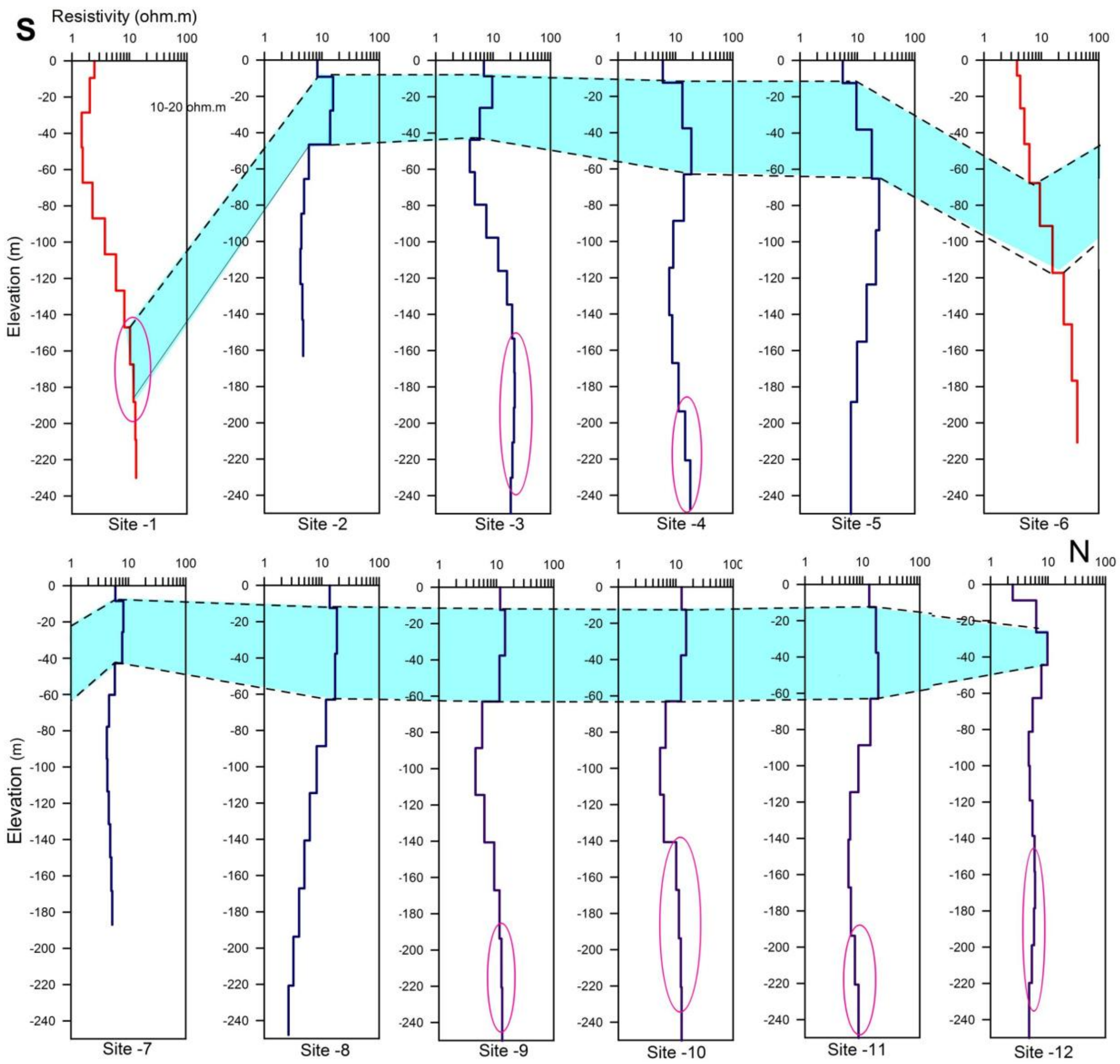

Figure 10. Combined one-dimensional resistivity structure of all the sites between Anjar and Rapar. The highlighted zone is the inferred aquifer at shallow depths. The presence of deeper aquifer is marked with ellipses.

5. Conclusions

In the present study multi-disciplinary approach has been used to investigate possible location of ground water from the palaeo-river valleys. Present- and palaeo-river channels have been mapped through satellite imageries and ground checking. Hydrological pattern has been noted through rainfall data, humidity analysis, discharge analysis, and subsurface geological information using litholog data. Borehole lithologs have been correlated with geophysical data. Following conclusions have been drawn from the above study:

1. From remote sensing and GIS analysis it is inferred that the palaeochannels in Kachchh are isotropically well distributed in the area. The drainage pattern shows migration of river channels in last few hundred years.
2. The borehole lithological data show that the possible ground water depth in central Kachchh is ~ 50 m near Nakhatrana; ~40 m (near Bhuj), and ~20 m near Anjar, whereas in the eastern Kachchh it shows ground water depth ~30 m at Gandhidham, Bhachau and Rapar areas. However the coastal region shows possibility of ground water at 9 m or less.
3. The MASW images obtained from the present and palaeo Khari River show presence of low shear velocity layers below 20 m depth. The low velocity layer (~400-600 m/s) below 20 m depth indicates a water saturated zone.
4. The TDEM method shows possibility of aquifer beneath palaeochannels at shallow depth of 30-40 m near Bhuj as compared to 100-200 m or more at other places in Kachchh with resistivity greater than or equal to 10 Ohm.m.
5. The borehole lithologs and MASW seismic surveys indicate that the water at shallower depths may be saline. The TDEM method indicates the possibility of aquifer of potable water at deeper depths ~ 200 m.

Acknowledgements

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