CHAPTER 3 HYDRO-GEOLOGICAL SETTING OF THE STUDY AREA

3.1 INTRODUCTION

The region of Kutch is unique in the domain of the Jurassic rocks of India in the presence of a much expanded sequence of the upper part of this system. It embraces widely variable sediments, lithologically as well as chronologically. The oldest exposed rocks are the precambrian syenities observed at Meruda Takkar (Biswas & Deshpande 1968) close to the khadir island in the Rann of Kutch. The youngest rocks, on the other hand, are the Subrecent to Recent sediments. There are, however no exposures of palaeozoic or even Triassic and it is supposed, of course without any direct evidence, that the Jurassic rocks lie over the precambrians. The Jurassic rocks of Kutch of the early workers in fact include the Cretaceous sediments and the igneous masses, supposedly equivalent to the Deccan Traps as well.

As estimated by earlier workers, the Mesozoic sediments range in thickness from 1800 to 1900 meters, but recent investigation (Poddar 1959) have shown it to be of the order of 2400 meters or even more. This variation in estimated of the thickness is probably due to the fact that individual lithich units show much fluctuation vertically in different localities and all of them are not exposed in any one locality or section.

3.2 GEOLOGICAL SET UP OF KUTCH:

Geologically, the KUTCH is constituted by the rocks of Mesozoic and Cenozoic age. The Kutch Mainland is having Jurassic rocks, mainly sandstone and shale with trappean basalt, whereas coastal areas are having Tertiary and Quaternary formations. The Great and Little Ranns contain Holocene sediments.

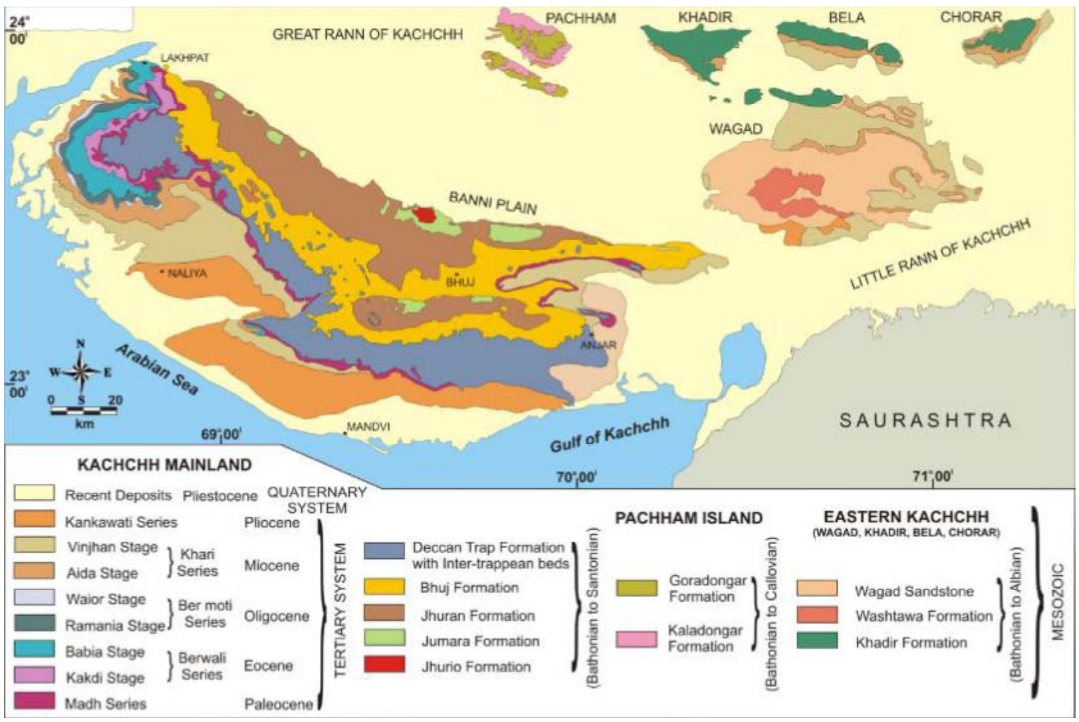


Fig 3.1 Geological map of Kutch showing major stratigraphic units (After Biswas and Deshpande, 1970) (Source: K. Swarna et. al)

3.2.1 Geological and Tectonic History

Kutch region of Gujarat is flanked by Nagarparker fault to the north and the Kathiawar fault to the south. Bounded between these two fault this region shows several E-W trending major faults viz. Katrol Hill Fault, Kutch Mainland fault, Banni fault, Island Belt fault and Allahbund Fault. Mainland Fault flanks the subset study area in the north and Katrol hill fault in the south. The Quaternary period experienced three major tectonic pulses, which are responsible for the most of the present topography and drainage system (Thakkar, et. al., 1999). Most of the drainage is flowing towards south and southwest in Kutch, while in the eastern part of the mainland of Kutch like in Anjar, the rivers are flowing in the east, and therefore at some places the drainage reversal took place due to the rise of the western part. The subsequent earthquakes have significantly raised the western portion of Anjar. Anjar town was also badly affected by the moderate (M_L 6.5) earthquake that occurred in 1956 in the eastern Kutch. Many earthquakes of magnitude below 4.0 arrived after the 1956 event, but the 26th January 2001 event (Mw 7.7) is the most vulnerable one in the known history in Kutch and Gujarat. 1819 Allahbund earthquake was equally large but it occurred in pre-instrumental era, so no record is available except the felt and study regarding changes in topography (Rajendran, et al.,2001).

3.2.2 Stratigraphic Framework

The Kutch basin is an E-W trending palaeorift graben that is located on the western continental margin of India. The basin originated in early Mesozoic and exposes a full sequence of rocks from middle Jurassic till present **(Fig. 3.1).** The Mesozoic sedimentation took place during the rift phase of the basin that ended in the late Createaceous. The basin was inverted at the end of Cretaceous (Biswas and Khatri 2002). Since then, the basin suffered intermittent phases of uplift and flexuring along the various E-W trending faults (Biswas and Khatri 2002). The Cenozoic sediments

(Tertiary and Quaternary) were laid down in the geomorphic lows that resulted from the differential uplift of the basin along faults (Biswas 1993). The present landscape framework of Kutch is therefore largely the result of pre-Quaternary tectonic evolution of the basin (Biswas 1974). Continued tectonic instability of the basin and the active nature of various faults is evidenced by several large magnitude earthquakes in historic times including the 2001 earthquake that have occurred in the region (Biswas and Khatri 2002). The evolution of Kutch, Narmada and Cambay rift grabens is related to the breakup of Gondwanaland in the Late Triassic/Early Jurassic and the subsequent spreading history of the Eastern Indian Ocean (Biswas 1982, 1987). The Saurashtra block remained as a horst while the Kutch, Cambay and Surat basins subsided around it for the deposition of Cenozoic sediments. The Kutch rift was initiated in the Late Triassic along the Delhi trend as evidenced by continental Rhaetic sediments in the northern part of the basin (**Kosal 1984).** The Kutch rift basin was formed by subsidence of a block between the Nagarparkar Hills and the southwest extension of the Aravalli Range (Biswas 1982, 1987). The Kutch graben became a fully marine basin during the Middle Jurassic period (Biswas 1981). In the Late Cretaceous, uplift of the Jurassic sediments took place in the Kutch Basin. The major structural elements that have played a significant role in the post Mesozoic geological and geomorphological evolution of southern Mainland Kutch are shown in Table 3.1

Table 3.1 Mesozoic Lithostratigraphy of Kutch (Biswas, 1971).

<table>
<tr><th colspan="2">Mainland</th><th colspan="2">Pachham Island</th><th colspan="2">Eastern-Kutch (Khadir-Bela-Wagad)</th></tr>
<tr><th>Formation</th><th>Member</th><th>Formation</th><th>Member</th><th>Formation</th><th>Member</th></tr>
<tr><td rowspan="3">Bhuj</td><td>Upper</td><td colspan="2" rowspan="9"></td><td colspan="2" rowspan="2"></td></tr>
<tr><td>Ukra</td></tr>
<tr><td>Ghuneri</td><td rowspan="5">Wagad Sandstone</td><td>Gamdau</td></tr>
<tr><td rowspan="4">Jhuran</td><td>Katesar</td><td rowspan="4">Kanthkot</td></tr>
<tr><td>Upper</td></tr>
<tr><td>Middle</td></tr>
<tr><td>Lower</td></tr>
<tr><td rowspan="4">Jhumara</td><td>Dhosa Oolite</td><td>Washtawa</td><td>Bhambhanka shale</td></tr>
<tr><td rowspan="2">Middle</td><td rowspan="8">Khadir (Khadir Island)</td><td rowspan="3">Gadhada</td></tr>
<tr><td rowspan="4">Goradongar</td><td>Modar hill</td></tr>
<tr><td>Lower</td><td>Raimalro</td></tr>
<tr><td rowspan="5">Jhurio</td><td>Upper</td><td>Gadaputa</td><td rowspan="2">Hadibhadang</td></tr>
<tr><td rowspan="2">Middle</td><td>Flagstone</td></tr>
<tr><td rowspan="3">Kaladongar</td><td rowspan="2">Kaladongar Sandstone</td><td rowspan="3">Cheriya bet</td></tr>
<tr><td rowspan="2">Lower</td></tr>
<tr><td>Kuarbet</td></tr>
<tr><td colspan="4"></td><td colspan="2">Precambrian</td></tr>
</table>

3.2.2.1 Mesozoic Stratigraphy:

The Kutch basin preserves about 2000 to 3000 m of Mesozoic and 1000 m of Cenozoic sediments (Biswas 1977, 1982). The Tertiary rocks are exposed along the coastal belt of southern and western Kutch bordering the Mesozoic rocks. The Pre-Quaternary evolutionary history of the Kutch basin is dealt at length by Biswas (1982, 1987) which has implications for the seismic instability (Biswas and Khattri 2002). Mesozoic rocks of Kutch were first mapped by Wynne (1872) who classified the sequence into upper and lower Jurassic Groups. Waagen (1875) proposed the popular four-fold subdivisions, namely, Pachchham, Chari, Katrol and Umia Series. Rajnath (1942) restricted the term 'Umia' only to the lower Umia of the Waggen (1875); the upper Umia made up of non-marine beds with plant fossils was called by him as Bhuj Series of Middle Cretaceous or even slightly younger age. Biswas (1977) recognized three main lithologic provinces within the basin and rocks of each province were classified separately (Table 3.1) and named the units according to their stratotypes (Biswas 1977). The lithostratigraphic sequence of Mainland is divided into four formations named as the Jhurio (Jhura), Jumara, Jhuran and Bhuj Formations (Biswas 1977, 1981). The Bhuj Formation is disconformably overlain by the basaltic flows of the Deccan Trap Formation (Biswas and Raju 1973) on the south while the base of the Jhurio Formation is unexposed. In Pachchham island stratigraphic sequences divided in two formations namely, Goradongar and Kaladongar whereas remaining island belt (khadir, Bela) and wagad has been marked with Wagad, Wasthawa and Khadir formation.

3.2.2.2 Jhurio Formation :

A thick sequence of limestone and shales with bands of ‘golden oolites’ has been named as the Jhurio Formation after the type section in Jhurio hill, in North-Central Mainalnd. (Balagopal, A T, 1972)

The Formation is exposed only as small inliers in three hills which are large domal structure, along the northern margin of the Mainland-Habo, Jhurio and Jumara, from east to west. The maximum thickness of this formation is exposed in the Jhurio Hill.

3.2.2.3 Jumara Formation :

A thick argillaceous formation conformably overlying the Jhurio Formation has been named after its type section in Jumara hill near the Rann, north of Jumara village. The formation is characterised by monotonous olive-grey gypseous laminated shales with thin red ferrugenous bands. The ~300m thickness of the formation is uniform throughout the area. Local disconformity is observed at places where the Jhuran shales are seen resting over the eroded Dhosa oolite member. The Jumara formation ranges between Callovian to Oxfordian.

3.2.2.4 Jhuran Formation :

It comprises a thick sequence of alternating beds of sandstones and shales. The formation is divided into four members-lower, middle (Rudramata Shale), upper and Katesar member (Biswas 1977). The formation is widely exposed along the southern flanks of the northern and central hill ranges in two wide east-west strips. Lithologically, the Lower Member consists of alternating yellow and red sandstone and shale beds in almost equal proportion with thin bands of hard yellow, fossiliferous, pebbly, calcareous sandstone. The Middle Member predominantly comprises of monotonous succession of dark grey to black well laminated gypseous shale weathering in to olive-grey color. Thin bands of ferruginous sandstones, laminated micaceous siltstone and yellow ochreous mudstone are common in shale. The Upper Member is arenaceous and consists of red and yellow, massive current bedded sandstone with intercalations and alternations of shale, siltstone and calcareous sandstone bands in the middle. The Jhuran Formation is thickest in Jara-Mundhanarea of NW part of the Mainland Kutch where it is about 800-900 m thick but, thins down eastwards to 425 m. in the type-section after attaining the minimum 350 m in the central part of the Mainland. The upper limit of this formation is demarcated by the contact between marine and non-marine rocks. The environment of deposition shifted from sub-littoral to supra-littoral environment and finally into continental deposition of the overlying Bhuj Formation. Age of this formation is Kimmeridgian to Valanginian.

3.2.2.5 Bhuj Formation :

Named after its type locality around Bhuj, the capital city of Kutch, this formation is defined by the marine beds of the Jhuran Formation below and the igneous rocks pertaining to the Deccan Trap Formation above. It is a huge thickness of non-marine sandstone of uniform character constitutes the youngest formation of Mesozoic stratigraphy of Kutch.

These rocks occupy about 75% of the total area of the Mesozoic outcrop in Mainland

Kutch. The lower member is categorized by cyclic repetition of ferruginous or lateritic bands, shales and sandstones. The formation is bounded by the planes of disconformity. The upper member contains wheatish to pale brown, massive, current bedded, coarse grained, well sorted sandstones. The formation is bounded by the plains of disconformity. In the south, Deccan trap flows on the eroded undulating surface of this formation. The sediments represent deltaic deposits with distal part (delta front) towards the west and the proximal part (fluvial) to the east in the direction of the land. Lower Cretaceous (Valenginian) to Santonian time range is fixed for this formation.

3.2.2.6 Deccan Trap Formation:

The Deccan Trap Formation is limited only to the Kutch Mainland bordering the Mesozoic extending from Lakhpat in the west to Anjar in the east. Lava flows are mainly tholeiitic basalts that superimpose the Jurassic sandstone, occupying the southern and southwestern slopes of the central highland. Six major flows have been described at the eastern extremity where they show alterations of columnar and amygdaloidal basalts. Sporadically separated by inter-trappean shale units, flows are similarly traversed by a number of long narrow dykes that occur to the north, northwest and northeast of the lava flow occurrence. Most of the dykes occur along transverse faults spreading N-S, NNE-SSW and NNW-SSE. An remarkable aspect of the Deccan volcanism in Kutch is the occurrence of alkali basalt and its derivatives as plugs, laccoliths and sills within the dome structures in the Mesozoic rocks. The intertrappean beds were deposited in shallow basin and depression over trappean surface fed by concurrently formed rivulets. An uppermost Cretaceous age is incidental for this inter-trappean bed. The laterites form a narrow elongate Paleocene belt, a few hundred meters wide and several hundred kilometers long squeeze in between the basalts of the Deccan Trap Formation and the Tertiary sediments.

3.2.2.7 Tertiary stratigraphy

Wynne and Fedden (1872) studied these rocks for the first time. Biswas (1974) suggested a revised stratigraphy and established that the Tertiary sediments in Kutch

were deposited on the eroded surface of the Deccan Trap and the Mesozoic sedimentaries, and deposition started with a marine transgression during Lower Eocene that ended in Pliocene.

3.2.2.8 Madh Series

The type area of the rocks of this series is the famous village of Mata-No-Madh in western Kutch. It consists of volcanoclastic sediments deposited in variable environments, ranging from fluviatile to littoral. The sediments were mainly derived from the Deccan Trap and the pyroclastics ejected during the waning phase of the volcanism. The Madh series overlies the basalt but underlies the Kakadi Stage of Lower Ecoene. On the basis of plant fossils, the rocks of Madh Series havebeen assigned a Paleocene to Lower Eocene age (Biswas 1974).

3.2.2.9 Naredi Formation

The Naredi Formation is named after village Naredi. The type section is discontinuously exposed in the cliffs along Kakdi Nadi near Naredi and partly (i.e.upper parts only) along the Guvar streams to the NNW of Naredi. Three distinct members are recognized in the type locality. The lower Gypseous Shale Member is about 25 m thick and consists of grey, brown and olive green, splintery, glauconitic claystone and shale with occasional thin layers of gypsum, yellow limonite and also a few layers of calcareous concretions which occasionally contain fossil in its core.

Table 3.2 Tertiary Litho-Stratigraphy of Kutch (After Biswas, 1992)

Age	**Formation**	**Members**
Middle to Upper Miocene	Sandhan	
Lower Miocene (Burdigalian)	chhasra	Siltstone
		Claystone
Lower Miocene (Late Aquitanian)	Khari Nadi	
Upper Oligocene	Maniyara Fort	Bermoti
Lower Oligocene		Coral Limestone, Lumpy Clay, Basal Member
Late Middle Eocene	Fulra Limestone	
Middle Eocene	Harudi	
Upper Paleocene to Lower Eocene	Naredi	Ferr. Claystone
		Assilina Limestone
		Gypseous Shale
Upper Paleocene	Matanomadh	
Cretaceous-Lower Paleocene	Deccan Trap	

The middle Assilina Limestone Member is about 6 m thick and comprise dirty white argillaceous limestone and yellowish, grey marl studded with Assilina. The upper Ferruginous Claystone Member is around 10 m thick and consists of grey, yellowish brown claystone with deposits of gypsum and red ferruginous laminae. Here, the Naredi Formation directly overlies the Deccan Trap Formation, but a little to the south of Naredi, it unconformably overlies the Mata-no-madh Formation. The middle part of the unit shelters micro-fauna that has suggested lower Eocene age of the Naredi Formation. The environment of sedimentation of this formation differs from lagoon to marine inner shelf, becoming non-marine towards the upper part.

3.2.2.10 Harudi Formation

This formation is named after a small village Harudi to the north-west of which the Harudi Formation is very well exposed in an impressive escarpment. The section is uninterruptedly visible over a short distance of 300 m along the escarpment at a locality about 2 km NW of Harudi on the Naliya-Narayan Sarovar Road. The Formation consists of green and greenish grey, splintery shale with yellow limonitic partings in the lower parts and calcareous claystone and siltstone interrupted with layers of gypsum and carbonaceous matter in the upper part. Sometimes concretionary fossiliferous marl bands are seen in the lower part. Nummulite bed is a distinctive as marker bed within the formation. The lower contact of the Formation is disconformable and fixed on the top of the laterite bed of the Naredi Formation. The upper contact is conformable and is placed at the base of the lowest massive foraminiferal limestone bed containing characteristic saddled to undulated Discocyclina. The environment of deposition of this formation varies from littoral to middle shelf condition in a slowly transgressive sea.

3.2.2.11 Fulra Limestone Formation

The Fulra Limestone Formation is named after the Fulra village. This is best seen along the southern flank of Babia Hill, about 1.7 km SW of Fulra. The upper part is also well exposed in the nala to the south of Fulra. The entire Formation is made up of thickly bedded, creamy to dirty white and buff coloured foraminiferal limestone. The limestones are fossiliferous micrites and biomicrites. Large saddled to undulated Discocylina, large flat Nummulites and other larger foraminifera are rich all over the formation. The Fulra Formation is also very well exposed in prominent scarps along Berwali Nadi where it is about 40 m thick. The lower contact is conformable and is fixed at the base of the massive foraminiferal limestone. The upper contact is para-conformable and well exposed in all stream section. It is locally disconformable exhibiting cut and fills structure.

3.2.2.12 Maniyara Fort Formation

This formation is named after the Maniyara Fort, is uninterruptedly visible along a stream flowing between the Maniyara Fort and the Bermoti village from a locality 1.6 km NNE of Bermoti to a locality about 450 km SE of Bermoti. This divided into three Members viz., the Basal Member, Lumpy Clay Member, Coral Limestone Member and Bermoti Member in stratigraphically ascending order. The Basal Member consists of alternating beds of foraminiferal, glauconite, brownish to yellowish siltstone and calcareous, gypseous claystone studded with reticulate Nummulites, Pecten and other fossils. The Lumpy Clay Member consists of cement grey coloured to brownish calcareous lumpy claystone, occasionally containing thin limestone and marl beds. The Coral Limestone Member consists of dirty white nodular limestone which weather in characteristic bouldary pattern, alternating with calcareous claystone in lower part. The upper part includes grey to dirty white massive limestone with abundant corals, frequently forming small bioherms. All the three members are very well exposed in the stream west of Ramania. The Bermoti Member is the upper most unit and best developed in the streams SE of Bermoti and also NNE of Waior.

The lower part consists of rusty brown, friable glauconitic argillaceous sandstone. The upper part is composed of thinly bedded, very hard, grey to yellowish foraminiferal limestone with interbed of silty marl full of Spiroclypcus. The lower contact of the Maniyara Fort Formation is paraconformable. The upper contact is not well exposed in the type locality; it is noted to be conformable in other section. The Basal Member and Lower Clay Member are of Lower Oligocene; the Coral Limestone Member is of Middle Oligocene and the Bermoti Member is of Upper Oligocene age. The environment of deposition of this formation is mainlyinner shelf to littoral and locally lagoonal.

3.2.2.13 Khari Nadi Formation

The Khari nadi formation is named after a small river Khari Nadi. The type section is exposed along cliffs on banks of Khari Nadi between its confluence with Sugandhi Nadi near Goyela. The lithology consists of laminated to very thin bedded red andyellow mottled to variegated siltstone and occasionally grey brown gypseous claystone. A bluish grey claystone bed occurs regularly near the base in every section. Cross-bedded, fine grained micaceous sandstone is present in the middle part, while a few thin fossilferous arenaceous limestone beds are present in the middle and upper part. The lower contact is conformable and is fixed on top of the Spiroclypeus limestone bed and at the base of the bluish grey claystone bed. The upper contact is also conformable and gradational. The environment of deposition of this formation varies from tidal flat to littoral and shallow marine environment of a slowly transgressive sea.

3.2.2.14 Chhasra Formation

The Chhasra formation previously called Vinjhan Shale Formation is named after the Vinjhan village. The section is continuously exposed along the Kankawati River between an area north of Vinjhan and 1 km south of Vinjhan. It consists of two distinct members. The type section is exposed along Khari Nadi from top of the Khari Nadi Formation 1 km south of Chhasra village. The lithology consists of grey and khaki colored, laminated, gypseous shales and calystones with alternations of thin, hard, yellowish, highly fossiliferous, argillaceous limestone. Several Foraminifera Ostracoda, are found. The microfauna indicate the age of the member is probable of Late Aquitanian to Burdigalian age.

Siltstone Member is the upper member well exposed along the Kankawati river east of Vinjhan to a locality 1 km south of Vinjhan. This member consists predominantly of alternating micaceous siltstones and laminated silty shales of monotonous khaki color. The upper part is reddish. A few thin fossiliferous marl beds are present. A post- Burdigalian (Langhian) age is suggested for this member. The lower contact of the formation is confirmable with the Khari

Nadi Formation and distinguished between the overlying khaki claystone and underlying variegated siltstone. The environment of deposition of the sediments varies from shallow marine to littoral.

3.2.2.15 Sandhan Formation

This formation is named after the Sandhan village. The type section is exposed along the Kankawati River from Sandhan to 1 km south of Vinjhan. It is well developed in the coastal plain of southern Kutch where good sections are seen in cliffy banks of major consequent streams. The lower part of the formation consists of well arranged, medium to coarse grained, massive, micaceous sandstone, clayey laminated siltstone and thin, yellow, fossiliferous marl bands. The middle part comprises conglomerate and grey coarse grained sandstone with lenses of conglomerate. The upper part is mainly hard, brown, calcareous grit overlain by pink and grey mottled silty sand stone with calcareous nodules. Probable Pliocene age is suggested for this formation. The sediment indicate littoral to supra-littoral environment of deposition.

3.2.2.16 Quaternary Sediments

There are two principal areas of extensive Quaternary sedimentation, one is the Rann areas and the other is the narrow alluvial plain bordering the coastline in southern Mainland Kutch. The Rann, which constitute a very flat terrain with no surface exposures, are obviously the product of marine deposition. The second area is the narrow E–W trending plains of southern Mainland Kutch which are mainly formed by fluvial processes. These are characterized by basal unit of gravels which are either roughly stratified or are showing planer cross stratification

3.3 SOILS OF KUTCH

Entisols have developed over traps and alluvium in parts of Kutch. They are light grey, grayish brown and reddish brown in colour, and have formed under tropical semi-arid climate marked by annual precipitation of 55 to 950 mm and mean temperatures of 25° C to 26°C. The depth of the soils ranges from a few cm to 1 mtr and the profiles show A-C horizons. Texturally, they are sandy clay, loam or clay loam to clay. Structurally weak, mainly sub-angular, blocky and at places crumb like, these soils are calcareous and alkaline in nature. The Entisols of Gujarat taxonomically represent Ustorthents, Ustripsamments and Ustifluvents.

Inceptisols soils are found along the coastal plains. These have formed over basaltic and alluvial parents; occur on gentle to moderate and steep pediments, in sloping isolated plateaus, valley bottoms and moderately sloping interfluves. These are dark grey to light grey, reddish brown, yellowish-red and dark reddish brown in colour and are products of weathering under tropical semi-arid to humid climates with annual precipitation of 500 to 2000 mm and mean temperature of 26o C. Inceptisols are generally calcareous in nature and vary indepth from 30 to 80 cm.

Structurally, these are sub-angular and blocky and have A-C horizon characteristics. Texturally, the soils are silty-loam to clay, and are neutral to alkaline in reaction. The coastal Inceptisols have sandy-clay-loam to clay texture. Ustochrepts, Helaguepts, and Haplaquepts are the main taxonomic soils of this order.

Ardisols have mainly developed over the Aeolian silts and dune sands. Distributed on residual hummocky dunes and ridges, pediment surfaces, mud flats and dissected flood plains of Kutch. Aridisols develop under arid climate with mean annual rainfall below 450mm and mean annual temperature of 26°C having acidic moisture regime. The soils are fairly deep, light grey to brown in colour, having no definite structure. Texurally, these are sandy to sandy-loam with silty clayloam.

A few of the soils are salty. Some have argillic and nitric horizons and when dry are not hard and massive; others have either a calcic or petrocalcic or cambic horizon or a duripaan.

3.4 HYDRO-GEOLOGICAL SETUP OF STUDY AREA

Analysis of Geology, Geomorphology, Soil and Hydrology of the study area is described under this heading.

3.4.1 Geology of Study Area:

Hydrogeological units in the area can be grouped as Mesozoic formations, Deccan trap (Hard rock), Cretaceous rocks, Intratrappen, Tertiary formations & Quaternary sediments.

3.4.1.1 Mesozoic Formations

These formations belonging to the Bhuj (Umia) series forms the most prolific aquifer system in the north eastern and north central parts and a small patch in the north of Mandvi taluka. This aquifer is extensively developed in Gadhsisa-Mau, Anjar-Khedoi-Shinugra and Ratnal areas. Bhuj Sandstone comprises of fine to coarse grained sandstone interbedded with siltstone and shale. The sandstone, which mainly forms the aquifer, is soft, friable and highly porous/permeable. The unconfined or the phreatic aquifer system in this formation extends down to a depth ranging from 20 m to about 100 mbgl depending on the presence of aquitards /confining layers. Groundwater in central parts occurs mainly in unconfined to semi-confined conditions. Due to excessive development resulting in decline of water levels, most of the dug wells have gone dry, particularly in Anjar-Khedoi-Shinugra areas. In these areas, the ground water is mainly developed through medium and deep depth tubewells ranging in depth from 80 to 200mtr. These tube wells tap aquifer zones in the depth range of 40 to 200mtr. The aggregate thickness of granular zones ranges from 30 to 100m. The discharge of tube wells ranges between 40 and 360 m3/hr with drawdown ranging between 3 and 12m. The piezometric heads / water levels in Bhuj Sandstone range from 13 to 117 m bgl. The quality of ground water in general is fresh with TDS < 2000 ppm. (CGWB, 2011)

3.4.1.2 Deccan Trap

It occurs as almost one continuous belt from Anjar to Mandvi, north of the Manchhar series rocks. While it is present in the parts of villages like Gandher and Chubdak of Bhuj, Ningal, Sinugra, Vidi, Anjar, Nagalpar Moti, Nagalpar Nani, of Anjar and also at few patches in Shinay village of Gandhidham taluka. Ground water in Deccan traps occurs in the weathered mantle and along the interflow zones, joints and fissures. Groundwater development is limited in this formation due to poor water bearing characteristics. Dug wells tap the weathered portions & joints. They are 4 to 23mbgl deep with depth to water 1.05 to 11.25 mbgl. (CGWB, 2011) There many variations in the Ground water quality with very good to good at few locations and saline to brackish at others.

3.4.1.3 Cretaceous sedimentary rocks

In the geological time scale the Cretaceous period starts from 136 ma and ends at 65 ma. Most of the upper part of the Bhuj Sandstone falls under the Late Cretaceous age and is of fluvial and deltaic origin (Biswas, 1988 as quoted in K.C. Thakker, 2004). They are exposed from Luckpat in the west to Bhachau and Anjar in the east in the mainland of Kutch. The large delta region of the Aravali Rivers of that age is the possible origin of these beds. The Bhuj Sandstone is exposed in the form of small pockets and patches in Anjar town.

The upper part Bhuj Sandstone of Kutch is highly weathered, loosely cemented, friable and non-fossiliferous. It is known that these are the best aquifer and most of the ground water is exploited from this zone. Due to high groundwater exploitation water level at these places has gone below MSL. Water from these areas is also been provided to the coastal areas because of their poor water quality. The discharge and also the Specific Capacity of the Vidi, Nagalpar Mota and Sinugra are found to be of good quality compared to the other areas which is the indicator of kind of groundwater conditions prevailing over there (Fig 3.18 & Fig. 3.19).

3.4.1.4 Cretaceous Volcanic rocks

The end of the Cretaceous period i.e. at 65 ma is a period of great changes on the earth. There occurred large scale geological, tectonic, climatic and magnetic field changes at the beginning of Tertiary era. The lava erupted from the volcanic plugs and fissures, which are clearly visible today on the surface.

The volcanic rocks of Kutch are mostly basic in nature and composed of hard minerals like augite, olivine, plagioclase etc. The most common rock types are fine-grained basalt, andesite and dolerite. Dykes and sills of the basic rocks traverse them, at many places. There are volcanic plugs found near Anjar on the way to Vidi village, where large-scale excavation of basalt rocks is in progress for the use of the road metals. Exposures of trap flows are seen near the Vidi reservoir and in the contiguous hills adjoining the vide valley. The traps here are hard, fine-grained, non-vesicular, grayish-black basalt (balasubrahmanyam, 1969). The basalt exposed within a small stretch of Anjar town show unusual variations. Near Ganga Naka it is very hard and non-vesicular variety, while near Naya Anjar at Sang River the basalt rock is rich in secondary mineral and appears as a top part of the lava flow. This stretch continues up in the northwest direction and dies down under the alluvium and Lake Sediments of the Old Anjar. This variety of Basalt is highly weathered and easily friable, so during successive periods after 65 ma, it played major role in topographic changes. The hardest parts of the lava flow are projected out as hillocks. The Timbi Kotha, is the highest hillock in Anjar and surrounding area, which considered beings the best example of the massive basalt flow in the region. (Thakkar, 2001)

3.4.1.5 Intratrappen Beds

Between two lava flows there are layers of sedimentary rocks like cherty limestone, calcareous shale and mudstone of fluvial (river borne) and laccustrine (Lake Borne) origin. These rocks are known as Intertrappean beds, which are formed during the volcanic quiescence in the area. There are lots of evidences of skeletal remains of dinosaur like animals, lizards, fish, birds, frogs, tortoise and the remains of eggs of avian as well as reptilian species found in intertrappean beds (Ghevariya, Z.G., et al, 1990). Most of the fossils bearing intertrappean rocks are found at Vidi village near Anjar.

3.4.1.6 Tertiary Sedimentary rocks

Eocene rocks of Tertiary period cover the traps and Bhuj sandstone of Cretaceous age in the north and northeast part of Anjar. They are the best source of bentonite clay in Kutch. The typical sandstone of Eocene in Kutch is pink to buff colored, highly friable and less compact in nature.

These rocks occupy the area between the coastal alluvial and Mesozoic Bhuj sandstone. Here the groundwater level is around 10-30 m above MSL in villages like Antarjal, Shinay etc. Water quality is non-potable at most of the places.

3.4.1.7 Quaternary deposits

The Quaternary period is the last phase in the geological time scale and is still running. It occupies the last 1.5 my in the time scale. In comparison to the age of the earth. (4,600 my) this period is very short but is the most interesting as far as the present landscape, drainage system and evolution of the mammalian life is concerned. The Quaternary period in Kutch is dominantly a period of formation of alluvial and colluvial fan complexes at the foothills of major hill ranges (Maurya, et al, 2002). The tectonic movements or an assemblage of numbers of major to great earthquakes have uplifted the shallow sea in the north of Kutch. This desolate land of salt encrustation is known as Ranns today. Apart from the Ranns there are coastal tracks of the alluvial sediments and also river sand bar deposits in the hilly track of the mainland (Thakkar, et al 1999).

The land of present Anjar town has undergone many tectonic and sedimentary episodes in Quaternary period. The bore log samples from the old Anjar town show loose to coarse weathered sandstone at 4 to 10 meter of depth. The top 3 m part is made up of sandy and silty sediments. The younger alluvium or channel bed and windblown deposits also represent the Quaternary period in the area. (Fig 3.2)

A sequence of about 7 m thick alluvial sediments is exposed on Sang Nadi near Meghpar, SE of Anjar. It shows gray brown, poorly consolidated clayey/sandy loam 30 cm to 1 m thick, at the top of the fluvial plain of the Sang river. It is underlain by red -brown mottled coarse to medium grained sands and calcretised pebble conglomerate of ill-sorted, crudely cross bedded with clasts of quartz, basalts, purple-black limonite coated quarts of laterite granules. These are 1 to over 2 m thick, nodular in nature and are developed extensively in this aggraded older alluvium.

These deposits locally known as mullam are used commonly in road construction as foundation fillers.

Dominant composition of Aeolian deposits is quartz sand derived locally from the friable red and white sandstone of Bhuj formation. These aeolian deposits are porous and good aquifer therefore they are used for cultivation and fanning in the area. The huge thickness of sand and weathered trappean and lateritic soil in Anjar is a classic example of change of course of river and climatic conditions as well as tectonic conditions during the Quaternary time.

3.4.1.8 Alluvium (Pleistocene to Recent)

Alluvium occurs in streams, & coastal tracts spread over almost whole study area. The alluvium comprises of brown loamy, kankary. silt, clays, sand, gravel, loam & kankar with a total thickness of about 6 m. However, in southern parts of the study area parallel to the coast, the thickness is considerably high. Depth of dug wells varies between 4 to 21 mbgl with depth to water level in the range of 1.3 to 17.45 mbgl. A few Tube wells in the depth range of 30 to 115 mbgl are also present tapping recent alluvium aquifer with depth to water level in the range of 17 to 37 mbgl. The quality is highly variable factored by distance from coast and fresh water bodies.

3.4.1.9 Structural features

Major basin bounding faults of Kutch have played vital role in shaping the landscape around Anjar. The Kutch Mainland Fault (KMF) (Biswas, 1987) is running 35-40 km north of Anjar, while the Katrol Hill Fault (KHF) is ending at the western part of the

Anjar Taluka. The possible rotational movement along the KHF might have affected Anjar town in the Quaternary period. There are many unconformities and disconformities in and around the town. There is an erosional unconformity between Bhuj sandstone of Cretaceous age and Deccan trap basalt of Lower Tertiary age.

Anjar is located on the tip of an anticlinal nose trending nearly E-W, while in the north and northeast the Tertiary strata are folded and forms an anticline known as Varsamedi Anticline (Biswas, 1987). Further in the north there are parallel synclines and anticlines, that suggests buckling of the E-W shortening basin. The general trend of the lineaments is towards NE-SW. There are many igneous dykes and plugs in the area. They are well exposed around Vidi, Malingna, Chubdak and Ghander village of Bhuj and Anjar Talukas. The volcanic plugs suggest central eruption in the area.

The diViding line between the favorably placed auriferous upper Jurassic formation and northern boundary of the intruding island of lower Jurassic is characterized by a fault which runs east-west along the foot of the low range of hills which is visible south of Bhuj and south of the road to kandla the so called Vidi-Khedoi springs and wells in Anjar are situated along this fault line. A study of the dips in this region shows that strata on the both sides of the fault (North and South) dip towards the fault. By a consideration of dips the gathering around the fault appears to be 120 sq. miles against the catchment area of the 50 sq. miles computed by the Kutch authorities for the Vidi springs. (Chablani, 1949)

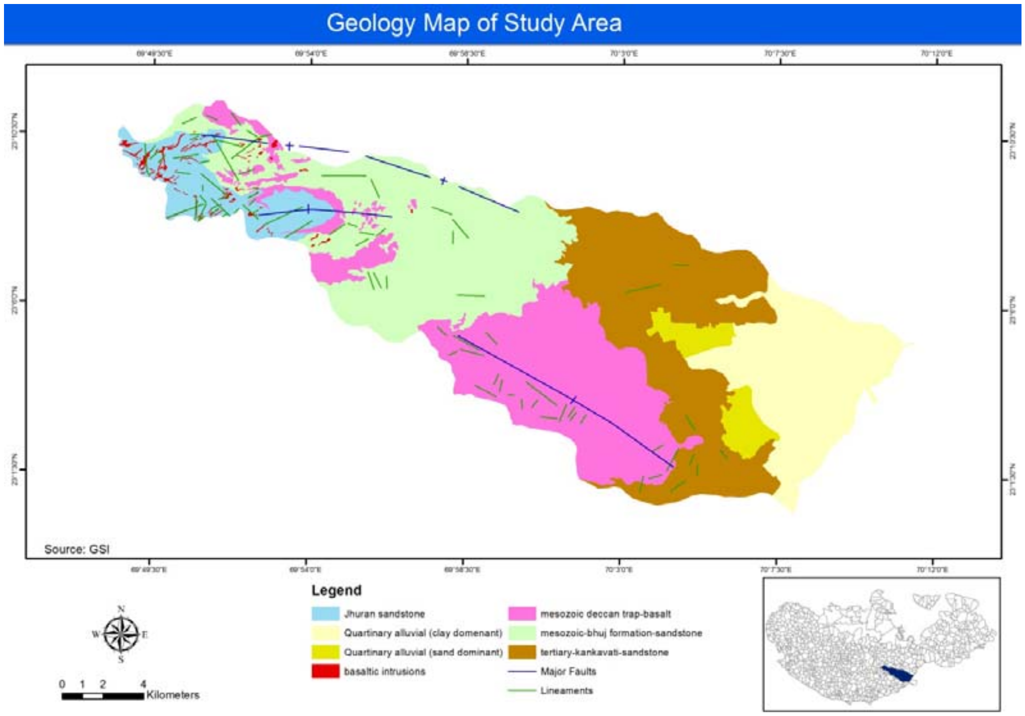


Fig. 3.2 Geological Map of Study Area

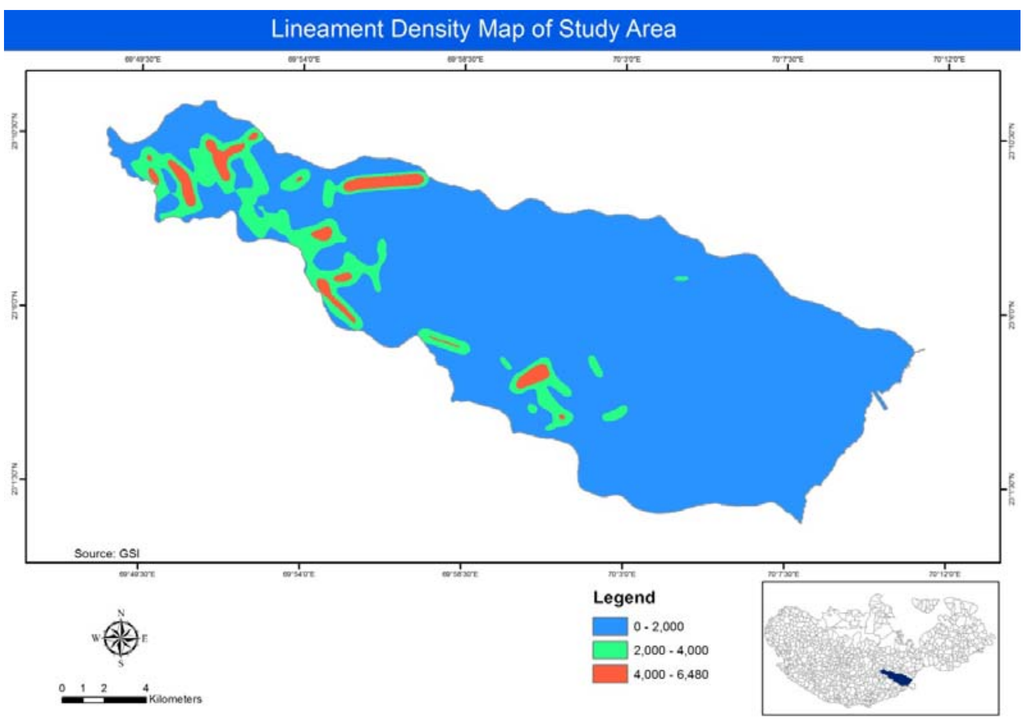


Fig. 3.3 Lineament Density Map of Study Area

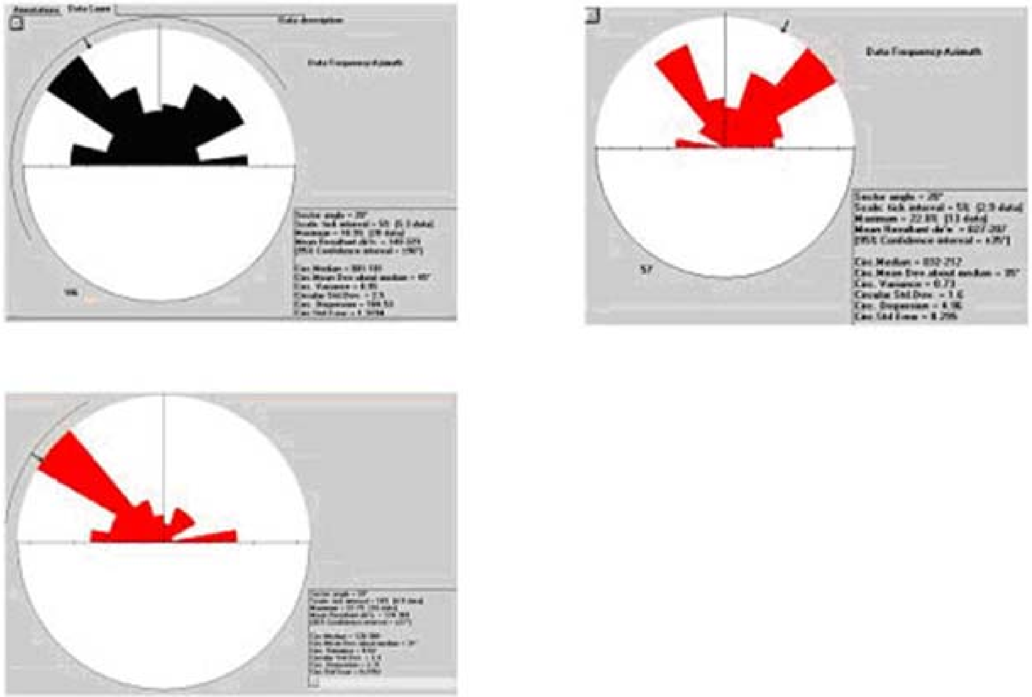


Fig. 3.4 Rose Diagram of Lineaments in Study Area

FIELD PHOTOGRAPHS:

Fig. 3.5 Exposed Basalt Formation at Anjar

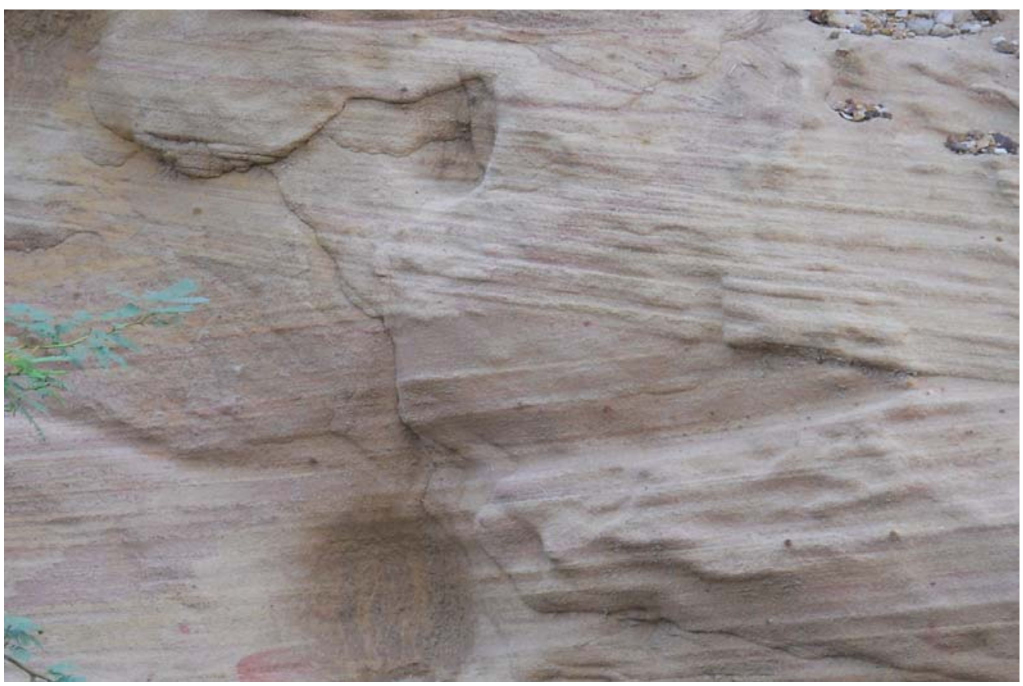


Fig. 3.6 Cross Bedding at Anjar

3.4.2 Geomorphology of Study Area

5.4.2.1 General

The interaction between Earth-surface processes (i.e. weathering, erosion, deposition) and a few sub-surface processes (notably surface movements caused by earthquakes) tends to produce distinctive sets of landforms made up of distinctive materials. Examples are fluvial processes producing terraces made up of alluvium or sub-glacial processes forming drumlins made of boulder clay. Thus from our knowledge of geomorphology we can make a fair estimate of the formative processes and component materials of a given landform. This can be very useful in hazard assessment, as landforms may provide clues to the types of hazardous processes occurring in the study area, as well as the frequency and magnitude of hazardous events. Similarly, landforms may also give useful indications of earth resources, notably various sizes of aggregate associated with coastal, fluvial and fluvio-glacial deposits.

Geomorphological mapping is based on the identification of landforms or assemblages of landforms. This involves subjective assessment by the mapper, with the most reliable maps being produced by the most experienced geomorphologists (e.g., John Doornkamp; Fookes; Brunsden et al 1975;). The best type of remote sensing data for detailed geomorphological mapping is vertical aerial photography, because of the general high degree of detail and possible stereoscopic (3-D) viewing. Image interpretation and fieldwork are iterative tasks: preliminary satellite or airphoto mapping precedes the initial field reconnaissance survey, with each stage of field survey producing additions or corrections to the image interpretation scheme. Some satellite data, notably CARTOSAT, SPOT and IKONOS panchromatic imagery (with 3 m and 1 m pixels respectively), can be viewed and interpreted stereoscopically. Digital Elevation Models (DEMs) can be generated from the CARTOSAT, SPOT and IKONOS data, allowing geomorphological mapping, 3-D visualisation and 'virtual reality' fly-overs of study areas. The only down-side of the SPOT and IKONOS imagery is its relatively high cost. However, SRTM or ASTER sensor can provide a DEM with 90 m, 30 m and 15 m pixels with best 15 m contours, equivalent to a 1:50,000-scale map for 15 m DEM. For regional-scale studies, free 1:250,000 DEM data are available from the Shuttle Radar Topography Mission (SRTM) and ASTER. One way to reduce to subjective/interpretive element is to limit a survey to morphological mapping: breaks of slope, amounts of slope and directions of slope are mapped using DEM, but no attempt is made to interpret the origin and composition of mapped features. Taking things a step further, morphometric mapping relies entirely on the mapping of slope breaks, steepness and aspect. Although this produces a map with a high degree of objectivity (and replicability), such 'walk-over' surveys take far longer than airphoto interpretation

3.4.2.2 Geomorphic Units of Study Area

In the study area, the remote sensing data (LandSat 8) has been used to delineate the different geomorphologic units. Based on the visual interpretation of the satellite data in combination with the existing data eight geomorphic units, have been mapped in the study area, which are described below. The geomorphological map is shown in Fig. 3.7

Valley fill

This unit is very important from groundwater point of view because of its high infiltration rate. In the study area, the valley fill material is deposited along the 'Sakar' and 'Song' river course. It occupies around 5 % of the total area. It is found near to Ningal, Vidi, Shinay and Meghpar Kumbhariya villages. This unit is mostly composed of sandy material. The groundwater prospects in this zone are generally good to excellent. Gandher, Malingna are having moderate prospects for groundwater recharge.

Moderately weathered pediplain

The weathered sandstone and Basalt zone where the depth of weathering varies between 10 to 20 m is identified as Moderately Weathered Pediplain. Next to the valley fills, this area is very significant because the weathered zone forms the good aquifer. This geomorphic unit occupies around 25 % of the total area. This unit is found in and around Gandher, Malingna, Dabda, Shinay, Khambra, and Bhadroi.

Shallow weathered pediplain

The weathered granite gneiss area where the thickness of weathering is less than or around 10 m is delineated as Shallow Weathered Pediplane. Out of the total area, this unit covers about 19% of the total area. This area forms the aquifer wherever the fractures / joints traverse this unit. This geomorphic unit is found especially away from the stream courses in the villages of Anjar, Bhadroi, Sinugra etc.

Inselbergs

The study area is covered with the small inselbergs. These are the remnants of erosion and weathering of the basalt rocks, which stand alone as inselbergs. The inselbergs form run-off zones and are not suitable for groundwater development

Linear ridges

These are mainly the remains of Basalt dykes, which occur, as linear ridges because of their resistant nature. In the study area, the linear ridges of dykes are mainly trending in North- East to South -West directions. These are very significant from groundwater point of view. And they act as groundwater barriers and control the movement of groundwater

Alluvial Coastal Plains

These are mainly the quaternary alluvial, which is highly brine due to the effect of the seawater intrusion.

Denudo structural Hill

This are the hill with the highest elevation in our study area with the height reaching upto 250 m. this hill are basically of sandstone and falls in Mesozoic Jhuran formation.

Structural Hill

These are the hills which are governed by structure like recumbent fold near Ningal village.

Dissected Plateau

The rocky tracks with nearly flat tops to the disserted plateau comprise the basalt lava flows of the deccan trap and nearly horizontal bedded ferruginuous and friable sandstone belonging to the Bhuj formation. They form the western and southwestern geomorphic domain of Anjar area. Few narrow and linear residual ridges have developed over the basic igneous dukes in the south of the Anjar town. The dissected plateau is further distinguished into three sub-units. Dissected upper plateau made up of basalts, ranging in general elevation from 65 to over 100 mtr msl. The plateau extends east to west and shows moderate to intense dissections trending NE and NW directions. Dissected lower plateau made up of basalt and sandstone ranges in general elevation from 60 to over 80 mtr msl. These undulating surfaces have been altered into terraces at different levels and converted into cultivation fields. Low mounds of laterite constitute the geomorphic unit in the northern and NW part of Anjar area. These low mounds grade into an area surrounded by the fluvial plain deposits of alluvium and reworked Aeolian sands.

Deeply weathered pediplain

The weathered sandstone and Basalt zone where the depth of weathering is more 20 m is identified as deeply Weathered Pediplain. These weathered zone forms the good aquifer. This geomorphic unit occupies around 14 % of the total study area.

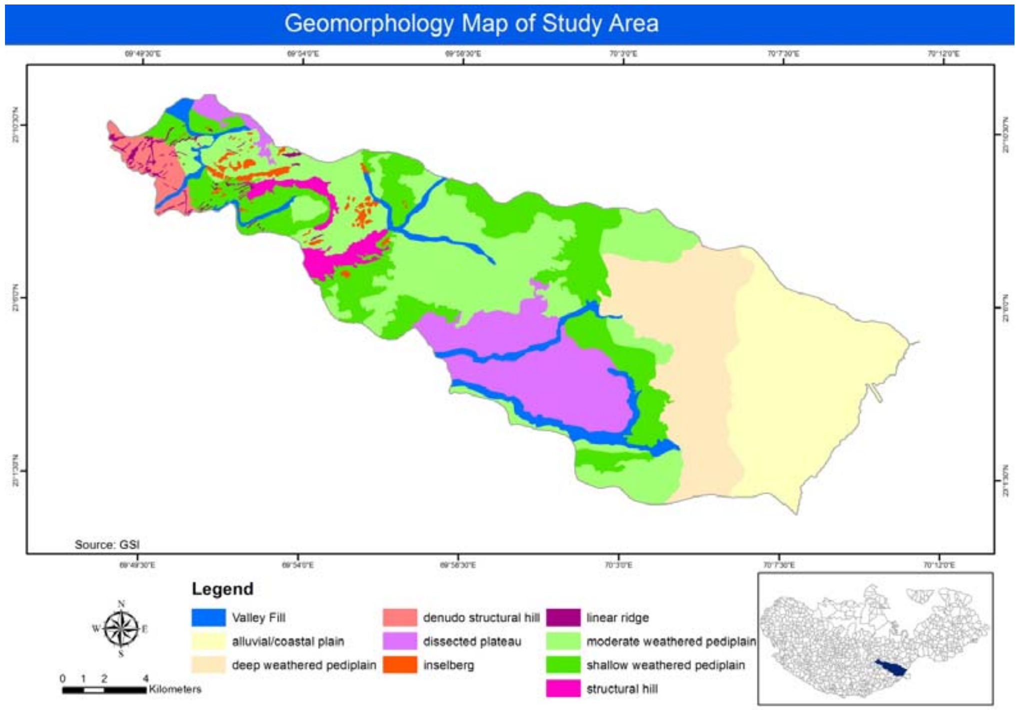


Fig. 3.7 Geomorphology of Study area

Field Photographs:

Fig. 3.8 Structural Hills seen at Anjar Taluka

3.4.3 Soils of Study Area:

The soils found in Kutch district can broadly be grouped into four types, i.e., Shallow Black soils, Residual Sandy soils, Coastal Alluvial soils and Desert soils. (Sandeep Vidyarthi, 2013). Out of these three major types of soils found in the study area. The **Shallow black soils** are found near the southern part of Anjar i.e near Vidi and its surrounding area. These soils have developed from basaltic rocks and rocks of Jurassic period. The depth of soil ranges from a few cm to 30 cm. Reddish brown colour soils with fine granular structure to poorly developed one was seen at **various places in Anjar**. These soils are sandy to sandy loamy in texture dominated by coarse sand. These **Residual Sandy soils** are developed in-situ from the parent material originated from red sandstone and shale and are fou**nd mostly over the areas underlain by Bhuj Sandstone.** These are the few areas on the northern part of Anjar, Nagalpar Nani, khambra Sapeda and parts of Ningal villages. All these residual soils are shallow in depth. These are non-calcareous, neutral to alkaline in reaction with poor base saturation. They may be affected due to salt accumulation. The soil profile is not well developed at places along hill slopes because of the steep slope and erosion. They are formed from the parent materials existing in the respective areas. They are shallow in depth made up of undecomposed rock fragments. The **Coastal Alluvial soils** are found all along the southern coast i.e. Gandhidham. These soils are sandy clay loam to clay in texture. The soil reaction varies with situation ranging from neutral to highly alkaline. At places, these soils are saline in nature. The alluvial deposits due to the river system flowing through the area have subsequently been overlain by the aeolian deposits. These soils are fairly deep, light grey in colour. The texture is sandy to sandy loam with silty clay loam in some areas. Half of the Abdasa, Anjar and Mandvi talukas are covered by marginally saline to high pH class (Shah and Thivakaran, 2014). Few non saline area was observed in parts of Anjar towards the north. A generalized map of Anjar soil with its description is shown in Fig. 3.9

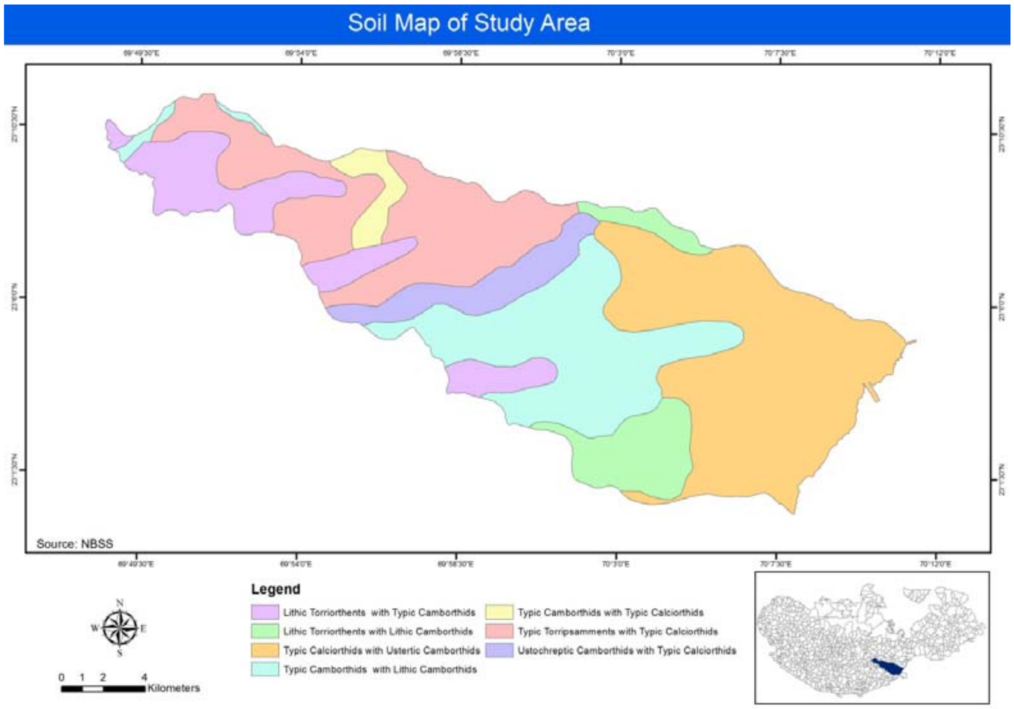


Fig 3.9 Soil Map of Study Area

Field Photographs:

Fig. 3.10 Fine grained Yellow Soil at Anjar

3.4.4 Hydrology of Study Area

3.4.4.1 Aquifer Geometry-Shallow and Deeper

The study area has both shallow and deep aquifers. The shallow aquifers have been considered up to the depth of 25 mbgl and are developed mainly by dug wells covering all the hydrogeological units. Due to heavy exploitation, most of the dug wells have dried up. The dug wells inventoried during course of study are mostly situated near favourable situations such as water bodies, river beds etc. The deeper aquifers are the main user aquifer in the study area and are developed by dug-cum bore wells and tube wells. The depth of the deeper aquifers is 30-152 m within study area. Deeper aquifers are mostly tapped in Manchhar series and Bhuj series rocks. (CGWB, 2011). While this has deepened to almost 190 mbgl during the current field study at many areas within the study area. This is represented in the Fig. 3.15 & Fig. 3.20 of SWL map and SWL wrt MSL

3.4.4.2 Depth to water level

The depth to water level in the shallow aquifer varies between 1.3 mbgl to 39.65 mbgl in the alluvium formation. In basaltic aquifers it ranges between 1.05 to 11.25 mbgl. Aquifer tapping Manchhar series have the depth to water level between 1.5 to 30.08 mbgl.The depth to water level in the deeper aquifers tapping Manchhar series ranges from 33.61 to 105.78 mbgl.The depth to water level in the deeper aquifers tapping Bhuj series ranges from 34.65 to 117.9 mbgl.The depth to water level in the shallow aquifer during the post monsoon period varies between GL to 34.85 mbgl in the alluvium formation. In basaltic aquifers it ranges between 1.75 to 11.25 mbgl. Aquifer tapping Manchhar series have the depth to water level between GL to 16 mbgl. The depth to water level in the deeper aquifers tapping manchhar series ranges from 30 to 87 mbgl. The depth to water level in the deeper aquifers tapping Bhuj series ranges from 24to 130 mbgl. (CGWB, 2011).

Wide fluctuation in the water levels is observed in response to the monsoon. During the study period the area received good monsoon. Except a few places, there is general rise of few meters to 27.71 m considering all the aquifers. The wells tapping shallow aquifers in alluvium formation shows rise in water level in the range of 0.38 to 11.41m compared to pre monsoon water levels. The shallow aquifers tapping basaltic formation shows rise in the range of 0.05 to 6.67m compared to pre monsoon water levels. The shallow aquifers tapping Manchhar formation shows fluctuation in the range of -0.15 to 19.33m compared to pre monsoon water levels. The deeper aquifers tapping Manchhar formation show rise in the range of 0.21 to 17.5 m compared to pre monsoon water levels. The deeper aquifers tapping Bhuj formation show fluctuation in the range of -7.97m fall to 27.71 m rise compared to pre monsoon water levels. (CGWB, 2011).

The attempt was also made to observe the changes between the pre-monsoon and the post-monsoon water level fluctuations. The rise in water level ranges from few meters to about 15 mtrs from the observation sites during the study. However there was no particular trend observed. This may be due to the surplus rainfall observed during the period of 2015 in Anjar taluka.

Near Ningal village a rise of water level was around 12 meters. In case of Ningal taluka, it can be said that the location of the tubewell under observation was closer to the village pond. Also there has been a dam constructed near the village. This may be a reason for such a rise in the water level observed in that area. Hence this analysis could also be particularly helpful in suggestion of a recharge site.

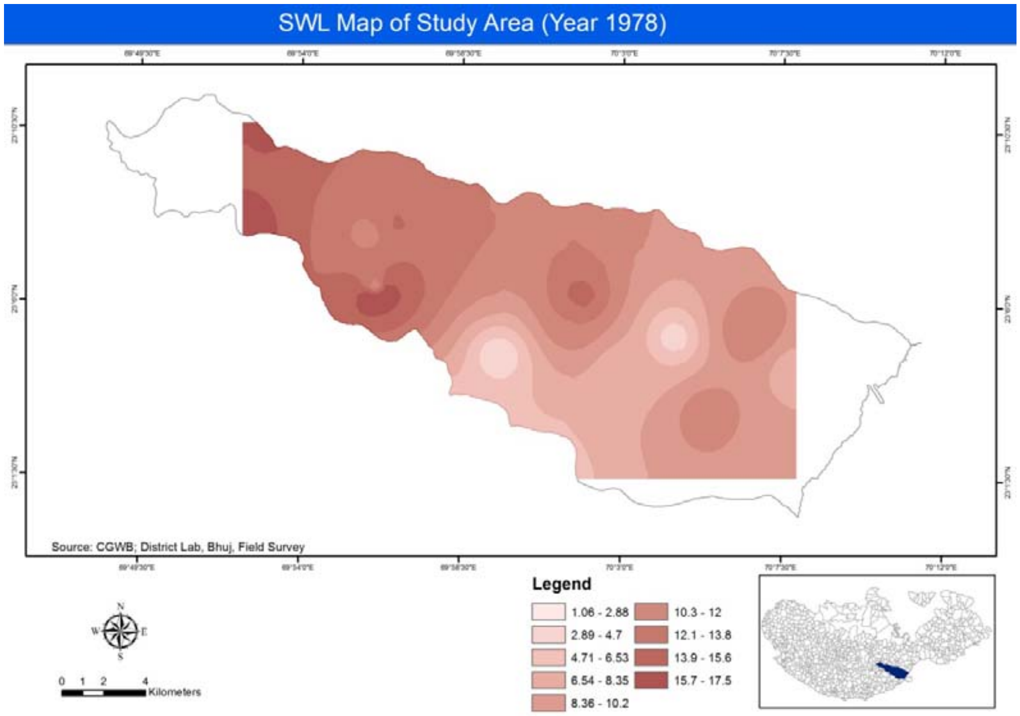


Fig. 3.11 Maps of SWL for the year 1978

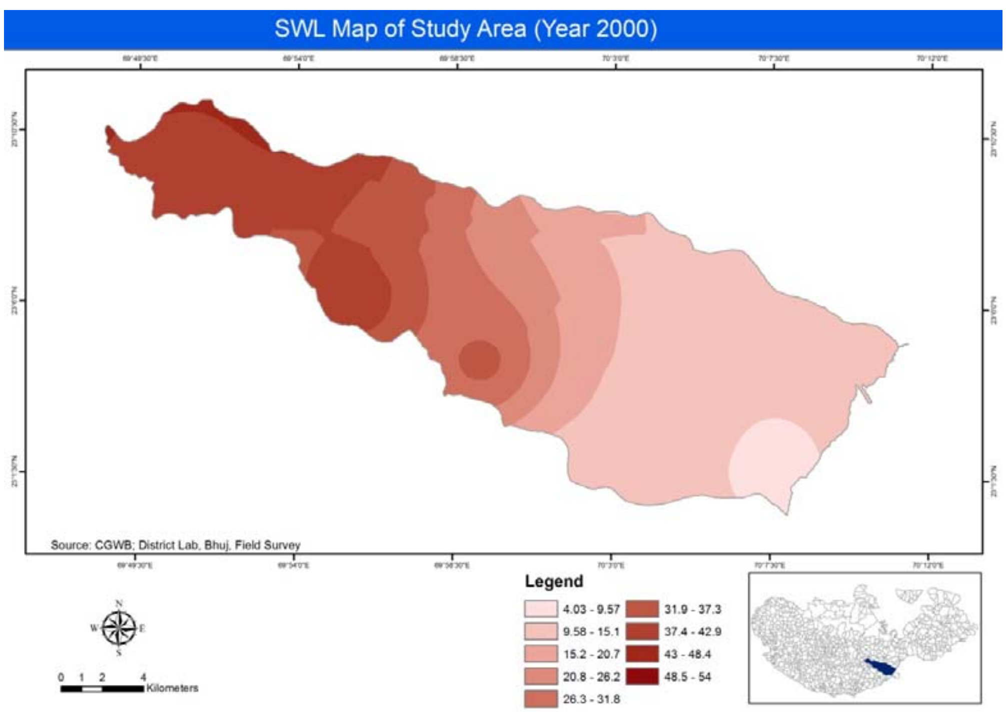


Fig. 3.12 Maps of SWL for the year 2000

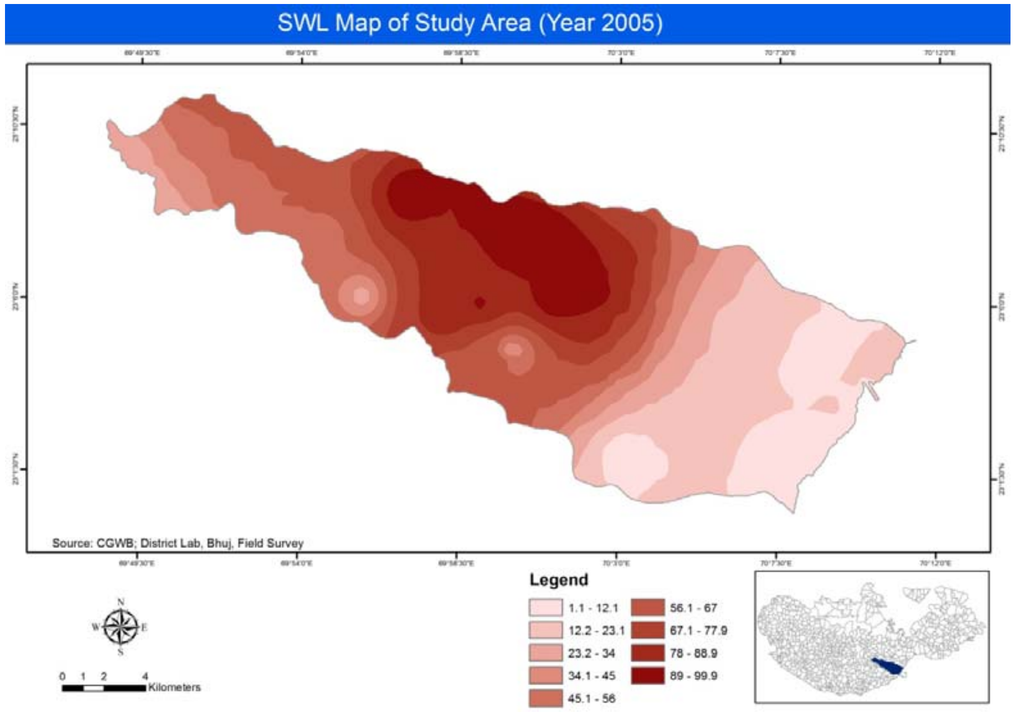


Fig. 3.13 Maps of SWL for the year 2005

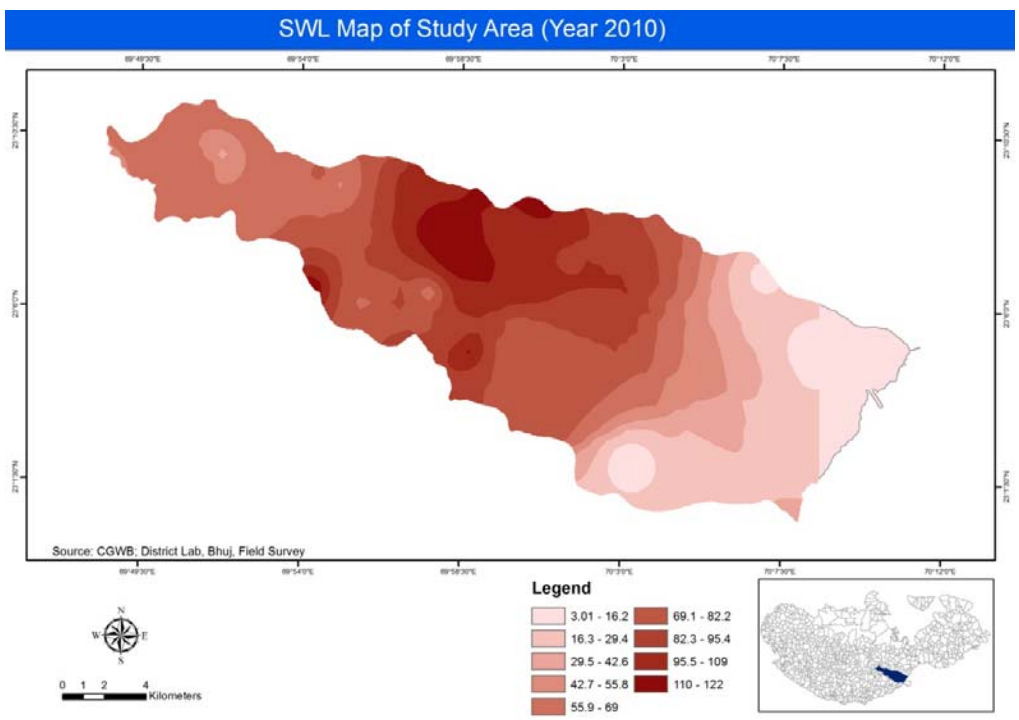


Fig. 3.14 Maps of SWL for the year 2010

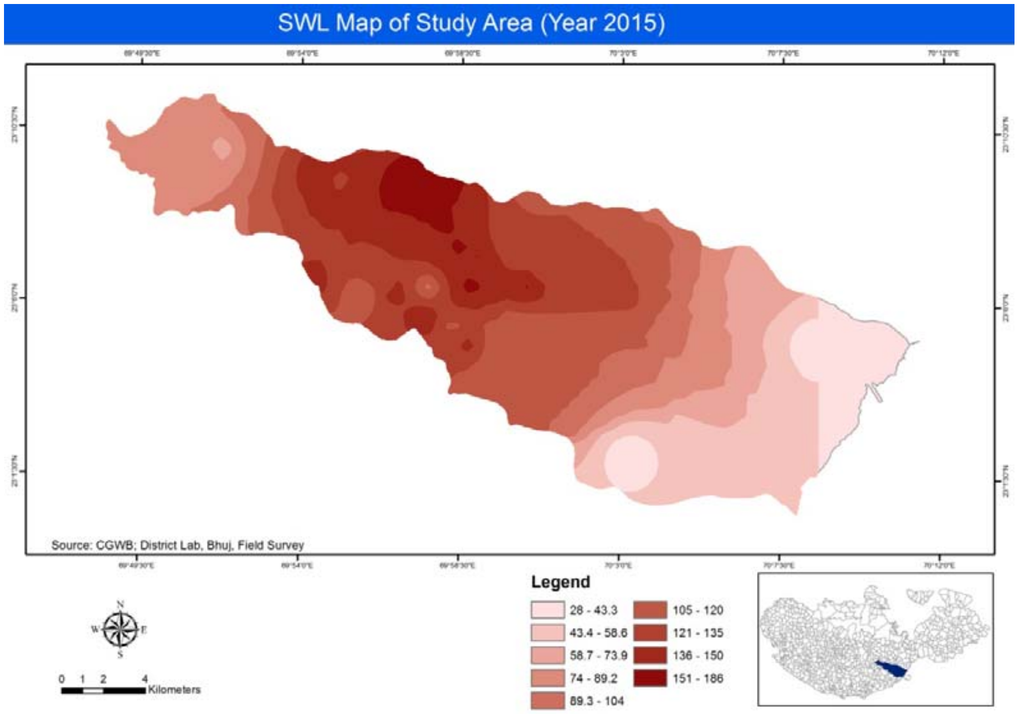


Fig. 3.15 Maps of SWL for the year 2015

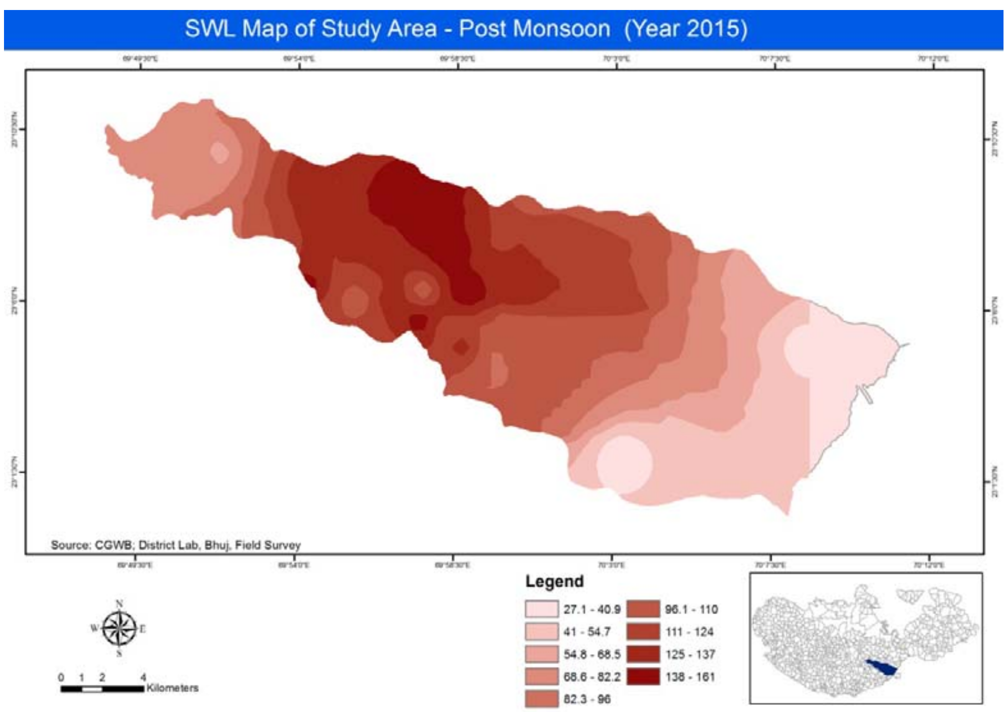


Fig. 3.16 Maps of SWL for the year 2015 Post Monsoon

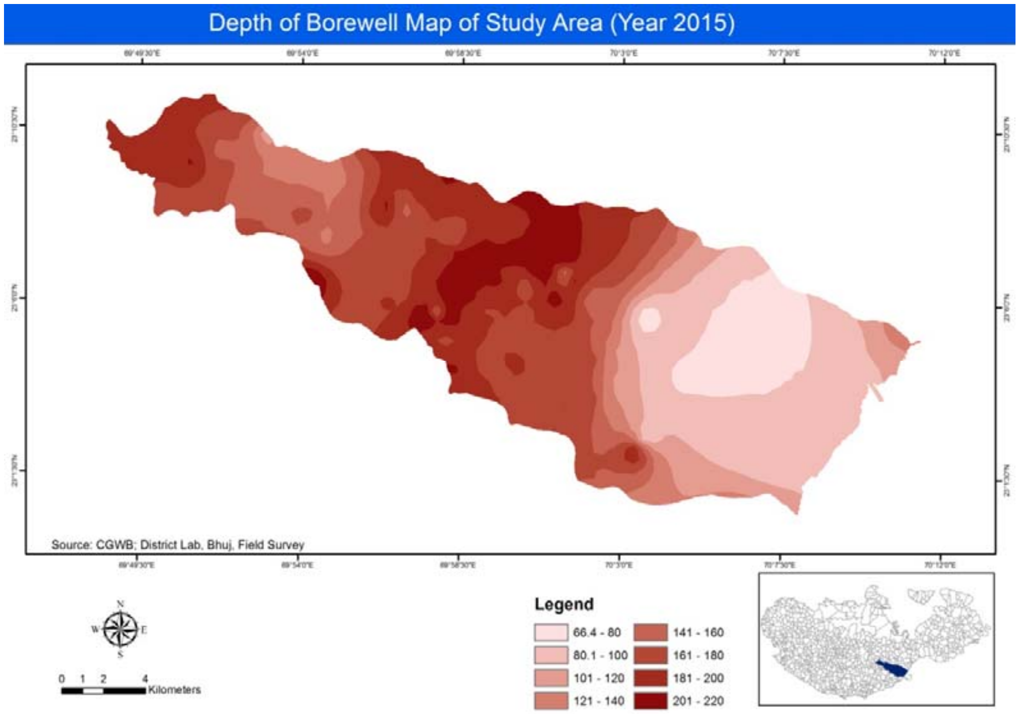


Fig. 3.17 Depth of Borewells Map for the year 2015

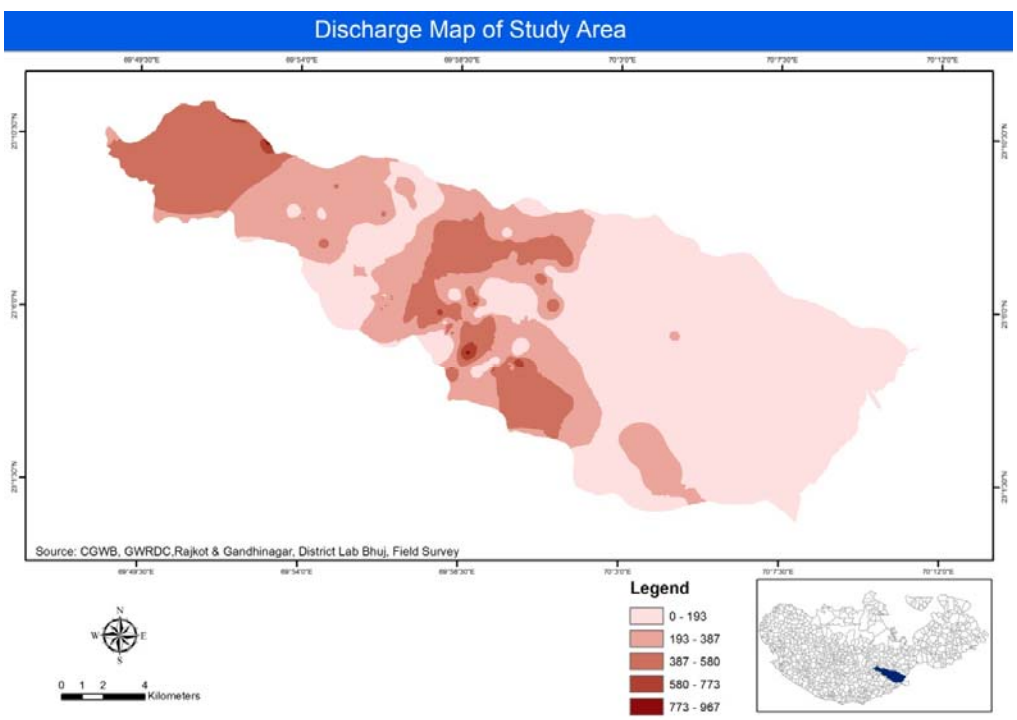


Fig. 3.18 Discharge Map of Study Area

Depth of bore well ranges from 66 mtrs to 220 mtrs with the study area. This is in particular helpful while correlating this map with the SWL map, sp. capacity and discharge map to understand the groundwater regime of the study area. This has been incorporated in the final groundwater prospect map for the suggestion of recharge sites. The data of drawdown was collected from the pump test results from various sites.

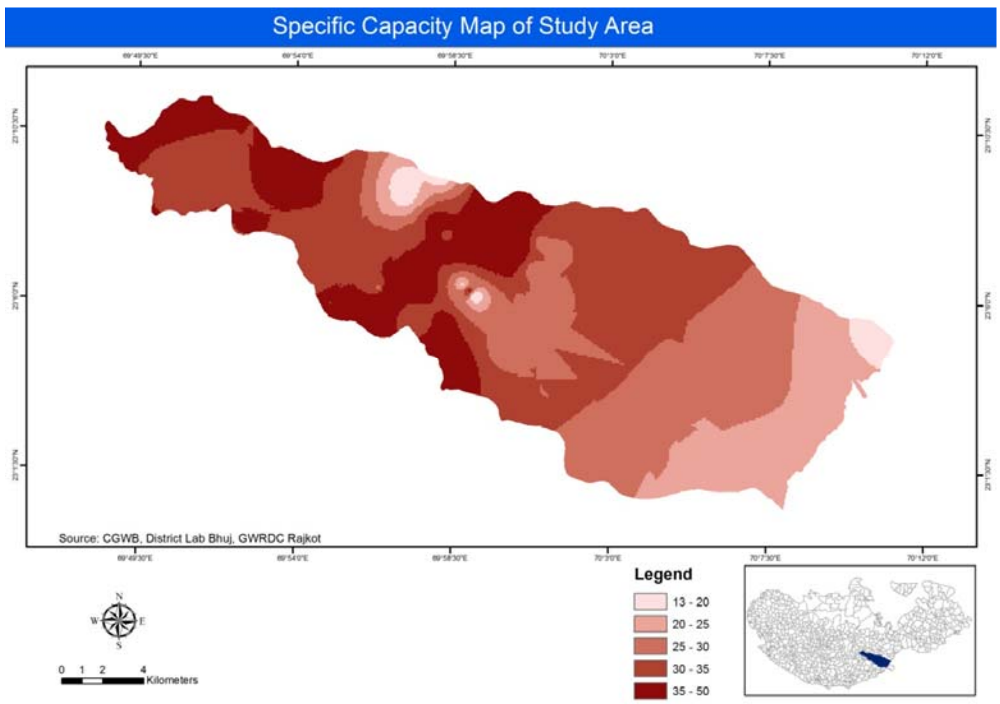


Fig. 3.19 Specific Capacity Map of Study Area

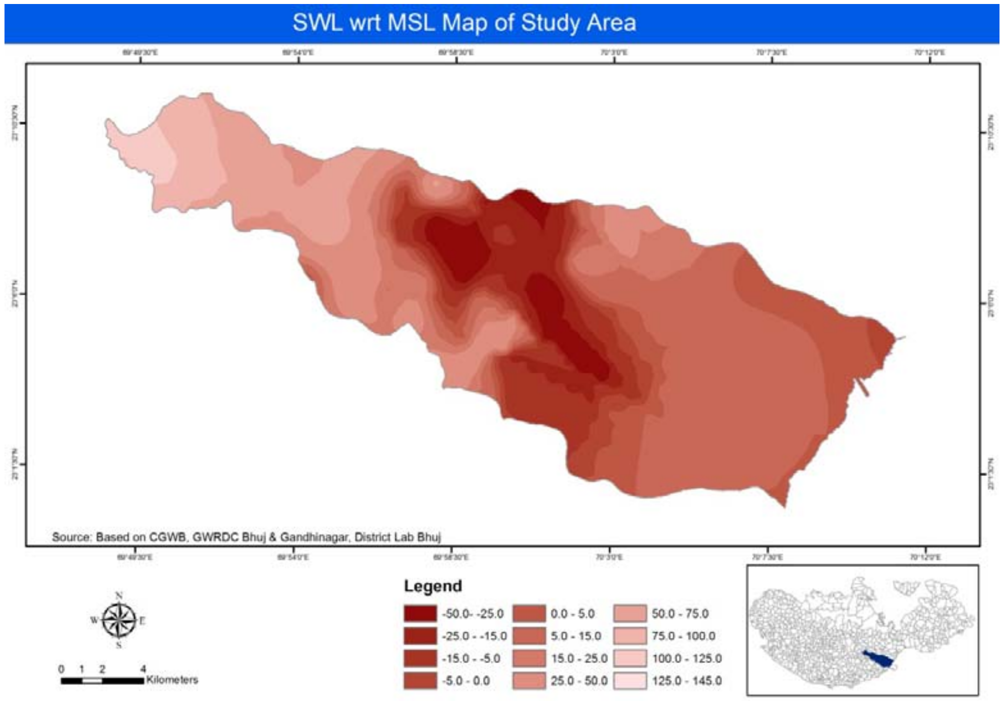


Fig. 3.20 SWL wrt MSL Map of Study Area

Field Photographs:

Fig. 3.21 White patch seen on an exposed rock formation due to salinity

Fig. 3.22 Bore cum recharge well at anjar

Fig. 3.23 Field visit to various Borewells site with Sr. Geologist Kuldipsingh Bist, Bhuj Division

3.5 THREE DIMENSIONAL MODEL OF STUDY AREA

The whole purpose of this study was to understand the sub-surface geology of the study area in a better visual form.

3.5.1 Methodology:

1. Initially all the data from the published reports were gathered in order to understand the surface and sub-surface geology of the study area.
2. Lithologs were collected from the GWSSB, District lab Bhuj and local contractors and an attempt was made to associate it with the geophysical logs generated in the field with the help of Uptron Geophysical Logging machine from Uptron, Lucknow.
3. Location in terms of Lat/Long. of the borewells were verified and confirmed on site during the field visits.
4. Water levels and average drawdown during the pumping were also identified for the wells under observations as well as for the wells whose lithologs were available for 3 dimentional modeling.
5. GMS software was used to generate 3D model of the study area.
6. Drainage map was superimposed on the 3D model for better understanding.
7. Due to the complex geology of Kutch the data was generalized for visualization purpose durng the development of 3D model however the same details were shown during the cross-section i.e. Fine, medium and coarse sand to Sand (in general).

8. Fence diagram, Borewell lithologs, cross-sections and solid 3D model were generated for the study area and water level along with the MSL were also represented in the model for visual clarity.

3.5.2 Geophysical Investigation

Geohydrological survey is supplemented by Geophysical Resistivity test to ascertain the depth & thickness of aquifers/weathered or fractured zones at shallow to deep horizons so that suitable location and design for rain water harvesting structure can be detected. For Geophysical survey, the Electrical Resistivity method is the best and most reliable for ground water prospecting. All geological formations possess a property called electrical resistivity, in which the current flows through them. Resistivity, thus is defined as the resistance offered by a unit cube of material to direct current flow through it in a direction perpendicular to two of its opposite faces. The numerical value of the resistivity is expressed in "Ohm.m". Thus the electrical resistivity is principally based on the study of resistance offered by the sub-surface formation to the flow of current. The study helps in evaluating the characteristics of the sub-surface layers in terms of electrical Resistivity.

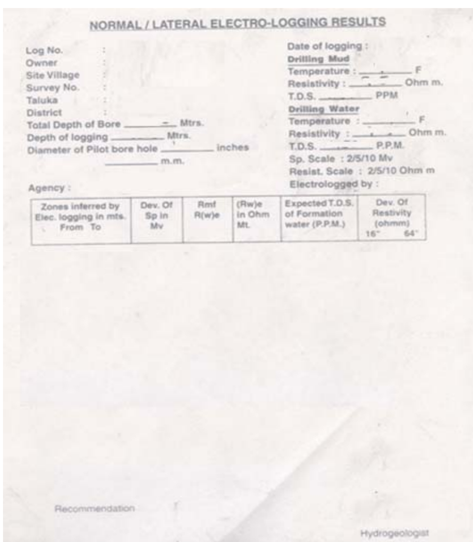
3.5.2.1 Subsurface Geophysical Logging

Surface logging was supported by a subsurface geophysical logging for better results and accuracy. In this study a geophysical logging prepared by "UPTRON ltd., Lucknow govt." was used for determining the accuracy for the groundwater acquifers.

Based on the comparison of deflection of curves of SP and “short Normal-16’” and “Long Normal-32’” resistivity with the TDS of water found in the Mudpit of the waterwell, a approximate quality and the quantity of the aquifers are inferred.

Results found very accurate and much reliable than any other systems for finding out the groundwater prospective zones.

The water quality was also confirmed with a hand held TDS meter HANNA DIST 2 which can measure upto 0.0 ppm to 10,000 ppm for the immediate understanding of the water quality within the study area.



NORMAL / LATERAL ELECTRO-LOGGING RESULTS

Log No. :
Owner :
Site Village :
Survey No. :
Taluka :
District :
Total Depth of Bore ________ Mtrs.
Depth of logging ________ Mtrs.
Diameter of Pilot bore hole ________ inches
________ m.m.

Date of logging :
Drilling Mud
Temperature : ________ F
Resistivity : ________ Ohm m.
T.D.S. ________ PPM
Drilling Water
Temperature : ________ F
Resistivity : ________ Ohm m.
T.D.S. ________ P.P.M.
Sp. Scale : 2/5/10 Mv
Resist. Scale : 2/5/10 Ohm m
Electrologged by :

Agency :

Zones inferred by Elec. logging in mts. From To	Dev. Of Sp in Mv	Rmf R(w)e	(Rw)e in Ohm Mt.	Expected T.D.S. of Formation water (P.P.M.)	Dev. Of Restivity (ohmm) 16" 64"

Recommendation

Hydrogeologist

Fig. 3.24 (a) Geophysical Logging Report

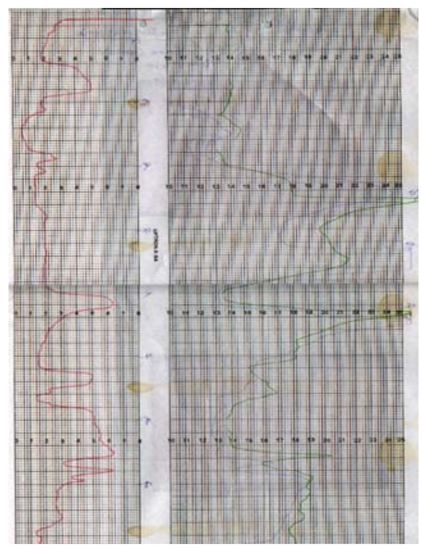


Fig. 3.24 (b) Geophysical Logging Graph

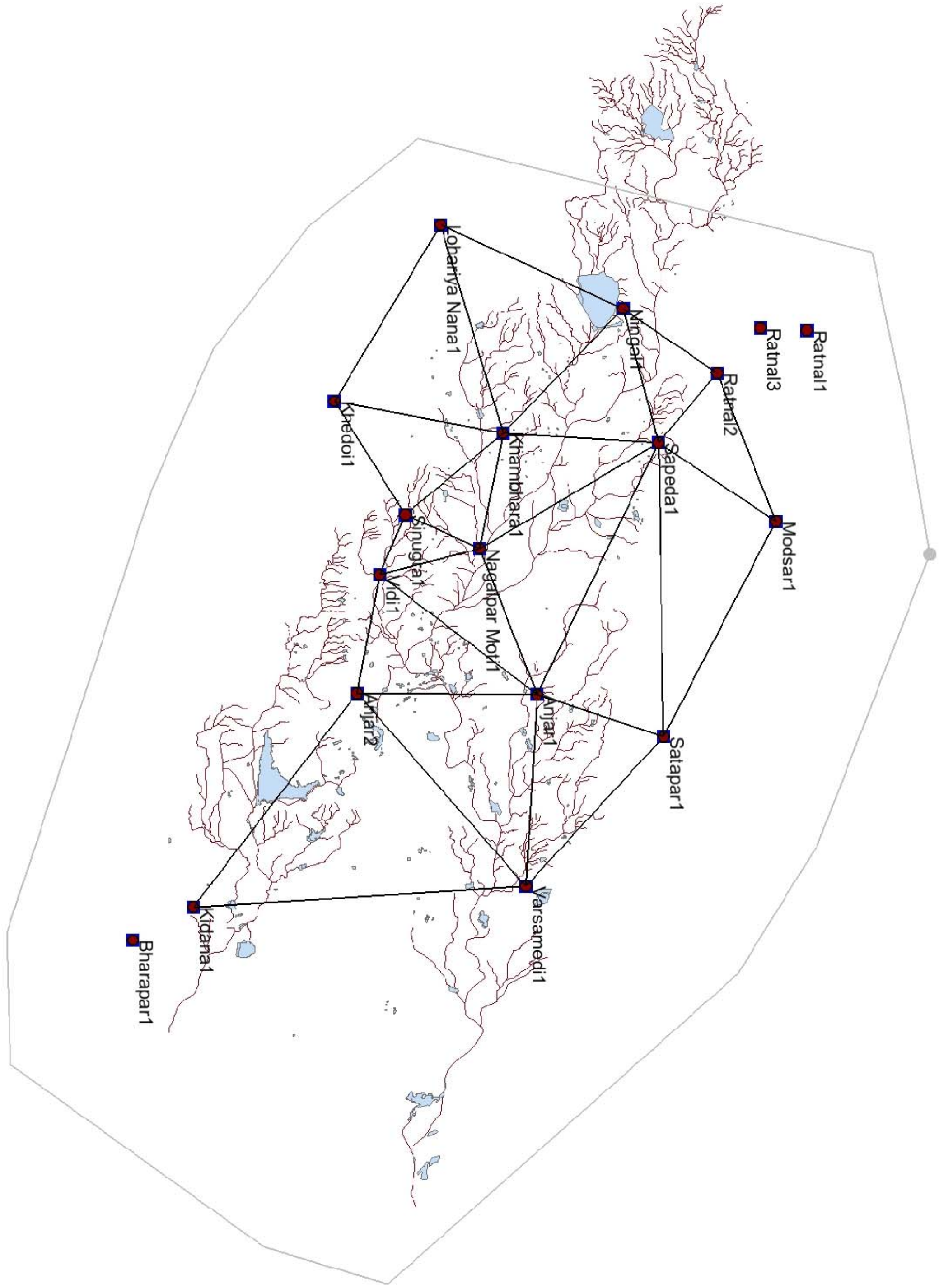


Fig. 3.25 Location of the Borewell Lithologs

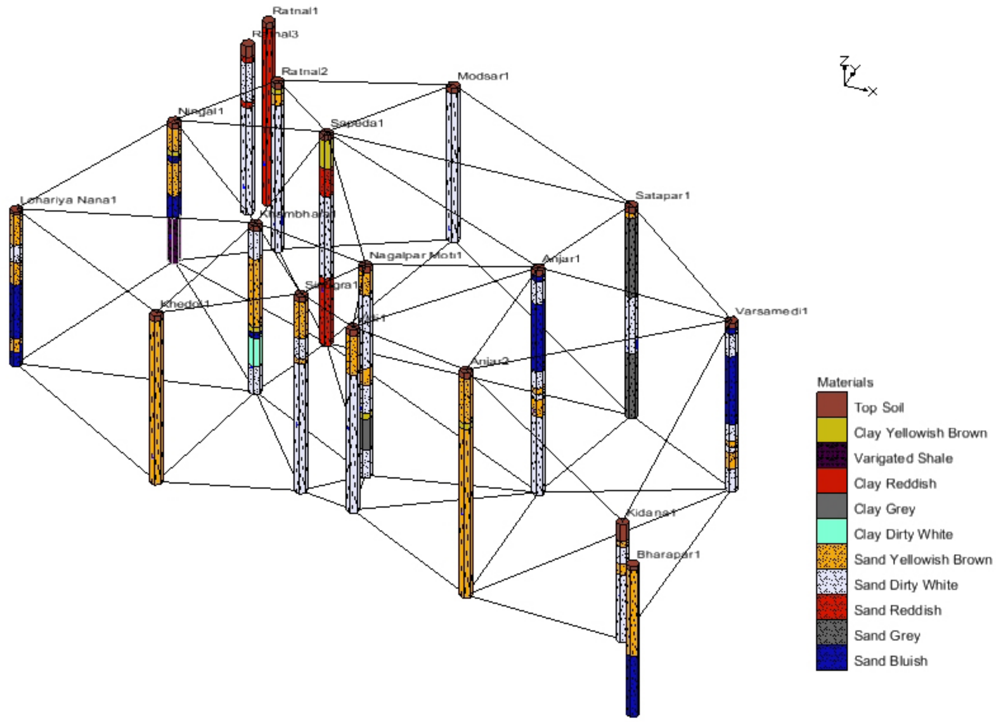


Fig. 3.26 Borewell Lithologs of the study area

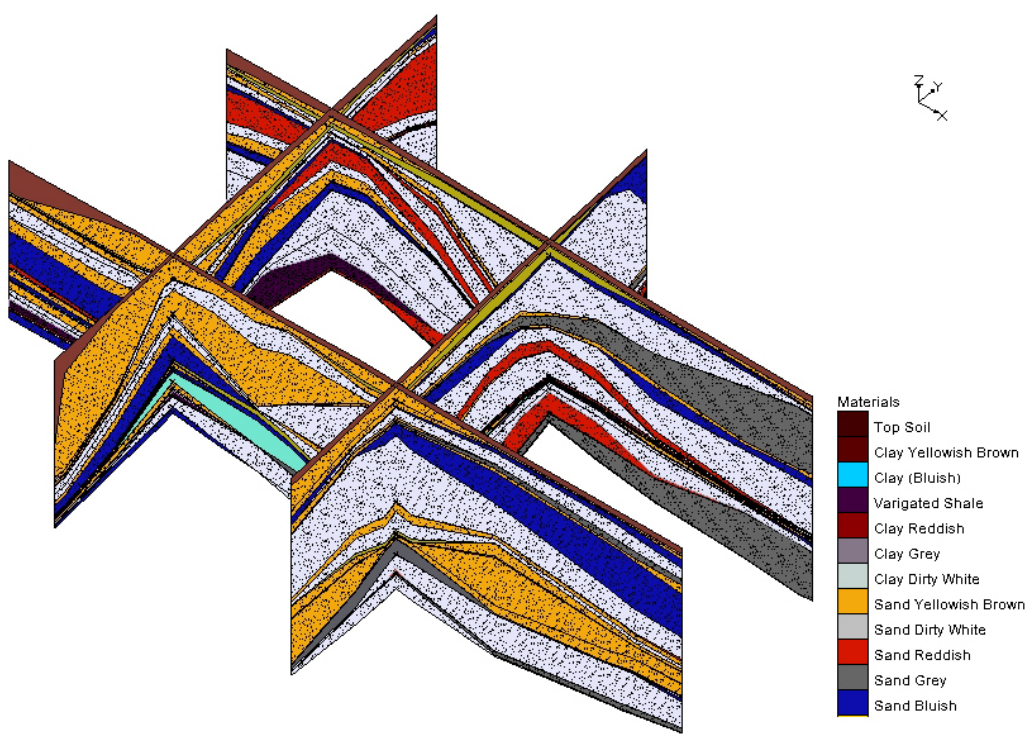


Fig. 3.27 Cross Sections from the Solid 3D model of the Study Area

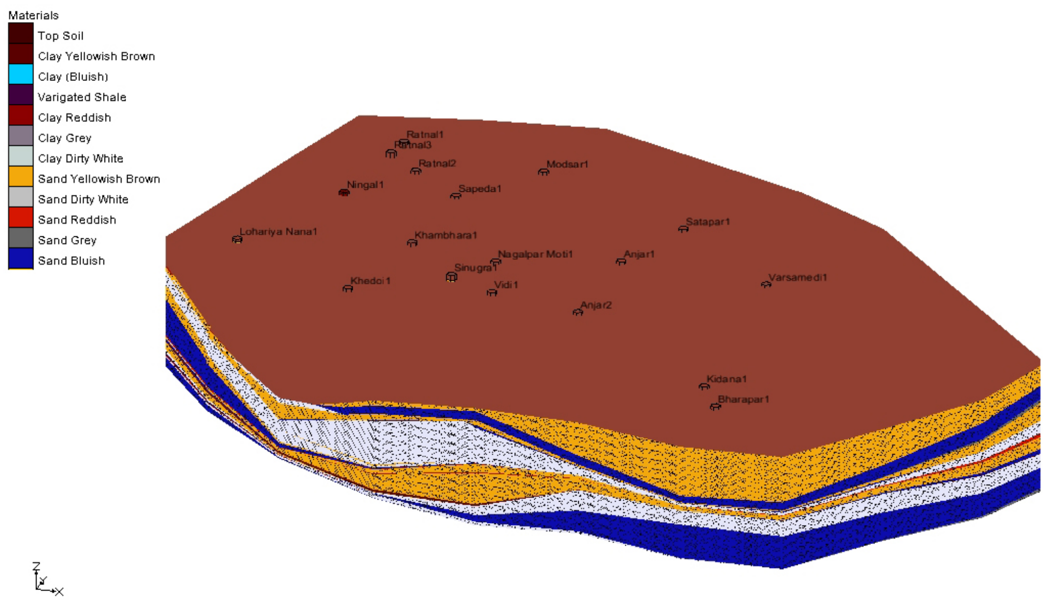
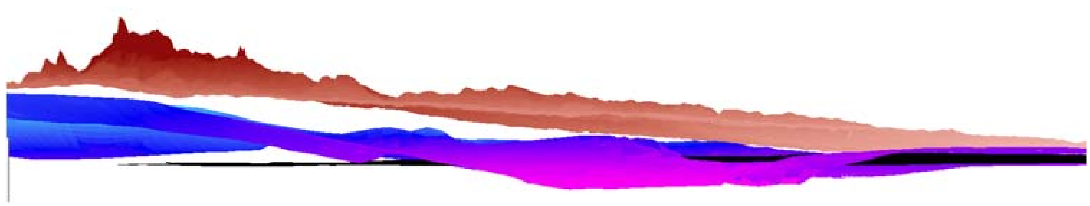


Fig. 3.28 3D solid Model of the study area



Brown=Terrain; Black Line = MSL, Blue-Pink=SWL wrt MSL

Fig. 3.29 Water table wrt Ground Level of Study Area

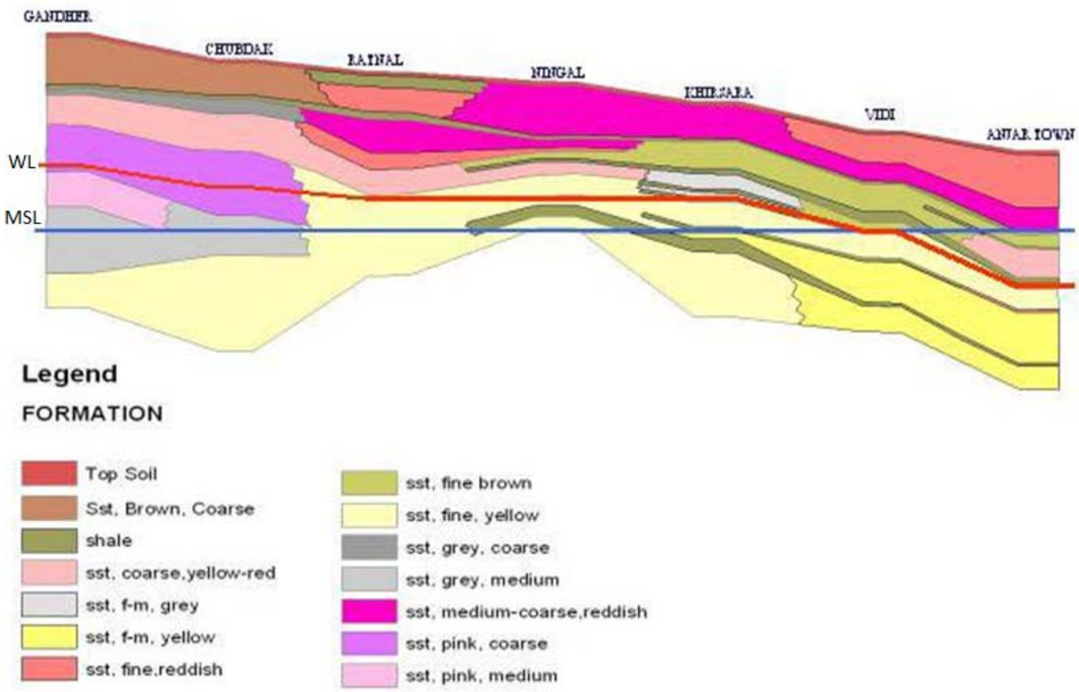


Fig. 3.30 Cross Section of Seven Villages of Anjar Taluka

3.6 CONCLUSION

The problem of water supply at Kandla and Gandhidham is a part of the larger problem of the supplies of domestic, municipal and irrigation water in Kutch as a whole. Both aspects are briefly described here. Water is without question the most important mineral possessed by Kutch, a mineral which is renewable, but not perennial so in view of the occasional almost complete failure of the rainfall.

The groundwater resources may be considered to be a sub-surface reservoir, the capacity of which depends on the degree of percolation of direct surface precipitation and stream run-off, and the amount of withdrawal from wells by means of pumps.

The succession of the study area consists of alternations of water bearing and water yielding strata, with shale beds, which will not yield water. Whether or not the permeable strata will yield water depends on the geological structure. Uniformly flat-lying beds might prove to be water barren in the lower levels, since the topmost major horizontal shale beds would prevent percolation of rainwater downwards to the subsurface. Consequently it is essential to consider the geological structure. This is utmost important in case of Kutch as well as study area as it represents one of the most complex geology in Gujarat and probably in india as well.

Anjar taluka of Kutch District is a classic example of a junction of various geological formations, which have different modes of origin in geological time. Various types of geological rocks formations are seen within the town itself. A small patch of Lower Cretaceous sandstone is exposed at the north, NW and middle part of the town, while Late Cretaceous to Early Tertiary basalt rocks of volcanic origin covers the town from west and south. The Intertrappean beds of cherty limestone of lower Cretaceous age are also found in the area. The weathered basalt and Laterite rocks is capping most of the southern part around the town. Loosely cemented sandy rocks of partly pyroclastic origin of the age of Lower Tertiary covers the older rocks in the north and northeastern part of Anjar town.

From a report by J. B. Auden in 1949 it was noted that there are numerous intrusions of basic rocks in the Jurassic and cretaceous sedimentary. A conspicuous NW-SE dyke is well seen from the air extending for 5 miles in the Katrol range south-east of Bhuj. There is an evidence of Wynne's geological map, which suggests that some of the dykes may be radial to possibly dissected volcanic centers or plugs. These dykes are likely to have an important local influence on the migration of groundwater in the direction of the rising hydraulic gradient, and lowering it on the opposite side in the study area. The water table was higher on the south side of the Ratnal dyke than on the North side. Such influences will have to be borne in mind in selecting sites for deep borings in search of artesian water.

Examination of the rainfall data available appears to indicate that a total failure of the monsoon is not unknown in this region and that is quite often, two (and sometimes three) successive years of scanty rainfall occurs.

Most of the water on the coastal side is brackish due to seawater intrusion. But dug wells up to the depth of 70 ft. can still be dug for the purpose of drinking water. As we go below it the water quality deteriorates.

Bhuj formation is found to be the best site for recharge. It also possesses better groundwater quality compared to surrounding area. The soft and friable sandstone acts as a good aquifer in these areas within the study area however at Khirsara (falling outside of our study area) the shale intercalation affects the groundwater locally. Most of the agriculture is done in these areas.

Due to the high exploitation of groundwater around these areas the SWL has gone even below the MSL. It varies from –50 m below MSL at the places like Anjar and Nagalpar Taluka to about 145 m above MSL at ghander and Chubdak. Water from the central part of the Anjar i.e. Villages like Vidi, Anjar, Khamra, Nagalpar Mota, Sinugra provide water to the coastal areas through different governmental schemes. The TDS of around 600 to 1200 ppm is found in these areas that falls within the WHO standards.

From the existing government data and local interaction with the villagers it is noted that there is a problem of iron persisting at some places like Bhadroi, Nagalpar Mota, Khedoi, Malingna, Sinugra etc.

On the far west of the study area near to Ningal and Gandher village the water quality is nearly potable i.e.2000-3000 ppm. Majority of the Lineaments are seen in these part of the study area affecting the groundwater quality and quantity locally i.e. dykes as well as fault.

Ningal village is situated at the foothills of a structural hill, which also acts as a runoff zone. Chubdak is other such area that acts as a runoff zone for the surface water.

Conservation of rain water both in the underground basins and in surface storage reservoirs, depends upon several factors such as:

- Total rainfall and intensity of showers
- The porosity or otherwise of the soil
- The conditions of the surface i.e. whether the surface soil is dry or damp or wet or saturated
- The surface slopes, conformity of the basin etc.,
- Vegetation
- Conditions of climatic and weather, like humidity temperature prevailing winds etc.

As a rule, factors that make for maximum conservation of water in the subsoil basins militate against conservation of water in surface reservoirs.

The nature of the soils is porous and permeable but they have further disadvantage of having inclined or even particular attitude presenting upturned edges, generally in a direction at right angles to the flow of surface water, facilating the entry and preservation of water. These is particularly the case in the central part of the Kutch region i.e. Bhuj and Anjar (Chablani, 1949).

Where massive sandstones of the Jurassic series composed of auriferous formations are exposed conditions are most favorable for the conservation of water in underground basins. Surface reservoirs will, consequently serve as large percolating basins retaining water which would otherwise flow to the sea and gradually passing it on to the subsoil, thereby assisting in the conservation of such supplies of water as are available from rainfall replenishing the underground resources and envisage the use of water for town supplies both from surface reservoirs and underground sources in a scientific manner, so that evaporation losses can be reduced to a minimum and percolation into the subsoil is induced.

Summering the conclusion, which can be drawn from the forgoing reports:

- Having regard to the conditions of rainfall, the nature of the soils and the geological formations, which prevail in Kutch, reliance cannot be placed upon the surface storage for an adequate or satisfactory water supply for the town of Gandhidham.

- Storage reservoirs should however be constructed as a measure of conservation of the water resources of Kutch. These reservoirs will impound run-off from the surface, which would otherwise flow, to the sea or the Rann. Water so impounded will be put to maximum use in such a manner that evaporation losses would be kept to a minimum while percolation water will replenish supplies available in the underground water.

- Ground resources of study area have not been intensively developed for other purposes like agriculture with the result that adequate quantities of water will be regularly available from the source to maintain population. Though good amount of water is being used for the drinking purpose from the dug wells.

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