CHAPTER-II

GEOLOGICAL ENVIRONMENT

2.1 INTRODUCTION

Groundwater occurrence, distribution and its chemical content is solely dependent on geological environment. Groundwater potential is a function of basic hydraulic characteristic of various sediments whereas, sediments composition coupled with physio-chemical environment governs the chemical characteristics of groundwater. Therefore, study of geological environment in time and space holds vital key in understanding the intricacies of groundwater regime.

2.2 Review of Geological Studies

Geologically Gujarat state is unique, characterized by variety of well defined litho-stratigraphic sequences ranging from Precambrian to Holocene periods. (Fig-2.1). Further, its geological record signifies a major stratigraphy hiatus due to complete absence of Paleozoic rocks. The major geological events are confined to Mesozoic and Cenozoic Eras and its tectonism is related to the break up of the Western continental Margin and its subsequent drift. The depositional history and Deccan volcanism are part of this major tectonic phenomenon. The Precambrian basement tectonic lineaments i.e. NE-SW (Aravalli-Delhi trend), E-W to ENE-WSW (Saputara Trend) and NW-SE (Dharwar trend) controls the structural setup of the Gujarat. Subsequent reactivation along these Precambrian trends due to break up of the Gondwanaland gave rise to three important rift basins in Gujarat i.e. Kachchh, Narmada and Cambay which in turn had controlled the geological evolution of the three distinct parts of Gujarat viz. Kachchh, Saurashtra and Mainland Gujarat (Biswas, 1987).

In South-Central Gujarat opening of Narmada rift system during early Cretaceous with marine transgression has paved way for the deposition of Mesozoic(Bagh formations)sediments. Subsequent Deccan Trap eruption and development of the Cambay Graben has led to the deposition of vast Tertiary sediments. Post-Miocene reactivation of Narmada rift coupled with eustatic changes was responsible for thick accumulation of Quaternary deposits of fluviatile and marine nature.

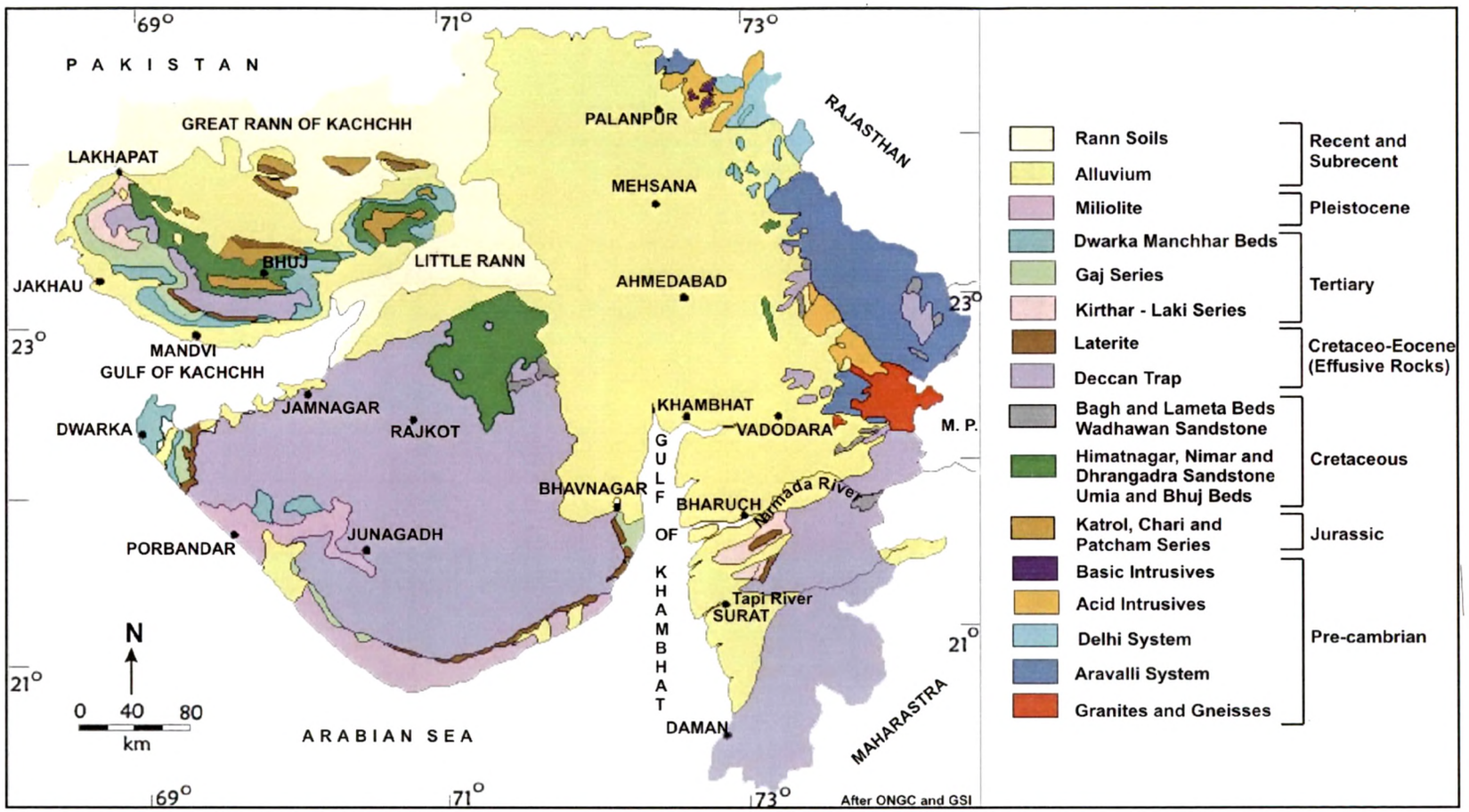


Fig-2.1 Geological Map of Gujarat

Geologically, the regional setup of the study area is characterized by a sediment record ranging from Precambrian to Recent times. The geological aspects of the study area and its environs have been extensively studied by the various workers since pre-independence era. A gist on geological investigation carried out by various workers is given as under.

The highland region in the eastern parts of the study area is characterized by varied rock type viz Precambrian crystalline and metamorphic; Mesozoic sedimentary sequence, Deccan Volcanics and Carbonatites etc. Many worker in the past have studied the various aspects of geology in eastern highland and few note worthy contribution have come from Lush (1863, Wynne (1867), Blanford (1869), Vanpele (1869), Foote (1891), Bose (1908), Chiplunkar (1942),Chaterjee (1964), Sukheshwala & Udas (1963), Sukheshwala and Sethna (1967, 69, 73), Sukheshwala & Avasia (1971), Rao (1974), Sukheshwala & Borges (1975).

Extensive work on Gujarat alluvial plains for their Stratigraphy, palaeoclimate, sedimentology, depositional process and tectonics history has been made by Mathur et al., 1968, Raju, 1968, Biswas, 1982, 1987, Pant & Chamyal, 1990; Chamyal & Merh, 1992; Merh & Chamyal, 1997; Tandon et al., 1997; Sareen et. al 1993; Maurya et al., 1995, 1997a, b, 1998, 2000, Jain et al. 1998 Rachna Raj et al. 1999.

Later, Rachna Raj (2003, 2004) studied the morpho-tectonic and stratigraphical aspects through the exposed Quaternary sediments of the Dhadhar river basin. The Dhadhar River which has been considered to be the palaeochannel course of the Orsang River (Sant and Karanth, 1993; Merh and Chamyal, 1997; Rachna, 2004) whose continuity passes through the study area.

Yousef Habous, 1989, has carried out the terrain resource evaluation on the Quaternary Alluvium of Mahi and Narmada Rivers in interstream region. He pointed out that the area has rich water resource wherein, the surface water potential through river discharge is to the tune of 50,000 Mm^3 (with 1100mm average rainfall). Similarly groundwater is available within semi-confined and confined aquifers extending to a depth of 150m to 300m. However, the groundwater quality deteriorates laterally from west to east and also vertically down. The estimated average annual gross recharge is about 953.75 Mm^3/yr against net draft

of 1349 Mm^3/yr which leaves 686.9 Mm^3/yr as surplus amount for further development. He has also divided the study area into four geoenvironmental zones.

Barodawala (1991) has made geo-environmental studies in and around Baroda and suggested that there is variation in the depth of groundwater which gets only recharged through rainfall. During his period of study out of 500 dug-wells, 166 were found to be polluted; out of 2000 bore-wells, 600 were polluted and out of 60 tube wells, 5 were polluted. Further, out of 68 wells monitored during 1988-89, 34 were found to be unfit for consumption, 24 were considered potable in the absence of a better alternate source, and 10 were found to be fit. The total availability of potable water stands at 63.9 MCM, whereas the estimated demand was 70.12 MCM therefore, creating a deficit of 6.2 MCM. He also emphasized that there is need for checking the surface and sub-surface pollution to ground water regime.

Tiwari (1986) has worked extensively on the hydrogelogical condition of the Heran river basin by investigating the various controlling factors which governs the groundwater occurrences, distribution, movement, recharge and potential available in the basin.

2.3 Geological Setup of the Study Area

As it has already been eluded that the study area constitutes a part of Central Gujarat (the Mainland Gujarat) and its geology is represented by Precambrian Crystalline, sedimentary rocks of Mesozoic (Cretaceous) and Tertiary Deccan Trap deposits of Quaternary periods. A major part of the Mainland falls within the alluvium tectonics of domains of Cambay and Narmada rift systems and the eastern and the northeastern Precambrian rocks mark a tectonic boundary as a shoulder mass.

The regional litho-stratigraphic succession of the Mainland Gujarat is given as Table 2.1. The distribution of the different rock types within the study area is shown in Fig-2.2.

Table 2.1 The Stratigraphy of Mainland Gujarat (After Merh, 1995).

Sediment Characteristics	Group/Formation	Age
Continental sediments (Fluviomarine, Fluvial and Aeolian)	Narmada Formation	Quaternary
Marine and Fluvio marine sediments		Tertiary
----------	**Unconformity** ----------	
Laterites	Deccan Trap	Palaeocene
Basalt of Deccan trap with associated Differentiates & intrusive bodies		Lower Eocene to Upper Cretaceous
----------	**Unconformity** ----------	
Marine, Fluvio-marine and Fluvial rocks	Himmatnagar, Bagh, Nimar and Lameta Formation	Cretaceous
----------	**Unconformity** ----------	
Crystalline rocks (metasediments with associated Granitic, Mafic & Ultramafic Intrusives	Champaner Group	Precambrian

----------UNCONFIRMITY ----------

Unclassified Gneisses (Basement Rocks)

A geological account on the study area based on the works of various earth scientists is given in ensuing paragraphs.

2.3.1 Precambrian

The Precambrian rocks represented by metamorphosed and intrusive gneiss, phyllite, and quartzite are exposed in the eastern part of the study area. The Precambrian rocks of the study area have been classified in to three broad stratigraphic units viz. Post Delhi Intrusives (Godhra Granite= Post Delhi Erinpura Granites), Champaner Group (Upper Aravalli Super group) and Unclassified Gneisses as Basement Rocks (Pre-Aravalli). The unclassified gneisses that have been considered as Basement Rocks are exposed in the extreme north eastern parts of the study area (Fig.-2.2) and dominantly characterized by high grade metamorphic rocks.

The Champaner Group of rocks are represented by an interbedded sequence of arenaceous (Quartzite), argillaceous (Schist, Phyllite and Slates) and Calcareous (Crystalline Limestone and Dolomite). These rocks are product of regional metamorphism. The eastern parts of the study area around Waghodia, Naswadi and northeastern parts around Shivrajpur etc. comprises of these rocks.

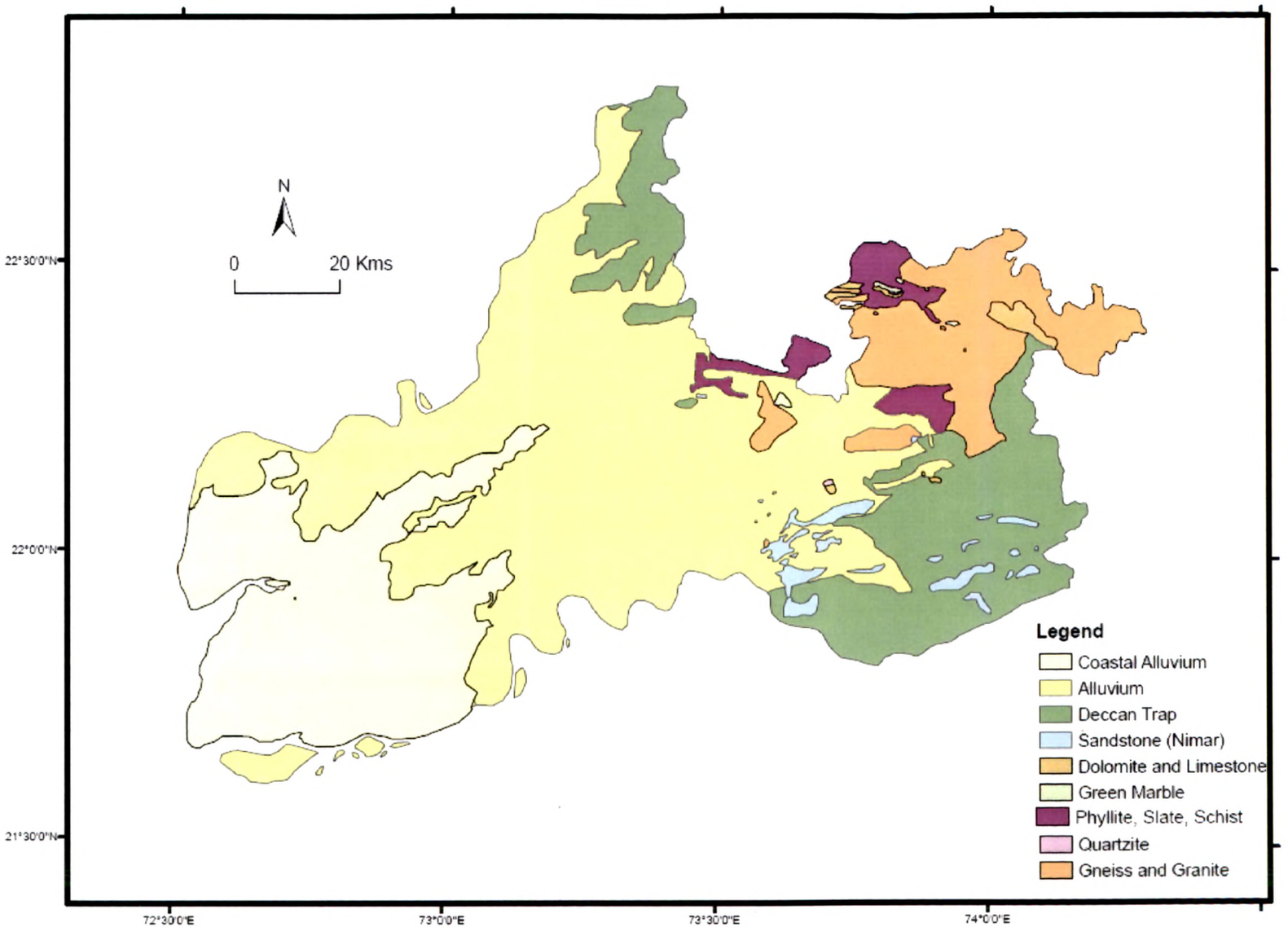


Fig-2.2 Geological Map of the Study Area (Complied After GSI)

Post Delhi Intrusive i.e. The Godhra Granite within the Champaner Group of rocks are typical of alkali composition and have been emplaced during the last phase of Erinpura magmatic activity. These rocks are exposed around Chotta Udaipur, Tejpur and Ranjitnagar area.

Due to very poor primary porosity and permeability, these rocks do not form productive aquifers. But at times due to intense weathering and presence of highly fractured and jointed nature, aquifers are productive locally.

2.3.2 Infra-Trappeans

Lying unconformably over the Champaner Group of rocks is a sedimentary sequence viz. the Bagh formation and Nimar formation are exposed as inliers within the Deccan Trap. The rocks are characterized by heterogeneous composition including charts, marls, limestone, quartzitic sandstone, conglomerate and varigated shales. The beds strike in a NE-SW to NNE-SSW direction with low angle dips towards SE and ESE directions. High angle joints are normally seen in NW-SE and NE-SW directions.These rocks are exposed around Sankheda, Kawant, South of Chota Udaipur and Garudeshwar(Fig. 2.1) These infra trappeans rock although sedimentary in nature but characterized by poor ground water potential. This is attributed to their partial metamorphism under Deccan Trap. In sandstone and limestone the movement of groundwater is controlled mainly along fracture and joints. Because of cherty nature of limestone and calcareous nature of sandstone the primary porosity is very poor. The Bagh beds, where overlain by Deccan Trap are likely to yield groundwater under confined conditions.

2.3.3 Deccan Traps

The eastern part adjacent to Narmada Valley is dominated by the presence of Deccan Trap comprising of hard and compact, cryptocrystalline to porphyritic basaltic flows which in turn are either massive or vesicular in nature. The vesicles are filled with secondary minerals like calcite, quartz, zeolite and secondary silicates. The Deccan Traps which occur around Naswadi comprises of fine grained amygdular and porphyritic lava flows. In Phenai mata-Rangpur area, these occur as trachy basalt, gabbro, granophyre and nepheline syenite which have intruded into the earlier formed lave flows. The Ambadungar area have witnessed intense volcanic activities and exhibit varieties of rock types i.e. basalt, dolerite, granophyre dykes, breccia, agglomerates-

tuffs, dykes and plugs of alkaline rocks like nepheline syenite, phonolites, ijolite and lamprophyre (Sukheshwala; Gopinath,1984). Further, numerous dykes of different composition occur in area between Panwad and Mohan Fort. The dykes which have intruded into Deccan Trap are criss crossed in nature and at times act as groundwater barrier. They restrict the movement of groundwater in such a way that one side its water is present while other side dry aquifer.

Weathering is a common feature in both the massive and vesicular traps but the preceding one is found comparatively more weathered. The weathered, jointed and fractured basalt are usually good from groundwater potential point of view. The quality of groundwater is generally good in basalt. The occurrence of different flows in the volcanics has given rise to multi layered stratified aquifer (CGWB, 1996). The massive basalt is hard and compact with no primary porosity but the vesicular basalt and especially which are fractured and jointed have developed productive aquifers.

2.3.4 Quaternaries

In the study area Tertiary are underlain by Deccan Traps and overlain by Quaternaries. The Quaternaries occupy major portion of the study area and its thickness varies from place to place. The thickness tends to increase towards the central and southern parts of the study area. The riverine alluvial formations greatly vary in their composition having clay, silt and sand, gravel, pebbles and boulders etc.

The Cambay graben is one of the three major marginal rift basins in the western margin of the Indian craton (Biswas, 1982). The Deccan basalts in the Cambay basin form the floor over which Cenozoic and Quaternary Holocene sediments have deposited. The thickness of Quaternary and Tertiary sediments varies in Cambay basin. The Eastern Cambay Basin Bounding Fault extends almost N-S across the middle of the Mainland (Fig 2.2). The structure is reflected in the topography which typically shows progressive stepping down from south to north along E-W faults and from east to west along N-S faults.

Post Mesozoic reactivation of N-S and NNW-SSE Precambrian faults and Narmada Geofracture gave rise to Cambay rift basin. Subsequent syn-sedimentation tectonism was responsible in deposition of thick Tertiary and Quaternary sediments. During Quaternary period E-W to ENE-

WSW fracture trends have provided preferred direction for the older rivers flowing SW to W to deposit their debris to pile up a huge thickness of Quaternary sediments. The last phase of tectonic activity (early Holocene) gave rise to numerous NNE-SSW trending fracture zones disrupting older river courses and tilting of blocks (*Merh and Chamyal, 1997*).

The Quaternary sedimentation in the Gujarat region began in early Pleistocene which continued till the beginning of the Holocene. *Maurya et al. (2000)* have given a well documented history of Quaternary deposition and subsequent geomorphic evolution of Gujarat alluvial plains.

There are no. of faults in the study area viz. East Cambay Basin Marginal fault, Paldi fault, Dudhpur fault, Thargon fault, Son-Narmada fault, Orsang fault with few minor ones. The area is also crossed by no of lineaments like Bhukhi, Jaisalmer-Barwani lineament, Vishwamitri, Mahi Lineament etc.

The Jambusar-Bharuch alluvial tract (Fig-2.3) being part of 'Gujarat Alluvium Plains' comprises huge thickness of marine, fluvial and aeolian sediments, deposited during the Quaternary period. These sediments consists of intercalation of sand, silt, clay and gravel with development of conspicuous clacretised bands and act as ideal repository for groundwater in unconfined, semi-confined and confined conditions.

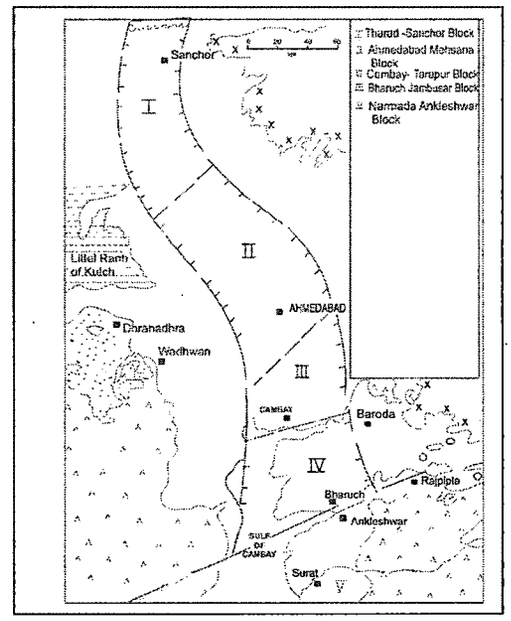


Fig-2.3 Tectonic map of Cambay Basin (after ONGC)

Subsurface geological information holds vital controls over understanding hydrogeological conditions of the area. Tube well lithologs on subsurface geology have been obtained from State and Central Ground Water Departments and have provided valuable information about the lateral and vertical variations in sediments characteristic within the alluvium material. Subsurface geological cross sectional profile (Fig 2.4), gives two dimensional subsurface view of thick accumulation of flood plain deposits having considerable lateral extent. It is interesting to observe that porous and permeable sand (aquifer) is

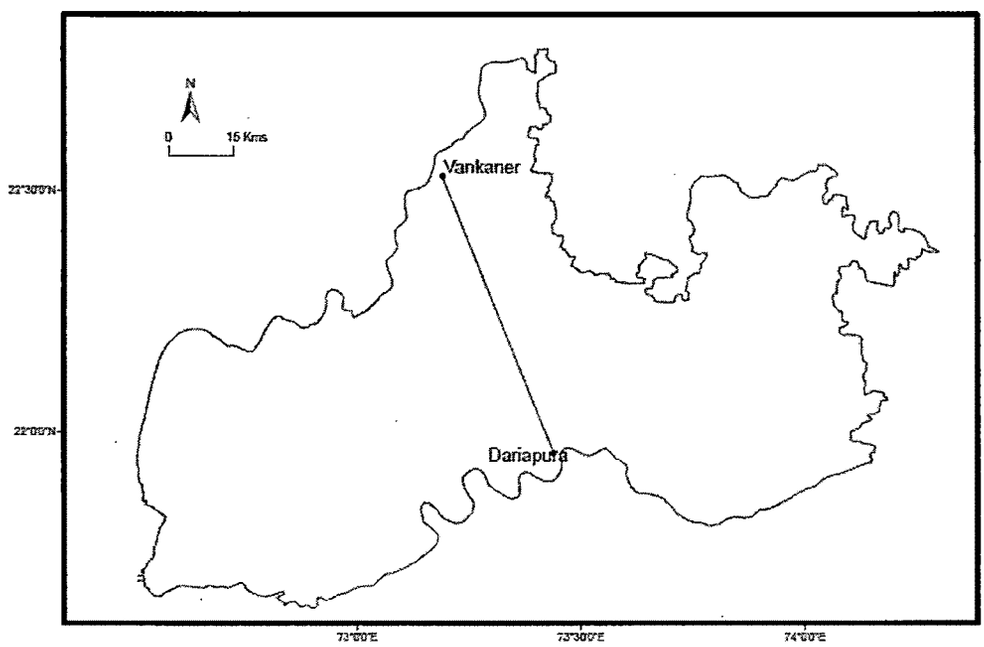
sandwiched between clay horizons (aquiclude). Therefore, in all probability the developed aquifer which is of regional extent may be characterized as semi-confined to confine in nature.

This 39 km of subsurface profile (>130 m deep) between Dariapur in the SE and Vankaner in the NW part of the study area lies in the alluvial plains. The section exhibits the thickness of alluvial material increases towards SE part. The sediments comprises alternating layers of sand, silt and clay.

The subsurface profile gives strong indications of the post trappeans (Miocene) tectonism. The bore holes in the north-eastern proximity viz. Dumad, Kunpad and Vakaner have encountered trappean rocks at different depths and have locally developed small graben that has filled up by the Quaternary sediments. Further, the encountered basal blue clay (marine) delimits the aquifers having potable groundwater.

Similarly another tectonically controlled sedimentation has been depicted between Anguthan and Palaswada borehole. Here the displacement has brought granular material which juxtaposition to the lower clay material. Within the sand layers lens of clay has been observed.

Borehole records after Deep Drilling done by ONGC as a part of hydrocarbon exploration suggests that the overall thickness of the Quaternary sediments is more than 500 m (Fig-2.5).



Index Map for Cross Section Profile.

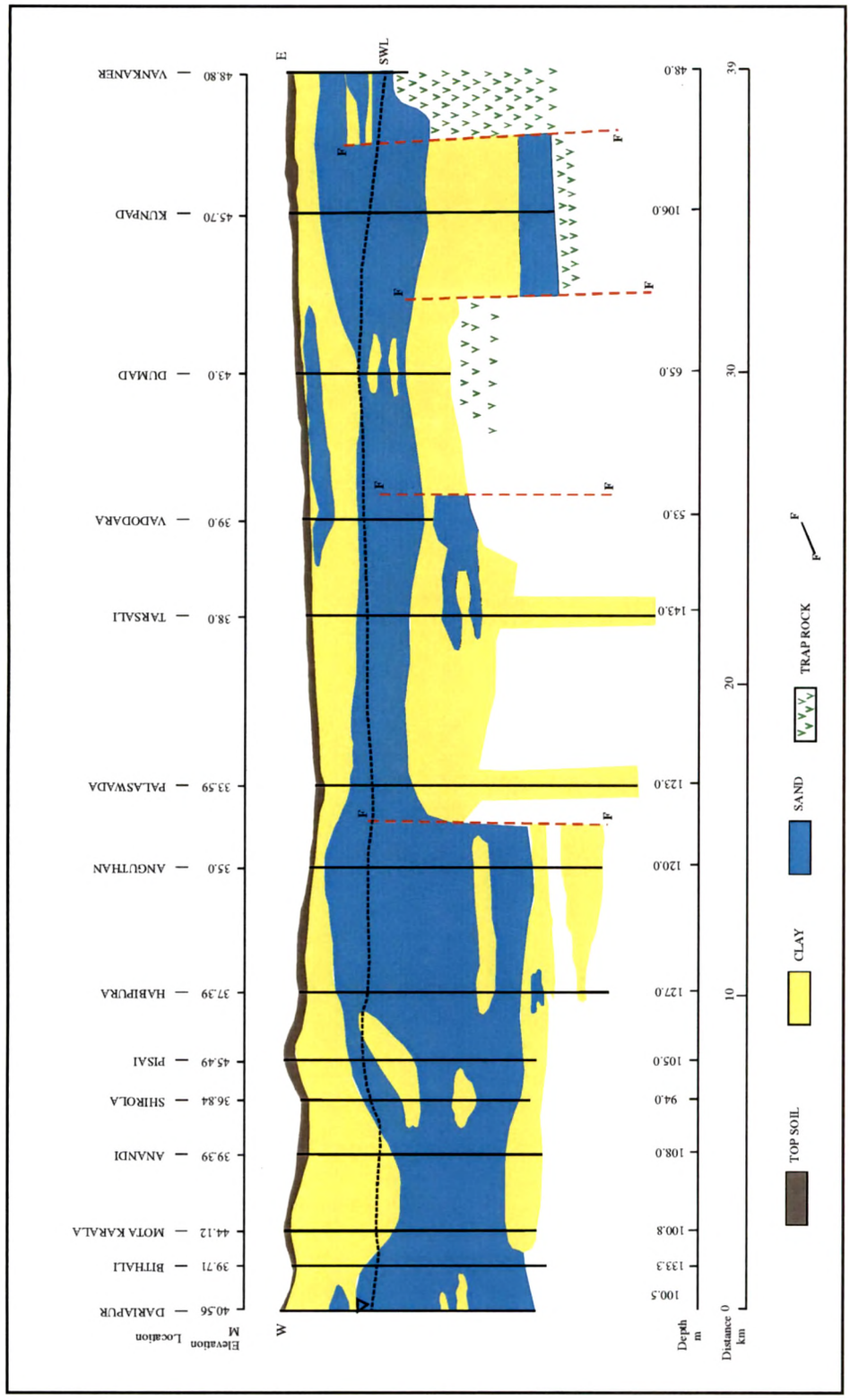
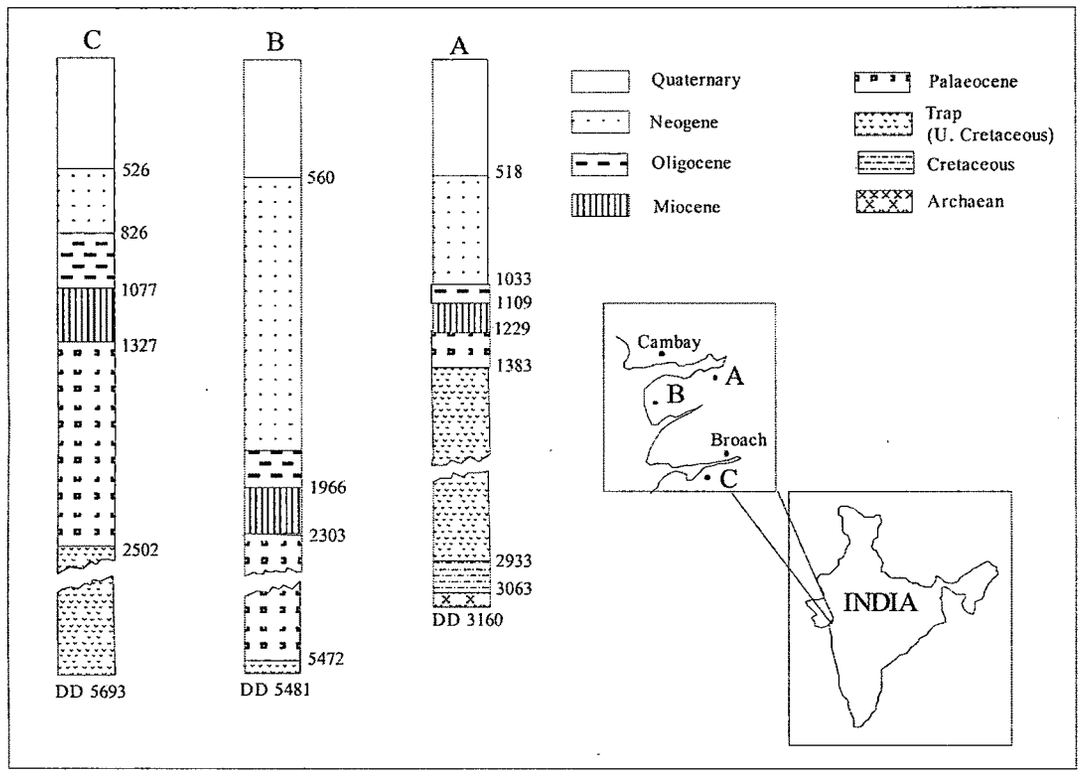


Fig-2.4 Sub surface Geological Cross Section along Dariapur to Vankaner.



(Complied After ONGC)

Fig-2.5 Borehole Records of Deep Hydrocarbon Exploratory Wells in Cambay Basin.

2.4 Geomorphology

The vast stretch of alluvial plains extending both horizontally and vertically, prima facie, appears to be monotonous and flat having less hydrogeological significance. The slope is gentle especially in central and western parts of the study area. Physiographically the area can be divided into two major geomorphic units having its own characteristic features and hydrological significance (Fig-2.6).

a) Coastal Plains (<15m AMSL): The coastal alluvial plains of the study area have been developed because of tectonics and climate. The various present day coastline features appear to be related to the Flandrian high sea level and its subsequent regression (*Patel et al., 1984*). The various geomorphic features identified in this coastal region using survey

of India topographic sheet and satellite imageries are; estuarine river mouths, foreshore and offshore mud banks, river bar, backshore alluvial cliffs, alluvium islands within mudflats, beach sands, sandy ridges, creeks, relict alluvial plains, salt pans, paleomeanders, high marsh etc.

The conspicuous feature in this physiographic unit is the three big estuarine mouths of the rivers in this area. They are broad, muddy and funnel shaped (except Narmada) and shows extensive accumulation of tidal mud. The mouths of the rivers Mahi and Dhadhar show muddy shoals especially during low tide. The entire length of the foreshore is made up of tidal flats, which in turn are punctuated, by numerous tidal creeks and channels giving highly crenulated shoreline. The Dhadhar River mouth shows more extensive mud accumulation because of which it has been choked.

At the mouth of these three rivers, vertical cliffs to the order of 30m (particularly Mahi river) have been recorded. A backshore coastal plain rises abruptly above the tidal flats forming cliffs which mark the entire shoreline. Behind these cliffs, lies the central alluvial plain.

b) Central Alluvial Plains (15 - 50m AMSL): Though alluvial plains are in continuation with coastal plains but there is gradual increase in height. The average ground slope is to the order of 1: 1500. Because of gradual slope and soft unconsolidated sediments, the drainage density is low. This area is under intense agriculture and rich source of good quality groundwater.

c) Transitional Pediment Zone (50-100m AMSL): it shows variety of topographical features (both erosional and depositional one). This zone is made up of landforms formed due to prolonged erosion and the subsequent sedimentation. As we move in along the slope direction the there is gradual drop in elevation and ultimately it merges with the alluvial plains. The noticeable depositional features are valley fills, low terraces, badland etc whereas the erosional features are scarps, cliffs, residual bedrock terraces etc. at places aeolian sandy accumulation of fossil dunes are also observed indicating past arid phase.

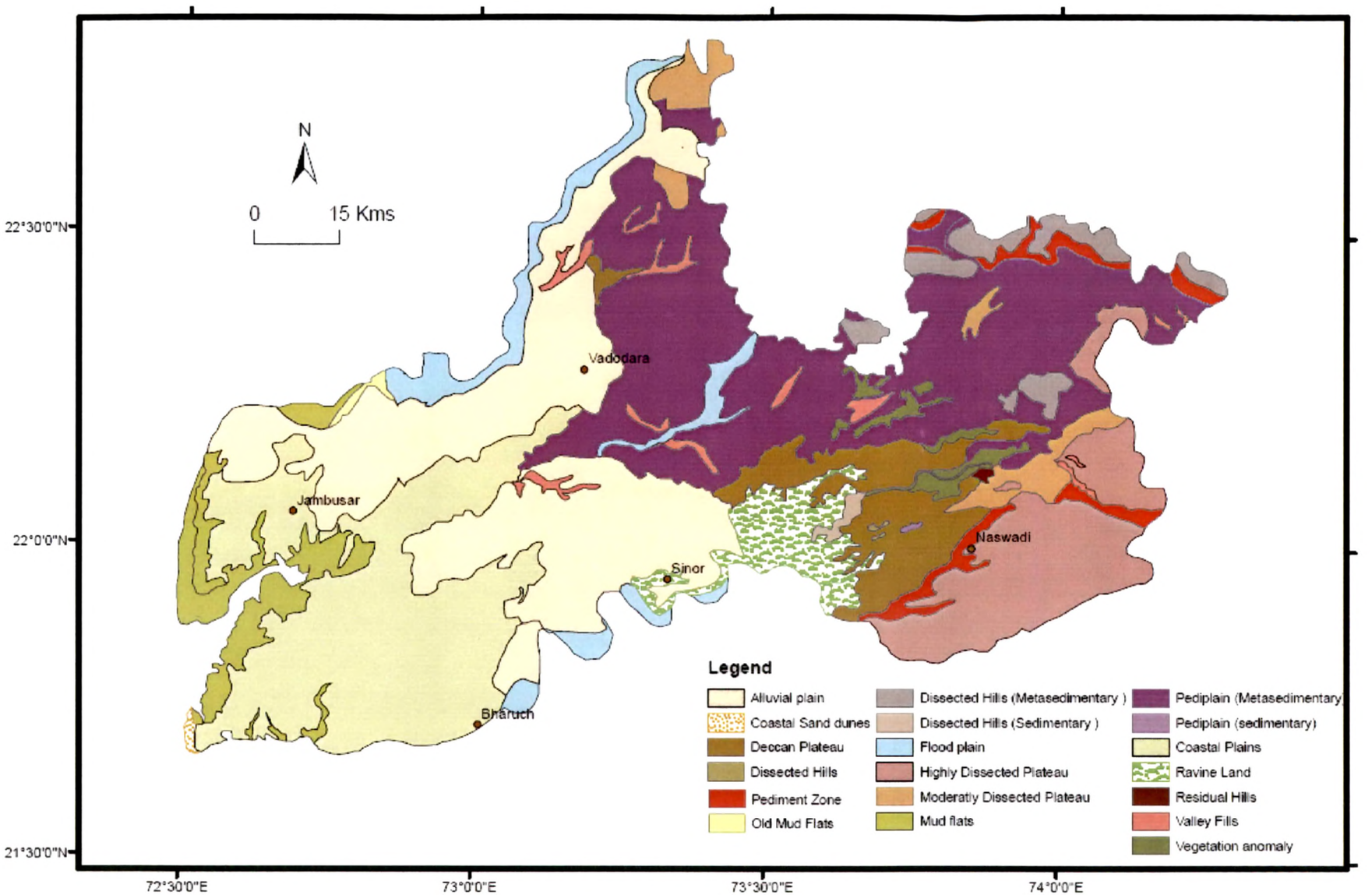


Fig- 2.6 Geomorphological Map of the Study Area.

d) Highlands Zone (100-540m AMSL): are characterized by rocky terrain formed by Precambrian crystallines and Deccan Traps. The area is marked by steeply sloping hills and ridges causing high runoff in this area. This is also supported by the high drainage density compared to other part of the study area and constitutes major recharge zone for the aquifer developed on downward gradient.

2.5 Fluvial System in the Study Area

The rivers of Gujarat alluvial plains are characterized by features which are indicative of tectonic influence. Moreover, drainage configuration also suggests subsurface structural features and the alignment of drainages correlates well with subsurface structural high and lows (Maurya, 2000).

Three west flowing rivers along with their tributaries drain the study area. Among the three rivers, Dhadhar with its five tributaries drains the study area (Fig-2.7). Dhadhar River originates from the eastern hill ranges flows across the Cambay rift graben. Its covers a distance of 200 km and has path of about 80km in Vadodara before finally debauching into Gulf of Cambay near Dahej. The river enters into Vadodara at Goraj and passes through the center of the study area. The river has five main tributaries mainly Vishwamitri, Surya, Jambuva, Dev and Rangal nadi and other sub tributaries. Out of these Viswamitri is one important tributary which rises from the hills of Pavagadh and joins Dhadhar at Pingalvada. The Dhadhar River basin forms large elongated basin gently sloping southwesterly. Physiographically the basin can be divided into three broad zones i.e. the upland zone, the pedimont zone and the alluvial

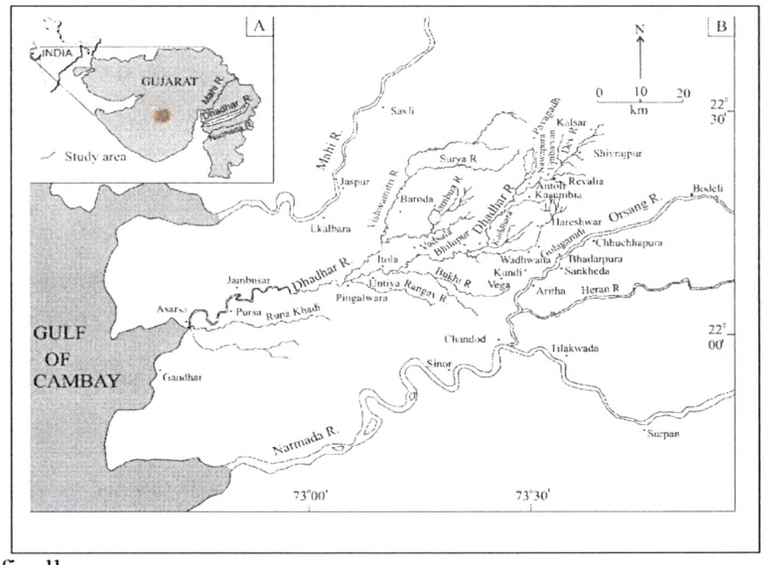


Fig-2.7 Drainage Fabric of Dhadhar River

zone. Within the basin, river shows different drainage pattern from head to mouth. In its upper reaches, with its main tributary Vishwamitri River, it shows dendritic pattern, which reflects strong control of the basement fracture system (Fig-2.8). In its middle course, it shows pinnate pattern while in the lower reaches the river shows parallel to sub parallel drainage pattern. The mouth portion shows anastomatic and braided pattern. Dhadhar River basin is endowed with several small and big ponds and reservoirs. Among them important one in its upper catchment near Pavagadh hill are like Medhi, Annapurna, Chassia and Dudhia talav while others in the alluvial plains are Wadhawana lake situated near vega, Vega, Vadsala and Kaumbia.

Dhadhar River has been considered as the paleochannel of the Orsang River (Sant and Karanth, 1993; Merh and Chamyal, 1997; Rachna 2003). Presently, the Orsang River suddenly takes a southward turn near Aritha and meets Narmada River at Chandod on its right bank.

The Mahi River in its lower reaches is controlled by a prominent E-W trending lineament. Two others important lineaments are enechelon lineaments (NNW-SSE) which reflect the step faulted eastern margin and the Mahi lineament (E-W) which mark the fault along the Mahi estuary. The Mahi in its lower reaches shows badlands topography with deep ravines. The Mini River is the last tributary of Mahi River which originates near Nani Bhadol village with a course of 50km and finally meets Mahi near the village Sindhrot. Important coastal geomorphic features in the Mahi estuary are channel boundary, floodplain boundary, three terraces T_1,T_2,T_3, flood plains, cliffs, creeks, mud flats, eroded land, salt pan, paleomeanders, oxbow lakes etc (Nayak et al., 1984-85).

The Narmada River originates from the hills of Amarkantak in Madhya Pradesh and shows important erosional and depositional features. The river in its lower reaches near Broach shows maximum breadth of ±1.5 km and further westwards it widens to a very broad estuary. The Narmada River in its lower reaches shows braiding pattern and development of bars and islands locally called 'bets'. Particularly worth mentioning are Kabirwad and Alia bet. Bhuki is the small river with a total length of 85km and meets Narmada estuary, very near to West Coast. This river originates from Sinor taluka. Bhuki is joined by three tributaries. From left it is joined by Khari and further down it is joined by two more tributaries viz. Ganwa and

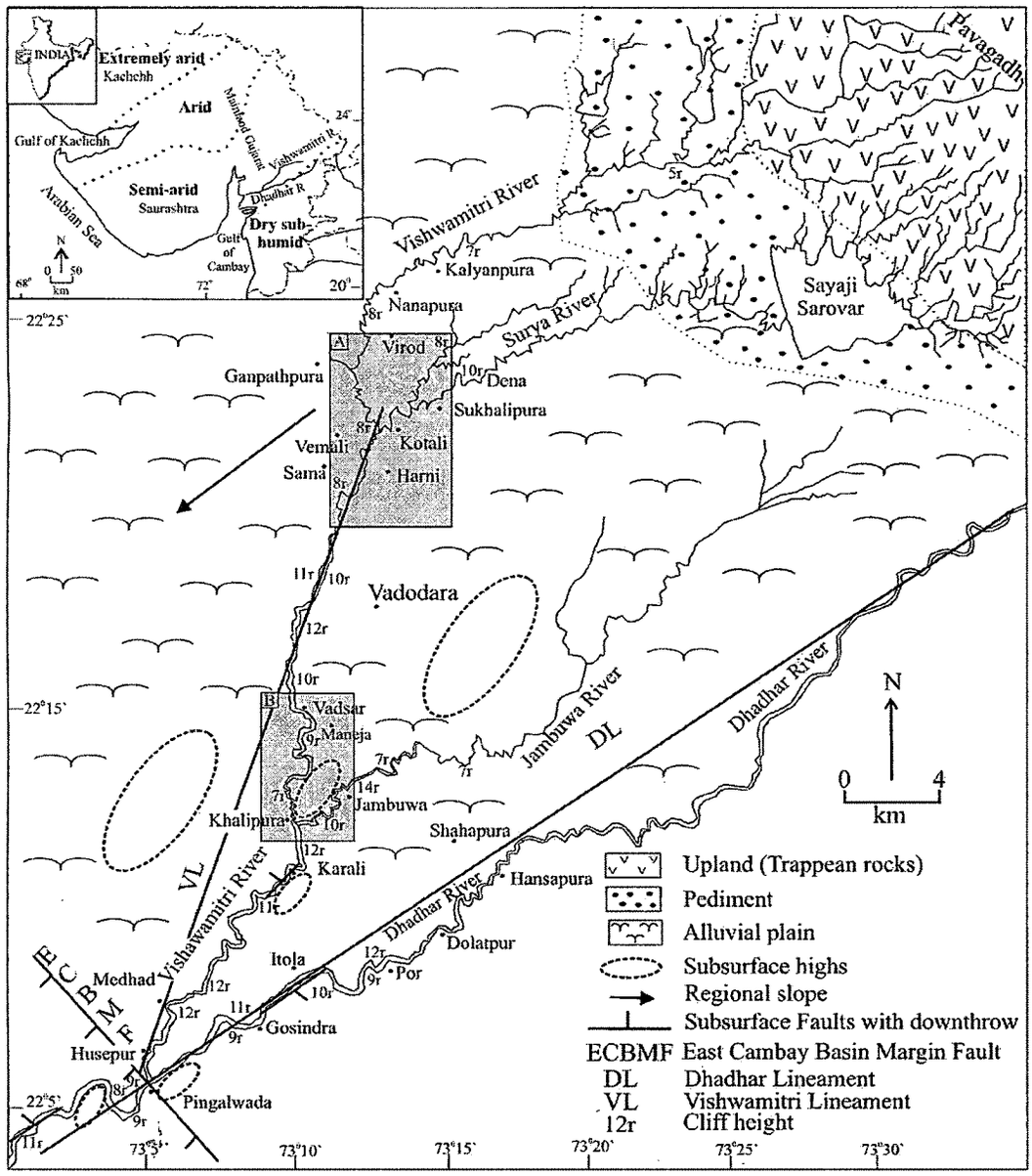


Fig-2.8 Morphotectonic Map of Vishwamitri River

Bhan. During high spring tides, the tidal water ingresses to landward side of Bhuki River, otherwise it is dry for most of the season. This river also flows through Bhukhi 'ENE-WSW' lineament (*Maurya et al. 2000*). Another important tributary of Narmada is Orsang. This river flows in E-W direction in its upper and middle reaches, but it suddenly swings to NNE-SSW in its lower reaches. The river meets Narmada at Chandod in Sinor taluka of Vadodara

district. The course of Orsang does not follow the general SW slope of the area which indicates a strong tectonic control. The Bhukhi and Orsang Rivers meet Narmada almost at right angle which again indicates some structural control.

All the three rivers i.e. Mahi, Dhadhar and Narmada have estuarine mouths which are affected by tidal fluctuations. Infact the effect of tidal waves is far upstream in Mahi River upto Vasad which is about 30km from coast. In Narmada River, the influence is upto Rajanpur, which is about 40 km away from Bharuch in the upstream direction. The tidal influence degrades the water quality. Similarly in the Dhadhar River, which is a seasonal river and its discharge is also less, the tidal influence is seen inward upto Karjan, about 50km upstream. Major rivers flowing through the study is shown in Fig2.9 and Details on the general characteristics of the rivers flowing in the study area are given in Table 2.2.

Table No. 2.2 Dimensional Characteristic of Rivers Flowing in the Study Area.

River basin	Catchment area **Km^2**	River length **Km**	Annual discharge **Mm^3**
Mahi	34,842	533	8500
Dhadhar	4,250	160	690
Narmada	98,796	1322	40,705
Total	**137,888**	**2,015**	**49,825**

(Yousef, 1989)

2.6 Soil: The soil in the study area as a result of geomorphic and climatic processes shows variation in texture and structure and also varying laterally from eastern highlands to coastal plains in the west. According to National Bureau of Soil Survey and Land use Planning (*NBSS&LUP, 1994*), Nagpur, soils in the alluvium plains are dominantly very deep, well drained, and fine loamy to fine in texture. They are slightly alkaline and calcareous. Along flood banks of rivers like Mahi, Dhadhar and Narmada they are severely eroded. The soils have varying degree of average water capacity from low to high depending upon textural variation. While the soil occurring on the coastal plains are dominantly very deep, imperfectly to poorly drained and fine textured they are slightly to moderately alkaline and calcareous and salt affected.

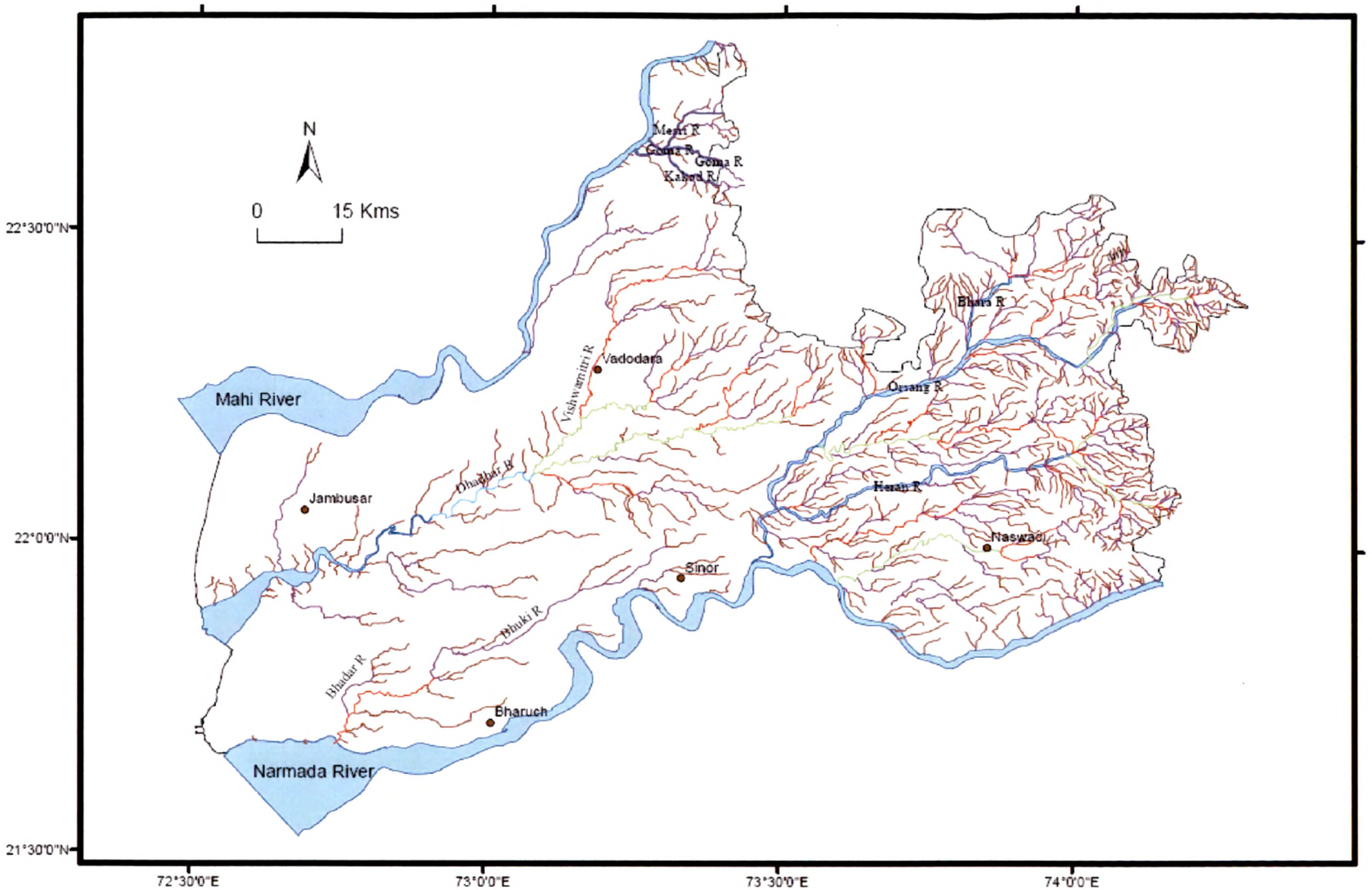


Fig-2.9 Drainage Map of the Study Area.

The area between Dhadhar and Mahi alluvium plain is characterized by soil which is very deep, well drained, fine loamy soils with slight erosion. While the area between Dhadhar and Narmada rivers consists of soil which is very deep, moderately well drained, calcareous, fine to very fine with slight to moderate erosion and at places with moderate salinity.

The eastern part comprising highland and piedment zone shows wide variation in soil types owing to different rock formations. The soils in rocky outcrops are shallow. In other areas it is shallow to deep and at places very deep, well drained, and calcareous to clayey fine soils are associated with slight to moderate erosion. The Heran river basin is marked by black cotton and lateritic soils of silty-clay in nature and belongs to residual soil category (Tiwari, 1986). Detail on soil types present in the study area is given in Annexure-2.1 and their aerial distribution is shown in Fig-2.10.

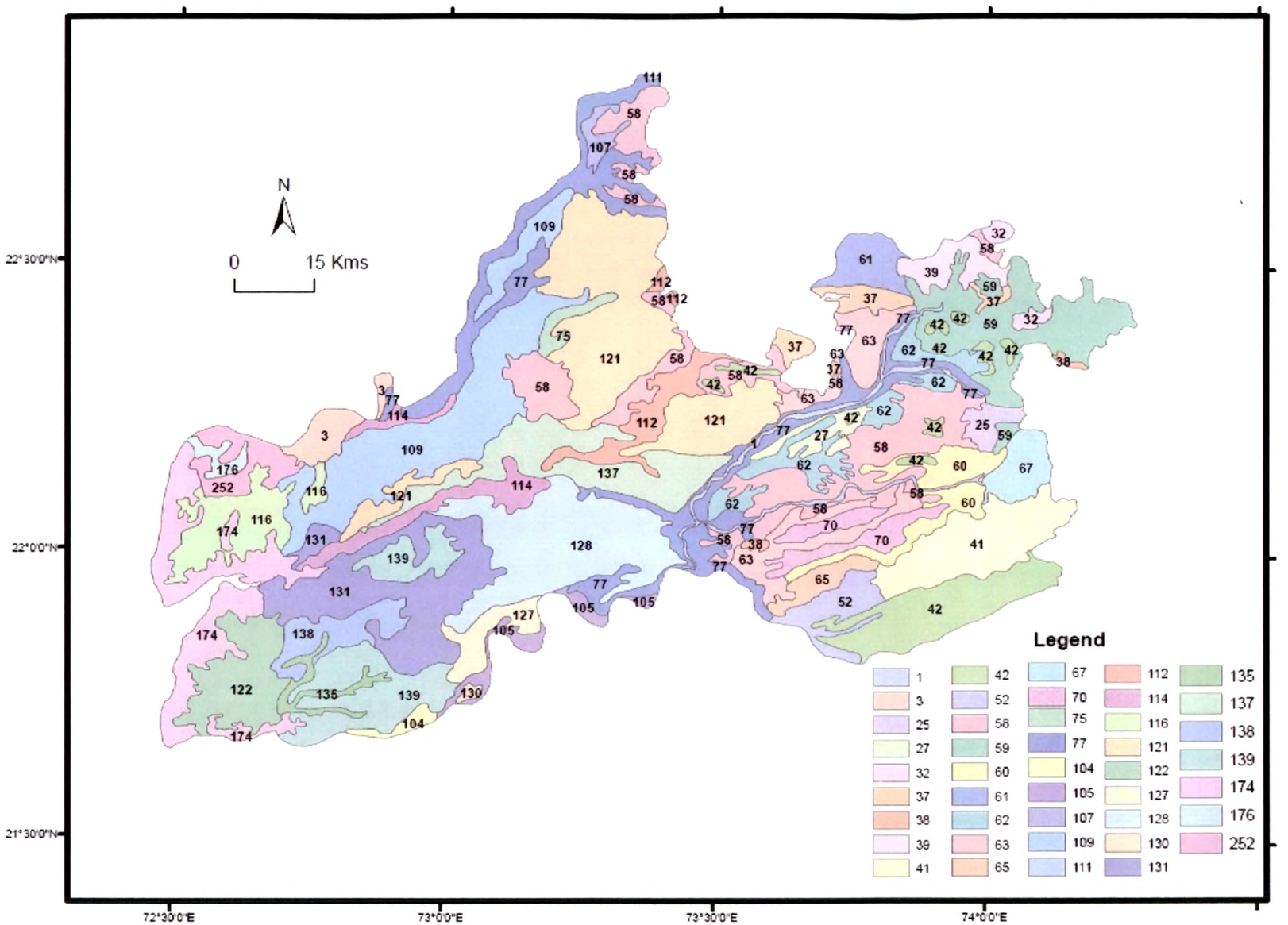


Fig-2.10 Soil Map of the Study Area.