CASE STUDY AREA AND DETAILS

3 CASE STUDY AREA AND DETAILS

The State of Gujarat is located on the north-western shores of India, lying between 20° 01' and 24° 07' North latitudes and 68° 10' and 74° 28' East longitudes. It covers a total geographical area of 1, 95,984 sq.km (Directorate of Economics and Statistics, 1987). Out of the total area nearly 1, 09,314 sq. km is occupied by rocky formations and 86,670 sq. km is by alluvium; of which 34,625 sq. km is saline area. The State has the longest coastline in the country measuring about 1,663 km along the Western part of India, extending from Lakhpat in the North to Valsad in the South. Gujarat State has common borders with Rajasthan, Madhya Pradesh and Maharashtra States in North, East and South respectively and with Pakistan in North-West.

The drainage in all areas of Gujarat has a distinct manifestation of the topographical features and physical characteristics of the rock formations. The flow directions of some of the major rivers are controlled by the major tectonic activities, which occurred during geological times. Except Narmada, Tapi and Mahi rivers, all other rivers in the eastern part of the state originate on the western slopes of eastern hills. They flow in the direction almost at right angle to the boundary i. e. towards South-West (Sabarmati and Mahi rivers) in the North-Eastern part, towards almost west (Narmada, Tapi and Dhadhar) in the central region and towards North-West (Kolak, Par, Ambica, etc.) in the Southern part. Most of the rivers in the alluvial plain meander with very wide courses whereas those in rocky tracts have deep and narrow courses. The rivers in Saurashtra and Kachchh originate from the central uplands and represent a radial drainage pattern.

Gujarat falls in the sub-tropical climatic zone and a large part of the state lies between 35° C and 45° C isotherms. The rainfall in the state is moderate. It forms a transitional zone between the heavy monsoon area of Kokan in the South and arid areas of Rajasthan in the north. Climatic conditions vary greatly in the state. The climate in general has three main seasons i.e. summer, monsoon and winter. The monsoon breaks by middle of June, reaches its peak in July and starts retreating by end of September. The overall climate is humid, sub-humid and semi-arid to arid. The relative humidity in the all parts of the state, except the coastal strip, is low (being about 50 % between October and May). Average annual relative humidity figures for different regions are South Gujarat 71 %, North Gujarat 64 %, Saurashtra and Kutch Uplands 56% to 67% and Coastal Saurashtra 69 % to 77 %. Wind velocities are generally moderate except during the period prior to onset of monsoon and during the monsoon period. Winds blow from West or South-West during monsoon whereas they blow from North-East during winter.

3.1 STUDY AREA

The present study is related to region of Mahi estuarine area. The location map of Mahi estuarine area in country, state and district shown in figure no 3.1

3.1.1 Geographical Location of Study Area

Geographic location of the study area is shown in Location map. Physiographically, it's northern and southern limits are marked by catchment boundary of Mahi basin. Mahi River meets Gulf of Khambhat near Kavi town. The western limit is determined by the Gulf of Khambhat and in the East the area stretches up to Khanpur between catchment boundaries of Mahi basin. The study area comprises an area of 2298.23 sq.km and is enclosed within the North latitude 22°05'06" to 22°33'36" and East longitude 72°27'18" to 73°13'57" covering Survey of India, toposheets nos. 46 B/14 to 16 and 46 F/2 to 4. (Survey of India, 1975)

Administratively, the study area is shared by the districts of Vadodara, Bharuch and Anand. In Vadodara district, it covers three talukas Padra, Vadodara and Savali, while in Bharuch district, it covers one taluka Jambusar and in Anand district, it covers five talukas Anand, Anklav, Borsad, Khambhat (Cambay) and Petlad. Vadodara and Bharuch districts are on left bank while Anand district on right bank of Mahi River. The Mahi River forms the boundary between Vadodara and Anand districts. The area between Wanakbori to Gulf of Khambhat is gently sloping to almost flat near the Gulf and is a fully developed and fertile alluvial tract. The location map of study area is shown in figure no 3.2(a) and (b).

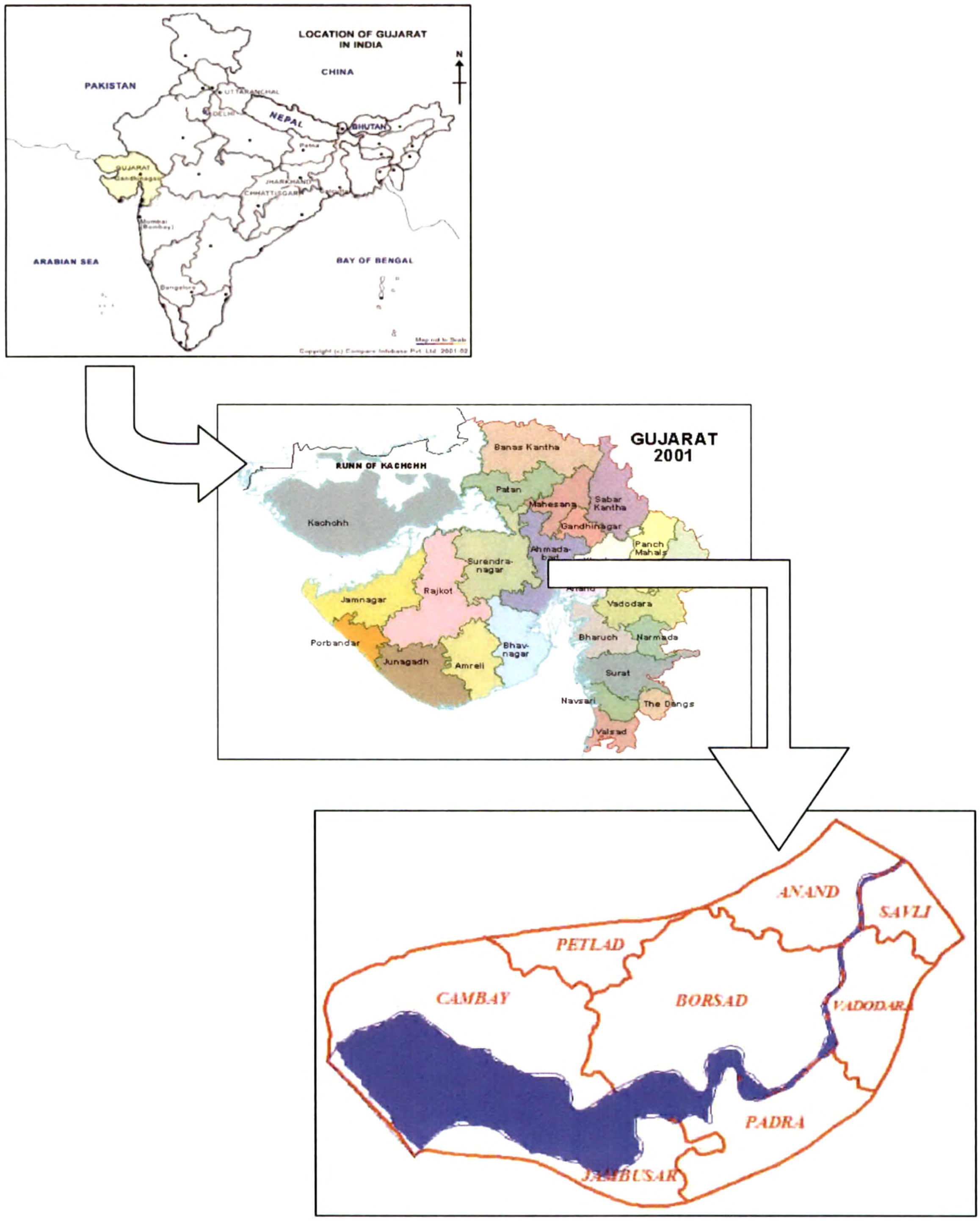
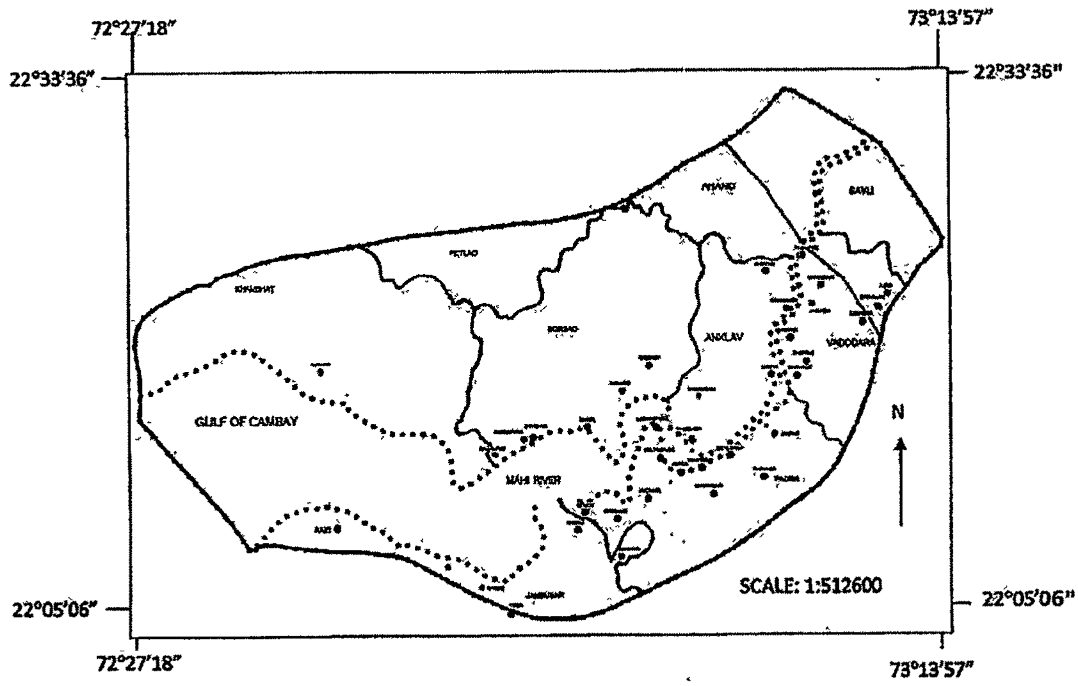


Figure 3.1 Location Map of Mahi Estuarine Area in Country, State and District

Scale 1:250000

Figure-3.2 (a) Location Map of Study Area



LEGEND

- Village
- ...... River boundary
- Taluka boundary
- ——— Study area boundary

Figure 3.2 (b) Location Map of Study Area

3.2 Mahi River

The river Mahi is third major west flowing interstate river of India, draining into the Gulf of Khambhat. It is one of the four major perennial rivers in Gujarat (Directorate of information G.O.G., 1960). It originates in the northern slopes of Vindhyas mountain ranges at an elevation of 500 m. above mean sea level (Rao, 1975). At about 22° 35' N and 74 ° 15' E near the village Sardarpur in Dhar district of Madhya Pradesh (Narmada Water Resources And Water Supply Department, 1999). Its total length is 583 km, traversing 167 km. in Madhya Pradesh, 174 km. in Rajasthan and remaining 242 km. in Gujarat. It flows initially in North-West direction through Dhar and Jhabua districts of Madhya Pradesh. Thereafter, it takes turn to the left and flows South-West direction through Banswara district of Rajasthan. It enters the Gujarat State near Bhukia village in Rajasthan and runs through the Panchmahal and Anand districts of Gujarat State before joining the Arabian Sea in the Gulf of Khambhat (Water Technology and centre of IARI, 1983). In the Vadodara district the river passes through three talukas, viz., Savli, Vadodara and Padra. In the Savli taluka the Mahi flows past Jambu Goral, Varsada, Kanoda and Pincha villages. Thereafter it enters Vadodara taluka and passes by Anagadh and Sindhrot villages. Lastly the river enters the Padra taluka and passes near the villages of Jaspur, Ekalbara, Mujpur, Dabka, Karkhadi and Tithor. After traversing a course of about 115 km., in this district; the river enters the Anand district and merges into Gulf of Khambhat (Cambay) (Government of Gujarat, 1979).The course of the river is well defined and has steep banks in most of its reaches. (Narmada Water Resources and Water supply Department, 1999).

3.2.1 Mahi Basin

The total catchment area of Mahi basin up to the point of its confluence in the Gulf of Khambhat is 34,842 sq. km of which 19% lies in Madhya Pradesh, 47% in Rajasthan and 34% in Gujarat (Rao, 1975). The basin lies between the geographical co- ordinates of 73° 00' to 74° 20' East longitudes and 22° 30' to 24° 20' North latitudes. The catchment area within Gujarat is 11,694 sq. km

The catchment of the river is mostly hilly and its shape is double fanned, which gives rise to high intensity flash floods (Water Technology Centre of IARI, 1983). The basin is bounded by the Aravalli hills in North and North-West, by the ridge separating it from Chambal basin in the East, by the Vindhya hill range in the South and finally by Arabian Sea in the West (Narmada Water Resources and water Supply Department, 1999). The upper basin lying in Madhya Pradesh has undulating terrain crisis crossed by ridges and valleys. In Rajasthan, the basin consists of hills, forests and eroded terrain. In Gujarat up to the confluence of Mahi and Panam, the basin comprises semi-developed lands. Below Wanakbori weir and up to the mouth, the basin is flat, fertile and well developed alluvial tract. The Plan showing the rivers of Mahi basin is shown in the figure 3.3 (Narmada Water Resources and Water Supply Department, 1999).

3.2.2 Tributaries of Mahi

The Mahi River receives several tributaries on both banks out of which the main tributaries are Som, Anas and Panam. The Som River joins the main river Mahi on the right Bank in Rajasthan (basin area 8,707 sq. km). The Anas (basin area 5,604 sq. km) and Panam (basin area 2,470 sq. km) join the main river on the left bank in the Rajasthan and Gujarat respectively (Rao, 1975).

The other major tributaries of Mahi River are Bageri and Pumpavati in Madhya Pradesh and Bhadar, Karad as well as Goma in Gujarat. The Mini River is a minor tributary of the Mahi. It originates near village Nani Bhedol of the Savli taluka of the Vadodara district. It flows through Savli and Vadodara talukas. After traversing the course of 50 km, it merges in Mahi near the village Sindhrot of the Vadodara taluka (Government of Gujarat, 1979).

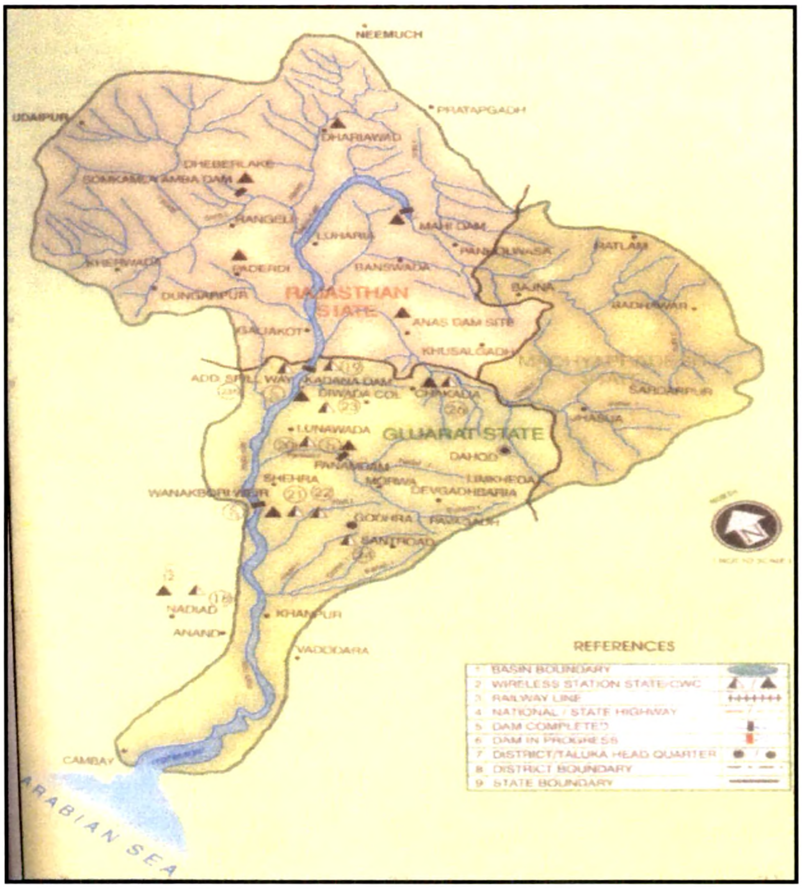


Figure 3.3 Plan Showing the Rivers of Mahi Basin
Source: Narmada Water Resources and Water Supply Department, (1999).

3.2.2.1 Mini River

The Mini River is a minor tributary of the river Mahi. It originates at a distance of about 30 km North- East of Vadodara district. Its course of 50 km is almost parallel to that of the Mahi River and flows towards West before it joins the Mahi River between the villages of Jaspur and Sindhrot at a distance of about 9 km towards North-West of Padra and 15 km downstream from Vasad. Sindhrot village is 1 km upstream of the confluence of Mini with Mahi near Jaspur and Dabka. The mini river crosses the National Highway and the Railway line to Ahmedabad at a distance of about 16 km North of Vadodara. This river remains dry almost all throughout the year except during the monsoon and is not of much use to the local people (NEERI and NIO, 1975).

Prior to the commissioning of effluent channel (1983) many industries around Vadodara used to release their waste waters (effluents) in the Mini rivulet and converted river Mini into an open uncontrolled gutter which can pollute surface as well as sub- surface water of river Mahi. The Mini River meets the Mahi River in the fresh water zone at Jaspur. The major findings of the field investigation during 1973-74 in the Mahi River stretch between Vasad and Gangua by NIO is that the river stretch between Jaspur and Mahammadpura was severely polluted during dry season as the sea water crossed the sill at Mahammadpura only occasionally (NIO, 2005). It was therefore planned to collect the effluent from different industries and transport through a channel to a site downstream of Mahammadpura for effective flushing to the Gulf of Khambhat. So after commissioning of the 56 km long effluent channel by the ECPL in 1983, the fresh water zone of the Mahi River was free from the polluted load (NIO, 2005).

3.2.3 Water Resources Projects on River Mahi

There are three projects on river Mahi, out of which the Mahi Bajajsagar dam is in Rajasthan state and the Kadana dam and Wanakbori weir are in Gujarat State. Mahi Bajajsagar dam is located in Banswara district in southern part of Rajasthan bordering the States of Madhya Pradesh and Gujarat. Major part of catchment and submergence is in the Madhya Pradesh state. Its gross storage capacity is 2067.17 MCM. Kadana dam (Mahi stage- II) is constructed 3 km upstream of Kadana village of Kadana taluka in Panchmahal district in Gujarat state, which is moderating the flood in Mahi River. The Kadana dam provides irrigation, generates hydropower and acts as flood protective reservoir. Its catchment area is 25520 sq. km and gross storage capacity is 1249.26 MCM. Wanakbori weir (Mahi stage-I) is a pick up weir across river Mahi near Wanakbori village of Balasinor taluka in Kheda district. Its catchment area is 30665 sq. km and gross storage capacity is 67.372 MCM.

3.2.3.1 Mahi Right Bank Canal Project

The Mahi Kadana Irrigation Project has been developed in two stages. The first stage comprised the construction of a diversion weir across the river Mahi near village Wanakbori in Balasinor taluka of district Kheda in Gujarat state. The weir was completed in the year 1958. It facilitated the diversion of the river flow to the canal system with negligible storage in the upstream of the weir.

The second stage of irrigation development comprised the construction of a major reservoir near Diwada colony 3 km upstream of Kadana in Kadana taluka of Panchmahals district of Gujarat. It is located 70 km upstream of Wanakbori weir. The Kadana reservoir, known as Mahi stage-II, was constructed in the year 1979 with the primary objective of augmenting the supply of water to the Mahi Right Bank Canal Command area. While the Wanakbori weir system was built primarily to provide supplemental irrigation for monsoon crop, the Kadana reservoir system was designed to store and supply irrigation water for the winter and summer crops in the same areas served by the Wanakbori weir system. After the completion of the Kadana reservoir, assured water supply has been made available in the MRBC command area and an irrigation potential of 2, 63,000 ha has been created.

The water from the Kadana reservoir is released into the Mahi river and is carried downstream to the Wanakbori weir. The natural course of the river itself is used for the conveyance of the releases.

3.2.3.2 Mahi Right Bank Canal Command Area

The MRBC irrigation project is one of the major irrigation projects of Gujarat State, in western central India provides irrigation waters in two stages through Kadana Reservoir and Wanakbori weir. The head works of the system comprise the Kadana reservoir and the Wanakbori weir, both of which are located on the river Mahi. The MRBC Command is bounded by rivers Shedhi and Watrak (Tributaries of Sabarmati) in North, Sabarmati

River in North-West and West, whereas Mahi river provides southern and eastern boundaries of the command area. The plan to harness Mahi river to irrigate the lands bounded by Mahi and Sabarmati rivers in Anand and Kheda district was first conceived after the devastating famine of 1900-1901.The command area served by MRBC, covers eleven talukas namely, Anand, Umreth, Anklav, Borsad, Petlad, Khambhat (Cambay), Sojitra, Tarapur of Anand district and Thasara, Matar and Nadiad of Kheda districts.

The irrigation command area of MRBC lies between the North latitudes 22°26' and 22° 55' and East longitudes 72° 49' and 73° 23' (CSSRI, 1993). With the help of its nearly about 2362 kms canal networks, provides irrigation water in the gross command of 3, 15,790 ha and culturable command area 2, 12,694 ha in Anand district and major part of Kheda district of Gujarat State. The water distribution system of MRBC project comprises of main canal of design discharge capacity of 198.10 cumecs and having a length of 73.6 km. Due to additional requirement of irrigation and non agriculture purpose (water supply scheme for Saurashtra area and Ahmedabad Municipal Corporation).

3.2.3.3 Radial Collector Wells

There are thirteen Radial collector wells and one intake well upstream of Mahi Weir site permitted to draw 5.2 cumecs water. Government of Gujarat has guaranteed Vadodara Mahanagar Seva Sadan and industrial companies like Gujarat Refinery (Indian Oil Corporation), Indian Petrochemicals Corporation Ltd., Gujarat State Fertilizer Corporation to maintain a flow of 5.2 cumecs at NH-8 Bridge at Vasad 11.5 km upstream of Mahi weir site. Any deficit in river flow is to be met by releasing flow from Panam dam. For drinking water supply and industrial requirements, these thirteen Radial Collector wells in river Mahi U/S and D/S of NH-8 bridge at Vasad constructed by VMSS and big industries. There is also one Intake well of Nirma located near Bhadarva. The locations of collector wells in Mahi River are shown in figure 3.4 and also given in table 3.1.

All Radial Collector Wells draw ground water from below river bed being recharged by river flow, as ground water source does not need filtration plant. The average discharge drawn by all RCW's has not exceeded 5.2 cumecs. Even though Government of Gujarat has guaranteed to release water from Panam dam to maintain base flow of 5.2 cumecs at Vasad, there has hardly been any need to release water from Panam dam till now, as river base flow and incidental leakage and flow from Wanakbori weir maintains sufficient flow to 13 RCW's even in driest months of March to June (Multimedia Consulting Engineers, 1997).

Table 3.1 Locations of Radial Collector Wells in River Mahi

Sr.	Owner of Well	Village	Distance from Umeta Bridge (m)
1	GACL/GIPCL	Kahanwadi	7000
2	Gujarat Refinery (IOCL) B	Fajalpur	10200
3	Gujarat Refinery (IOCL) A	Fajalpur	10550
4	Gujarat Refinery (IOCL) C	Fajalpur	11000
5	Vadodara Municipal Corporation-1	Fajalpur	12000
6	Gujarat Refinery (IOCL) D	Raika	13500
7	Vadodara Municipal Corporation-3	Raika	14500
8	Vadodara Municipal Corporation-4	Dodka	15500
9	Vadodara Municipal Corporation-2	Poicha	15700
10	IPCL –I	Khandi	16750
11	IPCL –II	Jalampura	18070
12	GSFC – I	Jalampura	19650
13	GSFC – II	Parthampura	20765
14	Nirma (Intake Well)	Bhadarva	24500

Source: Shah, (2000).

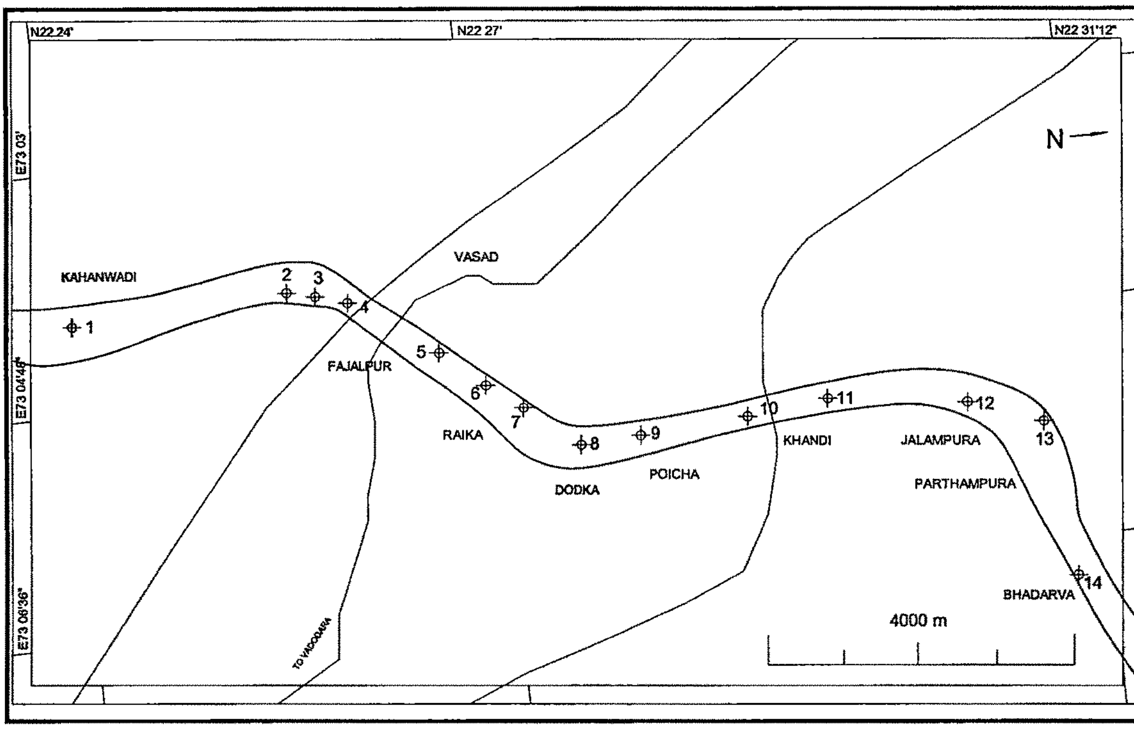


Figure 3.4 Map of Mahi River with Locations of Collector Wells
Source: Shah, (2000).

3.2.3.4 Mahi Tidal Regulator cum Recharge Scheme

Mahi tidal regulator cum recharge scheme envisages Sindhrot- Umeta of Vadodara district. The main purpose of the scheme is to prevent surface salinity ingress as well as to recharge the surrounding land. Three alternative sites were suggested. After further sub soil investigation by Gujarat Engineering Research Institute, Vadodara for the weir location was finalized at 1350 m downstream of Umeta Bridge. The Vadodara Irrigation Circle constructed a 540 m long weir on Mahi River near Sindhrot - Umeta. As a result of construction of this Weir, reservoir of fresh water is created on upstream side and automatically artificial recharge is done. The sea water intrusion to land ward side will be decreased because of this.

The weir structure would be resting on permeable foundation; therefore, pore pressure distribution beneath the structure has been determined using Khosla's theory. Based on this, the upstream cut off has been provided up to RL (+) 1.00 m in form of 1.0 m thick RCC key, as a monolith with the U/S concrete floor. Lesser concentration of discharge is considered as the weir is located on straight reach and without any feature like silt excluder or pier etc. On the downstream 0.6 m thick M-20 grade RCC diaphragm has been provided as cut-off.

3.2.4 Water Resources Projects on Tributaries of River Mahi

Anas dam site (on upper catchment) situated in Rajasthan State on Anas River, which is a tributary of Mahi River. Panam irrigation scheme is a medium irrigation scheme. Panam dam is situated in Gujarat State on Panam River (a tributary of Mahi River meeting on the downstream of Kadana dam) near village Kel-Dezar on the border of Lunawada and Santrampur taluka of Panchmahal district. Panam reservoir on this river also helps in moderating the floods in Mahi River. Area of catchment is 2314 sq. km Panam irrigation scheme is a medium irrigation scheme. The dam impounds gross storage of 735.8 MCM of water, which irrigates 41116 ha of land through left bank main canal having length 99.725 km in Santrampur, Lunawada, Shehera, Godhra and Kalol taluka of Panchmahal district and Savli taluka of Vadodara district.

3.3 Mahi Estuary

Mahi estuary is well-mixed estuary as there is gentle salinity gradient or homogeneous i.e. small salinity difference during the flood and ebb cycle. The estuary was vertically well-mixed. The advective river flow was appreciable during monsoon and for a few months thereafter subject to release of water from the Wanakbori weir upstream of Vasad. The stretch between Jaspur and Dabka remained nearly stagnant in the dry season. In an estuarine habitate salinity provides information on the intrusion of sea water which varies with the tidal stage and riverine flow. Normally sea water salinity is 35.5 ppt which may vary depending on competition between evaporation and precipitation and fresh water addition. The estuary experienced high river runoff during July-October effecting excellent annual flushing. The fresh water flow in the estuary decreased considerably with the withdrawal of monsoon and the estuary was sea water dominated after October (NIO, 2005).

The Mahi River is a tidal river. Mahi estuary joins the Arabian Sea at the northern part of the Gulf of Khambhat. The estuary is strongly influenced by the hydro dynamics of the Gulf of Khambhat. The mouth of estuary was considered at Gangua (Patel, 1983). The limit for the daily tidal zone of Mahi estuary is up to the horse shoe bend downstream of Mahammadpura, 50 km upstream from the mouth where a rocky sill on the river bed is formed by the deposition of silt carried by the river and tidal waters. Sea water intrusion normally occurred up to Mahammadpura. The sill near Mahammadpura acts as a barrier between tidal flow and river discharge during the dry season. Thus, on downstream of Mahammadpura the estuary is practically dominated by the tides while on upstream of Mahammadpura the influence is mainly of riverine flow. Further intrusion of sea water was obstructed by the sill at Mahammadpura. The tides were observed to cross the sill only during the high spring tides in summer and influenced the river segment up to Vasad on such occasions, the salinity of water increases and chloride concentration as high as 600-1000 mg/l has been reported at Vasad. The industries are, therefore, required to suspend operation on these days (NEERI and NIO, 1975). The fresh water regime of the river is limited to a few kilometers distance downstream below Vasad. Beyond this limit the water remains brackish throughout the dry weather conditions. The water is not suitable for drinking or agriculture.

3.3.1 Tidal Range in Mahi Estuary

The Gulf of Khambhat experiences semi-diurnal tides of high amplitude up to 10 m. Tidal bores are formed at the head due to typical 'v' shape of the Gulf of Khambhat. The Mahi estuary exhibited certain unique hydrographic features. The tidal range was less than 0.3 m at low tide periods and up to 6 m at high tide periods. The period between ebbing tide and flooding tide (called low slack period) was substantial in this estuary at and near point 'J' the two slack periods amounted to about 12 hours in a day. The Mahi experiences a semi-diurnal tide. i. e. high waters occur daily twice at intervals averaging 12 to 12.4 hours. The low slack period is about 6 hours and the water continues to ebb through the tidal channels between point 'J' and Shiv Mandir. The tidal range during neap and spring tides has been given in Table 3.2

Table 3.2 Tidal Range and High Water Level

Tide	Kavi Range	Shiv Mandir Range	HWL	Point 'J' Range	HWL	Sarod Range
	m.	m.	m.	m.	m.	m.
Spring tide	8.5	6.8	8.0	5.9	6.9	4.5
Neap tide	3.7	2.4	3.6	1.8	2.8	Nil

The tidal range at Gangua 3 days after the spring tide was 6.8 m (Source: NEERI And NIO, 1975).

3.4 DETAILS OF STUDY AREA

The more details of study area are described as follows.

3.4.1 Topography of Study Area

The overall topography of the area is more or less plain, except river courses where the topography is undulating. In general, the Mahi Right Bank canal command area is sloping south-west, towards the Gulf of Khambhat (Cambay). The land slopes from north-east to South-West with an average gradient of about 1 to 1600. The South-West region of the MRBC command area comprises a relatively flat land locally referred to as Bhal area (Water Technology Centre, IARI, 1983). The area between Narmada and Mahi covered by Jambusar, Padra and Vadodara talukas forms a part of the Vadodara-Bharuch plains. The area between Mahi and Sabarmati covered by Khambhat, Borsad and Petlad talukas forms a part of the Charotar plain. It is located on the lower reaches of canal irrigation system of the MRBC. The ground elevation of major part of the area is below 30 m above mean Sea level (GEC, 1997). The alluvial plain is a product of the age long processes of erosion and deposition carried out by the major rivers of southern and Central Gujarat flowing westwards to the Gulf of Khambhat (Cambay) (GOG, 1961).

3.4.2 Climate of Study Area

The study area in general experiences a semi arid (moist) to sub-humid climate. Aridity indicates status of climate in relation to moisture conditions. The climate of this area is characterized by a hot summer and general dryness, except during the south-west monsoon season which experiences heavy rain (GOG, 1979). The year may be divided into four seasons in the area. The cold season is from December to February. This is followed by the hot summer season from March to the middle of June. The period from mid-June to September is the South-West monsoon season where July is the rainiest month. October and November constitute the post-monsoon season characterized by moderate temperature and scanty rain (Water Technology Centre, IARI, 1983).

3.4.3 Temperature of Study Area

It may be seen that the period from March to May is one of continuous increase in temperatures. May is generally the hottest month, the mean daily maximum temperature being about 41°C and mean daily minimum temperature about 26°C. The weather is intensely hot in summer and during the same period the day temperature occasionally reaches 47°C or more. With the onset of monsoon in the area, there is an appreciable drop in the day temperature but nights are as warm as during the summer. With the withdrawal of the monsoon from the area by about the end of September, there is a slight increase in day temperature and a secondary maximum of day temperature is reached during October. However, the night temperature decreases after the withdrawals of the monsoon. After mid-November both day and night temperatures decrease rapidly till January which is the coldest month. The mean daily maximum temperature in January is about 30.1°C and the mean daily minimum is about 10.6°C. The area is sometimes affected by cold waves in association with western disturbances passing across north India and the minimum temperature may reach the freezing point of water. The highest maximum temperature recorded at Vadodara was 46.7°C on 20th May, 1955. The lowest minimum temperature recorded was 1.1°C on 15th January, 1935. Average temperature during winter and monsoon is 30°C and during summer is 43°C (GOG, 1979 and Water Technology Centre, IARI, 1983).

3.4.4 Humidity

During the South-West monsoon season the humidity is high, generally exceeding 70 percent. In the rest of the year the air is dry. Humidity decreases during the post monsoon months. The driest part of the year is the period from February to April with relative humidity's less than 30 percent mainly in the afternoons. Relative humidity is maximum in the early morning and minimum in the afternoon. Humidity in the morning varies from about 60 % in the winter months to about 85 to 90 % during the monsoon months. On individual days in the monsoon months it may be even 100 %. In the afternoon it varies from 20 to 25 % in the months November to March and is about 70 % in July and August. It is lowest in the winter months (GOG, 1961; GOG, 1979 and Water Technology Centre, IARI, 1983).

3.4.5 Cloudiness

During the South-West monsoon season, the Skies are generally heavily clouded or overcast. Cloudiness rapidly decreases in the post-monsoon season. Skies are mostly clear or lightly clouded during the period December to May (GOG, 1979).

3.4.6 Winds

Winds are generally light during most of the months in the year, ranging from 2.6 km p. h. to 9.8 km p. h. However, the summer months experience comparatively strong winds. Winds blow mostly from the South-Westerly and Westerly directions during the period from May to September. Winds blow from the North or North-East during the post-monsoon and early winter months. In the latter half of the cold season and the first two months of summer winds are mostly from directions between South-West and North-West (GOG, 1979 and Water Technology Centre, IARI, 1983).

3.4.7 Rainfall

About 90 to 96 percent of the normal annual rainfall in the study area is received during the South-West monsoon months mid of June to mid of September, July being the rainiest month. Most of rainfall during the monsoon season is generally associated with movement West or North- West wards towards Gujarat of the depressions from the North Bay of Bengal. There is no regular rainfall during monsoon months. Winter rains are not significant and seldom exceed 50mm. The variation in the annual rainfall from year to year is large. The range of annual rainfall is found to be 661 to 1009 mm for districts of Anand, Vadodara and Bharuch. The range of rainy days is found to be 45-31 days in a year in the area. The heaviest rainfall in 24 hours recorded at any station in the Vadodara district was 460.3 mm at Vadodara on 24th September, 1945. The annual rainfall in the study area shows wide variation in its spatial distribution. The average and extreme values for rainfall and rainy days have increased in recent years. It indicates the increasing trend of erratic character of rainfall in recent years (GOG, 1979; GOG, 1961 and GEC, 1997).

3.4.8 Special Weather Phenomena in Study Area

A special weather phenomenon experienced is the occurrence of occasional cyclonic storm originating from the Arabian Sea in the late summer season, and in the post-monsoon season, which may affect the weather over the area causing heavy rain (Water Technology Centre, IARI, 1983 and GOG, 1979).

3.4.9 Geology

The area around Gulf of Khambhat is covered by the alluvial deposits of Quaternary period (1.5 million years). During Quaternary, the sea level has fluctuated in the range of about plus 50 m to minus 150 m with reference to present level. Majority of the present sediments of this area around Gulf of Khambhat comprising raised mud flats and stabilized coastal and inland ridges represent the last marine transgression when the Sea had risen up to about 10 m around six thousand years ago and which is now regressed to the present level (GEC, 1997).

The present study area is a part of Cambay basin and consists of recent to sub-recent thick alluvial deposits of 'aeolian', 'fluviatile', and 'estuarine' which range in geological time scale from Holocene to Pleistocene. These alluvial deposits consisting of river laid and windblown sands and clays, overlying older sediments consisting of blue shales and sandstones of Tertiary age. The alluvial deposits overly the Deccan trap basements.

Alluvial deposits are mainly consisting of alternate layers of silt, clay, sand, gravel, pebbles and kankars in various proportions. The clay beds are generally yellowish in colour. Such strata are suitable for artificial recharge of groundwater. The blue clay formation is a marker horizon for tertiaries formation which is noticed at a depth varying from 65 to 130 m below ground level at the villages: Mokshi, Kunpad, Natwarnagar, Rania, Jalampur (taluka Savli), Fajalpur, Dashrath, Nandesari, Angadh (taluka Vadodara), Kanwadi, Bhanpura, Amrol (taluka Borsad), etc. The sand layers are yellowish to dark brown in colour and consisting of fine to coarse grained particles mainly of quartz. The lateral and vertical extents of clay and sand layers are non-uniform, which in general, is the characteristic feature of estuarine alluvial deposits. As compared to sand layers (beds), the clay layers are thin and oriented almost horizontally. The clay layers (beds) are found to be varying in its thickness and thin in the North East part (upstream) but in south-west part (downstream) of study area, its thickness increasing as much as 20m. The thickness of sand and clay layers is non-uniform.

Based on the study of the data of exploratory tube well drilled earlier by CGWB and others, it is reveled that the maximum alluvium thickness is about 300m below ground level. Within this depth there are about 12 distinguishing layers consisting of sand and clay (GOG, 1979, GWRDC, 1987, Yagnik et al. 2003).

3.4.10 Soils in the Study Area

The soils of the study area are formed through alluvial deposits carried by rivers. The Vadodara taluka is mainly covered by black cotton soil, except a small area along river Mahi in N-W parts, where soils are predominantly sandy type. The soils are generally dark brown to black in colour as the name black cotton soil indicates. However in some parts sandy soils are yellowish to brownish yellow in colour. Soils in the Anand, Borsad, Anklav and Petlad talukas are ranging from sandy loam to clay. The type of the soil is deep black coastal alluvium in Bharuch district and medium black in Vadodara and Anand districts. These soils lie on a comparatively higher elevation and are inherently porous and permeable.

The area is predominantly derived from rocks like phyllites, schists and quartzites. The phyllites and schists give rise to medium to heavy soils, varying from sandy loam to clay, where as the quartzites from the coarse material in the flood plains giving rise to loamy sand to sandy loam soils. Soils are of recent and sub-recent origin. During the process of alluvial formation, the coarse and heavy material are deposited near the source whereas the fine materials are carried away towards the Gulf of Cambay and form the clay soil deposits in the flat region near the Coastal-estuaries(GWRDC, 98-99 and Water Technology Centre, IARI, 1983).

The soil map of study area from Gujarat soil map by National Bureau of soil survey and land use planning (ICAR) Nagpur is shown in the figure 3.5. The brief description highlighting soil depth, texture, drainage, slope, erosion, salinity etc. of the dominant and associated subdominant mapped soils are given in Legend. Legend also provides taxonomy of soils as per USDA system of classification for national and international understanding.

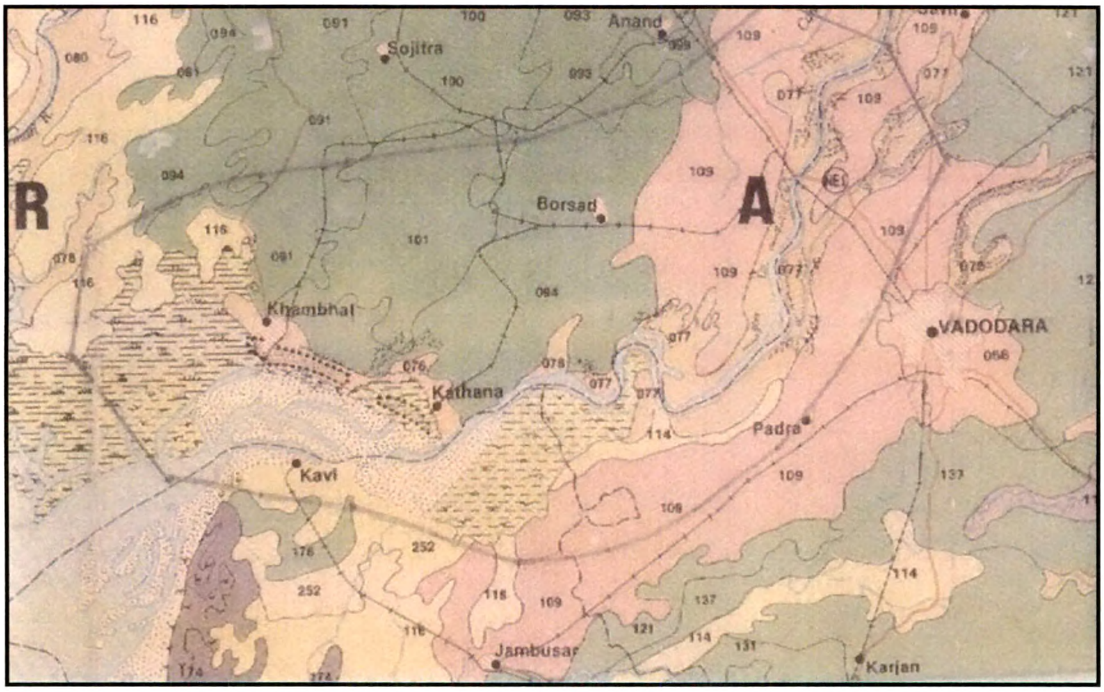


Figure 3.5 Soil Map of Study Area from Gujarat Soil Map by National Bureau of Soil Survey and Land Use Planning (ICAR) Nagpur

Table 3.3 Legend (Soil Map of Study Area)

Sr. No.	Identity color / Mapping symbol	Description	Taxonomy
Soils of Alluvial Plains			
1	- 076	SOILS OF ALLUVIAL PLAINS. This deep, 'drained, calcareous, coarse-loamy soils on very gently sloping dissected flood plain with moderate erosion and	o Coarse-loamy, mixed (calcareous), hyper-thermic Typic ustifluvents. o Fine-loamy, mixed (calcareous),

		strong salinity; associated with very deep well drained, calcareous, fine-loamy soils with slight erosion and moderate salinity.	hyper-thermic Fluventic usto-chrepts.
2	- 077	Very deep, well drained, calcareous coarse-loamy soils on very gently sloping dissected flood plain with very severe erosion; associated with very deep, well drained, calcareous, fine-loamy soils with severe erosion.	○ Coarse-loamy mixed (calcareous), hyper-thermic Typic ustifluvents. ○ Fine-loamy, mixed (calcareous), hyper-thermic Fluventic ustochrepts.
3	- 091	Deep, well drained, calcareous, fine-loamy soils on very gently sloping alluvial plain with slight sloping alluvial plain with slight erosion and moderate salinity; associated with deep moderately well drained, calcareous, fine soils with slight erosion.	○ Fine-loamy, mixed (calcareous), hyper-thermic Typic ustochrepts. ○ Fine, mixed (calcareous), hyper-thermic Typic ustochrepts
4	- 093	Deep, well drained, fine-loamy soils on very gently sloping alluvial plain with slight erosion; associated with deep, somewhat excessively drained, coarse-loamy soil with slight erosion.	○ Fine-loamy, mixed, hyper-thermic Typic ustochrepts ○ Coarse-loamy mixed, hyper-thermic Typic ustifluvents
5	-094	Deep, well drained, fine-loamy soils on very gently sloping alluvial plain with slight erosion and moderate salinity associated with deep, somewhat excessively drained, coarse-loamy soil with slight erosion and slight salinity.	○ Fine-loamy, mixed, hyper-thermic Typic ustochrepts ○ Coarse-loamy mixed, hyper-thermic Typic ustifluvents

6	- 099	Deep, well drained, fine-loamy soils on very gently sloping alluvial plain with slight erosion; associated with deep, moderately well drained, calcareous, fine soils on gently sloping lands with moderate erosion.	o Fine-loamy, mixed, hyper-thermic Typic ustochrepts o Fine, modntmorillonitic (calcareous), hyperthermic vertic ustocharepts
7	-101	Deep, well drained, fine-loamy soils on very gently sloping alluvial plain with slight erosion and moderate salinity associated with deep, moderately well drained, calcareous, fine soils on gently sloping lands with moderate erosion.	o Fine-loamy, mixed, hyper-thermic Typic ustochrepts o Fine, modntmorillonitic (calcareous), hyperthermic vertic ustocharepts
8	- 109	Very deep, well drained, fine-loamy soils on very gently sloping alluvial plain with slight erosion; associated with very deep, well drained, fine soils on nearly level lands with slight erosion.	o Fine-loamy, mixed, hyperthermic Fluventic ustochrepts o Fine, mixed, hyperthermic Fluventic ustochrepts
9	-114	Moderately deep, well drained, calcareous, fine soils on nearly level alluvial plain with slight erosion and slight salinity; associated with deep, moderately well drained, calcareous, fine soils with slight erosion.	o Fine, montmorillonitic (calcareous), hyperthermic Veric Ustochrepts o Fine, montmorillonitic (calcarious), hyperthermic Typic chromusterts
10	- 116	Moderately deep, well drained, calcareous, fine soils on very gently sloping alluvial plain with slight erosion and moderate salinity; associated with	o Fine, montmorillonitic (calcareous), hyperthermic Veric Ustochrepts o Fine,

		deep, moderately well drained, calcareous, fine soils with moderate erosion.	montmorillonitic (calcarious), hyperthermic Typic chromusterts
Soils of Coastal Plains			
11	- 176	SOILS OF COASTAL PLAINS. Deep, moderately, well drained, calcareous, fine soils on nearly level costal plain with slight erosion and moderate salinity; associated with moderately shallow, moderately well drained, calcareous, fine soils with slight erosion and moderate salinity.	o Fine, montmorillonitic (calcarious), hyperthermic Typic chromusterts o Fine, montmorillonitic (calcareous), hyperthermic Veric Ustochrepts
Soils of Piedmont Plains			
12	- 252	Moderately shallow, well drained, calcareous, fine soils on very gently sloping piedmont plain (with narrow Vlleys) with slight erosion and slight salinity; associated with moderately shallow, well drained, calcareous, fine soils with slight erosion and slight salinity.	o Fine, montmorillonitic (calcareous), hyperthermic Veric Ustochrepts o Fine, montmorillonitic (calcarious), hyperthermic Typic chromusterts

3.4.11 Vadodara Branch Canal

Vadodara branch canal having length of 115.09 km and design discharge of 76.04 cumecs at head and 2.142 cumecs at tail is one of the major branch canal off taking at Chainage 81.834 km of Narmada main canal near village Rameshara, district Vadodara runs Whaghodia, Vadodara , Savli, Padra and Jambusar talukas and caters C.C.A. of 80228 ha. in Vadodara district.

3.4.12 Effluent Channel Project, Vadodara (ECP)

Vadodara the second largest city in the State of Gujarat is one of the forcal points for industrial growth in Western India. The industrial complex near Vadodara comprises of many large and medium industrial units, most of these industries and even a part of Vadodara city draw their fresh water supply from the Mahi River through French type infiltration wells. Further prior to the commissioning of the effluent channel all the large industries and many other chemical industries round about, discharge their effluent in river Mini, a tributary of river Mahi that meets the Mahi river at Jaspur in the fresh water zone.

It was felt that with further industrialization of the region, the sweet water resources of river Mahi would be completely polluted and there would be a serious, threat to the environment of Vadodara city and villages depending upon river Mahi for their fresh water requirement. In order to protect these fresh water requirements, it was necessary to prevent the discharge of industrial effluents into the river. To achieve this objective, the State government decided a project to intercept the industrial effluents from industries in this area and arrange for efficient transportation of the same to a distinct safe disposal point into the Sea on Gulf of Cambay. Thus GIDC earned the distinction of providing India's first effluent disposal channel on co-operative basis (Mitun, 2003)

The Effluent Channel Project (ECP) is a pioneering project in India for providing effluent disposal facility through effluent channel. The common Effluent Disposal Channel in Gujarat is managed by ECPL.

Effluent Channel Project Limited (ECPL), Vadodara has constructed a 55.3 km long channel for conveying treated effluent from 31 large and medium scale industries and about 270 small scale industries in clusters at Nandesari and Umraya comprising Indian Petrochemical Corporation Limited (IPCL), Indian Oil Corporation Limited (IOCL) or Gujarat Refinery, Gujarat State Fertilizer Corporation (GSFC), Gujarat Alkali and Chemicals Limited (GACL), etc. in 1980. The purpose of the channel was to carry treated combined effluents for release in the Mahi estuary thereby protecting fresh waters of Mahi River from industrial pollution.

Based on detailed ecological and hydrographic studies in the Mahi estuary in 1973-74 conducted jointly by the National Institute of Oceanography (NIO) and the National Environmental Engineering Research Institute (NEERI), the J point near the Sarod village of taluka Jambusar, district Bharuch was selected by a committee comprising of the representatives from the Gujarat Pollution Control Board (GPCB), Government of Gujarat (GOG), NIO and NEERI. The gravity flow effluent channel was commissioned in 1983 originating from Dhanora and Terminating at J-point near Sarod village, where treated effluent is discharged in estuarine region of Mahi through diffuser out fall arrangement. Based on the study by NIO, six hours tidal cycle was established. To match the cycle, two lagoons of 4 MGD capacity were constructed at the disposal point to hold the effluent during high tide and discharge the effluent during low tide to achieve efficient dispersion.

The channel is constructed in the form of 'U' shape brick masonry conduit covered with RCC slab. The channel is designed to carry an average discharge of 145 MLD (32 MGD) and peak discharge of 218 MLD (48 MGD) taking peak factor as 1.5. Capacity of channel including free board is 65 MGD. Depth of flow is 1.65 m at a peak discharge of 48 MGD. The conveyance of effluent is by gravity only with a bed gradient of 1 in 3000 (NIO, 2005). The channel is provided with 139 cross drainage works to ensure free passage of natural waterways. Number of falls provided is 6. The channel passes through land admeasuring 15 m width, which is in possession of ECPL. The manholes and vent holes are also constructed on the channel. Though the channel capacity was designed for 32 MGD, the initial maximum discharge of 22 MGD was only flowing through the channel. This has however progressively reduced to10 MGD as a result of recycling and reuse practices followed by a majority of the industries contributing to the channel.

The channel presently passes through about 29 villages. Due to shortage of fresh water in the region through which the channel crosses the channel is being tampered by farmers enroute and utilize the channel effluent for irrigation purpose. This unauthorized indiscriminate use of partially treated effluent can cause adverse impact on the water, land and biological environment since the effluent does not conform to the discharge standards (NEERI, 2005).