CHAPTER-I

1.1 PRELUDE

It is an established fact that almost three fourth of our planet is occupied by water out of which only 5% of the total water is fresh water. Further, about 80% of fresh water is frozen and only 20% occurs in liquid form. It is significant to note that groundwater, which is a renewable resource, accounts for 95% of all the fresh water available on the earth at any given time. Moreover, it is more protected from pollution; requires little treatment, can be developed with little gestation period, and it has minimum interference with the land resources. Inspite of all this because of its uncertainty about the occurrence, distribution, quantity and quality aspects impose restriction on exploitation of groundwater.

India being predominantly agrarian country, its economy to a large extent is based on agriculture resource. Rainfall in India is mostly attributed to the SW monsoon between June to September which contributes 74% of the surface water input (Table-1.1). As a result our agriculture is monsoon dependent. The coefficient of variability of south west monsoon varies from 15% in high rainfall region of Assam to more than 60% in low rainfall areas of western Rajasthan (CGWB, 1995). It is estimated that nearly one third of the country is drought prone and one eight is flood prone (Raju, 1997).

Table-1.1 Rainfall Input in India (CGWB, 1995)

Sr. no	Precipitation Intake	BCM	Percentage Share
1	South West	2660	74
2	North East	120	3
3	Pre monsoon	520	13
4	Post Monsoon	400	10
5	**Total**	**4000**	**100%**

On the groundwater front wherein, sediments and their characteristics governs its occurrence and potential. Large part of the country is covered by consolidated and semi-consolidated sediments. The problems of groundwater occurrence in hard rock terrain (consolidated) are manifold. Lack of primary porosity and permeability in the rock, majority of aquifers are restricted to thin weathered zones and groundwater being dynamic resource gradually flows subsurface and contributes to the river system as base flow. The deeper aquifer are solely restricted to a few regional fracture system therefore, to have a sustainable resource hard rock areas need special management practices.

Whereas, semi consolidated and unconsolidated sediments (Davis and Dewiest, 1967) although considered to be the ideal repositories for groundwater, invariably suffers from poor quality of water due to continual salt built up and over-exploitation.

As the pattern of Indian monsoon is highly erratic the surface water resources are highly unreliable therefore, it becomes important to have a dependent source of water that can subsist our drinking, industrial and agriculture requirement on round the year basis. As a result groundwater becomes an obvious choice because of its ubiquitous occurrence, reliability and availability in all seasons. As such more than half the world's population is dependent on groundwater for their survival (UNESCO, 1992).

With the rapid pace of urbanization, industrialization and population growth, the stress on groundwater is tremendous. The stress is considered to be three dimensional viz.

- There is huge demand in terms of quantity in domestic, agricultural and industrial sectors.
- The quality aspect is the second dimensional stress as it becomes an important parameter for its use.
- The third dimensional stress is anthropogenic factors leading to groundwater contamination by direct or indirect means.

The impact of developmental activities due to over withdrawal of water resources invariably put groundwater resource under stress. Rapid and progressive decline in groundwater levels, de-saturation of aquifer zones, and increased energy consumption for lifting water from progressively declining groundwater levels, quality deterioration, ground subsidence and saline water intrusion in coastal aquifers are some of the most prominent outfall of over exploitation.

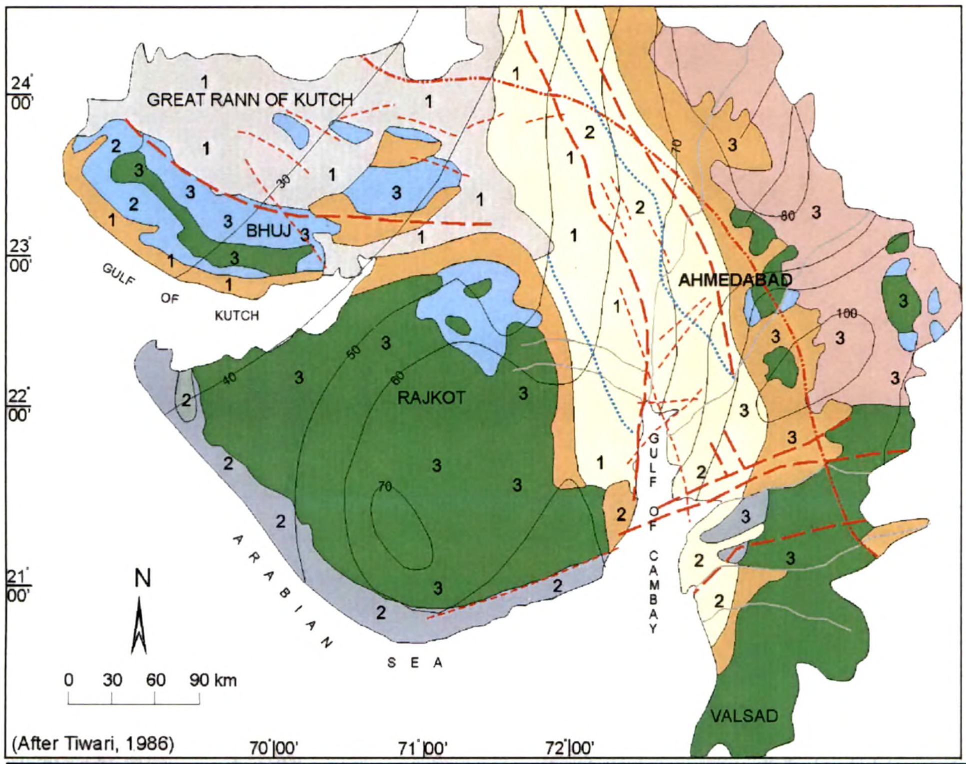
1.2 Status of Groundwater in Gujarat

The state of Gujarat spread over 1.9 lakh km^2 exhibits a wide variation in geo-environments. A wide range of geomorphic features are visible within a relief from sea level to ±1100m of elevation. Gujarat has a 1600km long coast line characterized by two gulfs and several estuaries. The sediments ranging from present day to Precambrian age comprises of wide variety of rock types seen occurring in the state. Out of total area of about 1, 96,000 km^2, nearly 80,000 km^2 is under hard rock and about 82,000 km^2 is an alluvium area. Groundwater in the state occurs in all geological formations. The porous and permeable formation includes unconsolidated and semi consolidated sedimentary and recent to sub recent alluvium formations. Fissured formations constituted by hard rocks, mainly igneous, metamorphic and intrusive rocks. A map depicting overall hydrogeological characterization of the Gujarat state is given as Fig- 1. The coastal belt is not suitable for groundwater development as the water is saline and aquifers are inflicted by the problem of sea water intrusion.

Groundwater quality in Gujarat state is highly variable and due to multiplicity of factors viz. influenced by direct sea water encroachment, inherent sediment salinity, water logging, overexploitation leading to overall deterioration in ground water quality, land subsidence and industrial pollution etc. In general overall quality of the groundwater is good in the eastern parts of Mainland Gujarat and the central parts of Saurashtra and Kachchh. Whereas, other regions are affected by natural and anthropogenic conditions have poor quality of groundwater.

Gujarat state inhibits large number of major river valley projects encompassing vast agricultural land in its irrigation command. Excessive irrigation and poor irrigation management has lead to its significant area into water logging problems and land degradation. Noteworthy regions are Ukai-Kakrapar Left Bank Canal Command in south Gujarat and Mahi Right Bank Canal Command in Central Gujarat etc. with a total land of more than 4.84 lac hectare is fully waterlogged.

The excessive fluoride concentration in groundwater in many part of Gujarat is also posing a serious threat to inhabitant's health. Worst affected districts by excess fluoride (over 1.5 mg/l) are Banaskantha, Kachchh, Saurashtra, Panchmahal, Kheda, Mehsana and Sabarkantha. Similarly excess nitrates (over 45 mg/l) in groundwater is also reported mainly from irrigation command areas and affected districts are Amreli, Banaskantha, Bhavnagar, Gandhinagar, Jamnagar, Junagarh, Kachchh , Mehsana and Surat.



Symbol	Age group	Nature of formation	Lithology	Tectonic Framework	Groundwater Conditions
	Quaternary-Upper Tertiary	Unconsolidated formation	Clay, Silt, Sand, Gravel, Pebbles, Boulders, Calcareous concretions	Groundwater basin occurring in platform area and fordeep zone.	Groundwater basin having extensive lateral extent and thickness of aquifers under confined conditions beyond 100 m.
				Platform margins in parts of Mainland river basin, coastal plains of Kutch.	Marginal area of groundwater basins having aquifers within 100m. with limited extension due to boundary conditions.
	Quaternary and Tertiary	Semi-consolidated formation	Limestones (Milliolite, Guj, Kirthar)	Coastal areas of Saurashtra and between Tapi and Narmada Mouths	Karstic limestone (Milliolite and Guj) in coastal area having groundwater in cavern and solution channels within 50 m.
	Tertiary and Mesozoic		Grit, Sandstontes, Siltstones, Shales, Conglomerate, Limestone	Platform area in Kutch and NW Saurashtra outlier and inliers in East Gujarat an dNarmada Valley	Tertiary and Mesozoic sedimentary rocks with restricted confined aquifers in platform areas.
	Cretaceo-Eocene	Consolidated formation	Basalt (with intertrappean beds)	Terrestrial volcanic effusiions on platforms.	Groundwater occurrence restricted to weathered zone, joint planes, zones of shearing and faulting and vesicals. Phreatic unconfined conditions prevail in weathered zone and piestic condtions in deep fractures.
	Pre-Cambrian		Sandstontes, Shales, Phylites, Slates, Wuartzites, Dolomite, Marbles, Schists, Granites, Basic Igneous Rocks.	Ancient platform area of Archean Folding.	Groundwater occurrence restricted to soil and regolith cover and weathered and fissured zones under phreatic unconfined conditions.

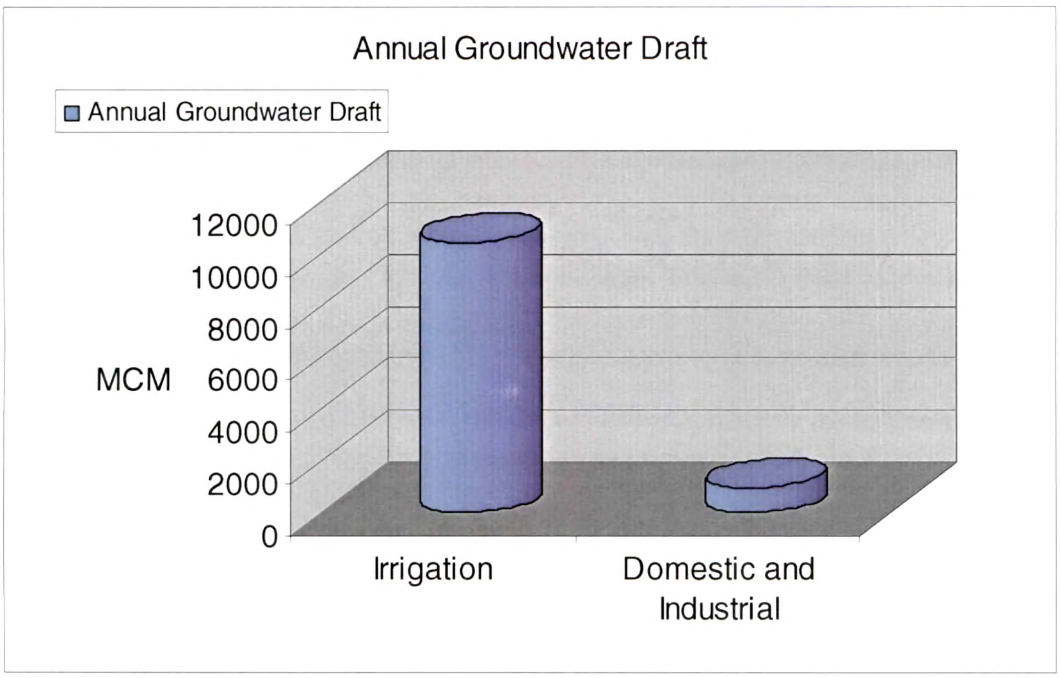
BOUNDARY AREAS WITH ARTESIAN FLOWING CONDITIONS — ISOHYTES ANNUAL AVG. RAINFALL

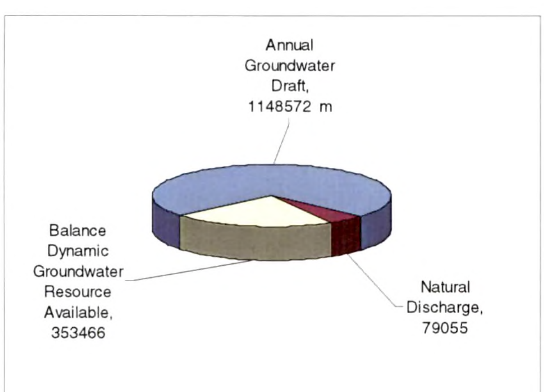
MAJOR FAULTS — MINOR FAULTS — TECTONIC ZONAL BOUNDARY

1 - GROUNDWATER SALINITY WITH LITTLE POSSIBILITY OF ENCOUNTERING FRESH WATER AT DEPTH
2 - GROUNDWATER SALINITY INCREASES WITH DEPTH
3 - GROUNDWATER FREE FROM SALINITY HAZARDS

Fig 1.1 Hydrogeological Dimensions of Gujarat State

So far quantitative aspects of the groundwater resource of the state is concerned, the estimated groundwater recharge stand as 15,81,093 ham/yr that includes 10,58,980 ham/year recharge from rainfall and 2,07,511 ham/year recharge from other sources during monsoon and 3,14,602 ham/year during non monsoon period (CGWB,2004). (Fig-1.2)





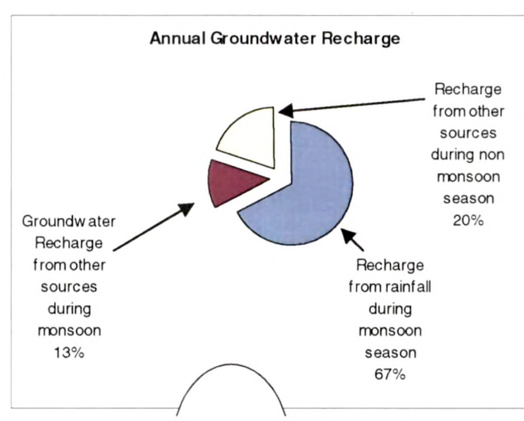
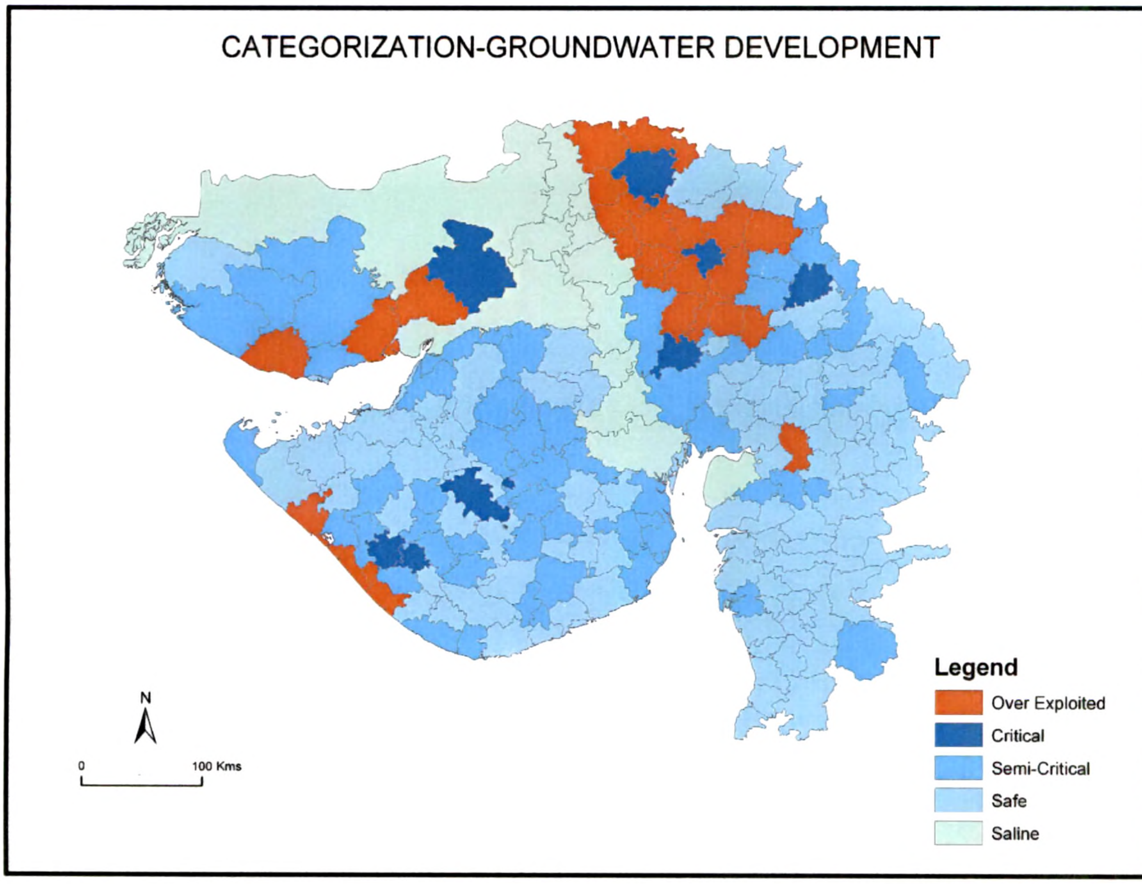


Fig-1.2 Groundwater resource and development potential in Gujarat

The whole of the state has been categorized into five different categories based on the stage of groundwater development. Out of the 223 Talukas of 25 districts; 30 taluka are in Over-Exploited category; 13 Talukas in critical category; 69 Talukas in semi-critical category; and 14 Talukas were found to be under saline category. The number of over exploited and critical Talukas has been found to be increased to 44 as compared to 39 Talukas in 1997.

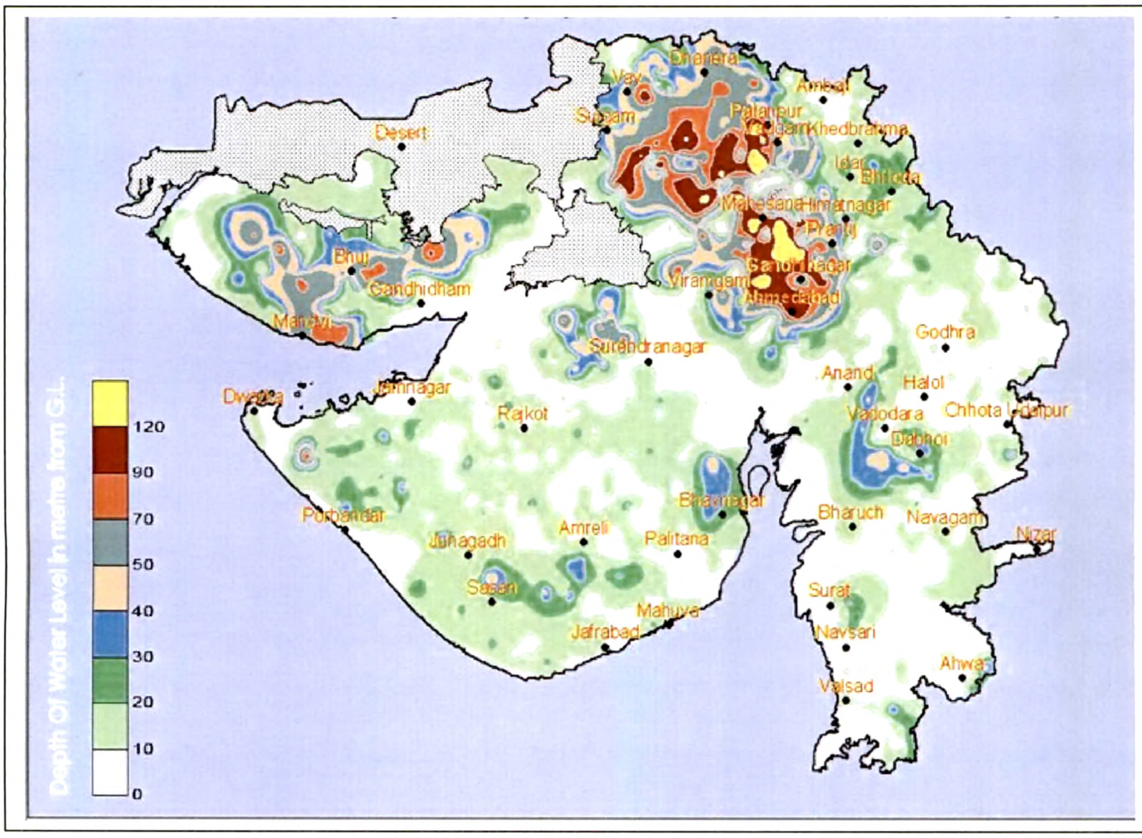


(Source: Redrawn after GWRDC, 2006)

Fig-1.3 Status of Groundwater Development in Gujarat State.

The groundwater level in the state varies from near ground level to a maximum of 120m (below ground level). The overall trend in the groundwater level is declining mainly due to excessive withdrawal (groundwater mining). An overall scenario depicting status of groundwater levels in various parts of the Gujarat is shown in Figure-1.3.

During the last decade, large scale exploitation of groundwater for irrigation and industrial uses has led to decline in groundwater table at a rate of approximately 4.5m/yr.



Source: GWRDC, 2006)

Fig-1.3 Groundwater Levels in Gujarat

1.3 The Study Area:

The Central Gujarat region i.e. Mahi-Narmada Inter stream Area (Doab) represents an ideal terrain characterized by a diverse geological environment infected from diverse hydrological problems. Therefore, the author found this region more apt to investigate and unravel its various intricacies related to groundwater regime.

1.4 Geographic Attributes:

- The study area has a distinct physiographic boundary and is bordered by Gulf of Cambay in the West, the rocky uplands in the East, Mahi River in the North and Narmada river in the South. The area lies between 72° 30’ E and 73° 43’ E Longitudes and 21° 40’ N and 22° 53’ N Latitudes, falling in 46/ B, C, F, G, J & K topographic sheets of the Survey of India. Administratively it covers almost all talukas of Vadodara district (Fig- 1.5) viz. Padra, Karjan, Vadodara, Dabhoi, Sinor, Savli, Waghodia, Sankheda, Nasvadi, Jetpur Pavi, Chhota Udaipur and Kavant,; four talukas of Bharuch district viz. Jambusar, Amod, Vagra and Bharuch; and two Talukas of Narmada district viz. Tilakwada and part of Nandod. The total study area stands at 11,187.89 km^2.

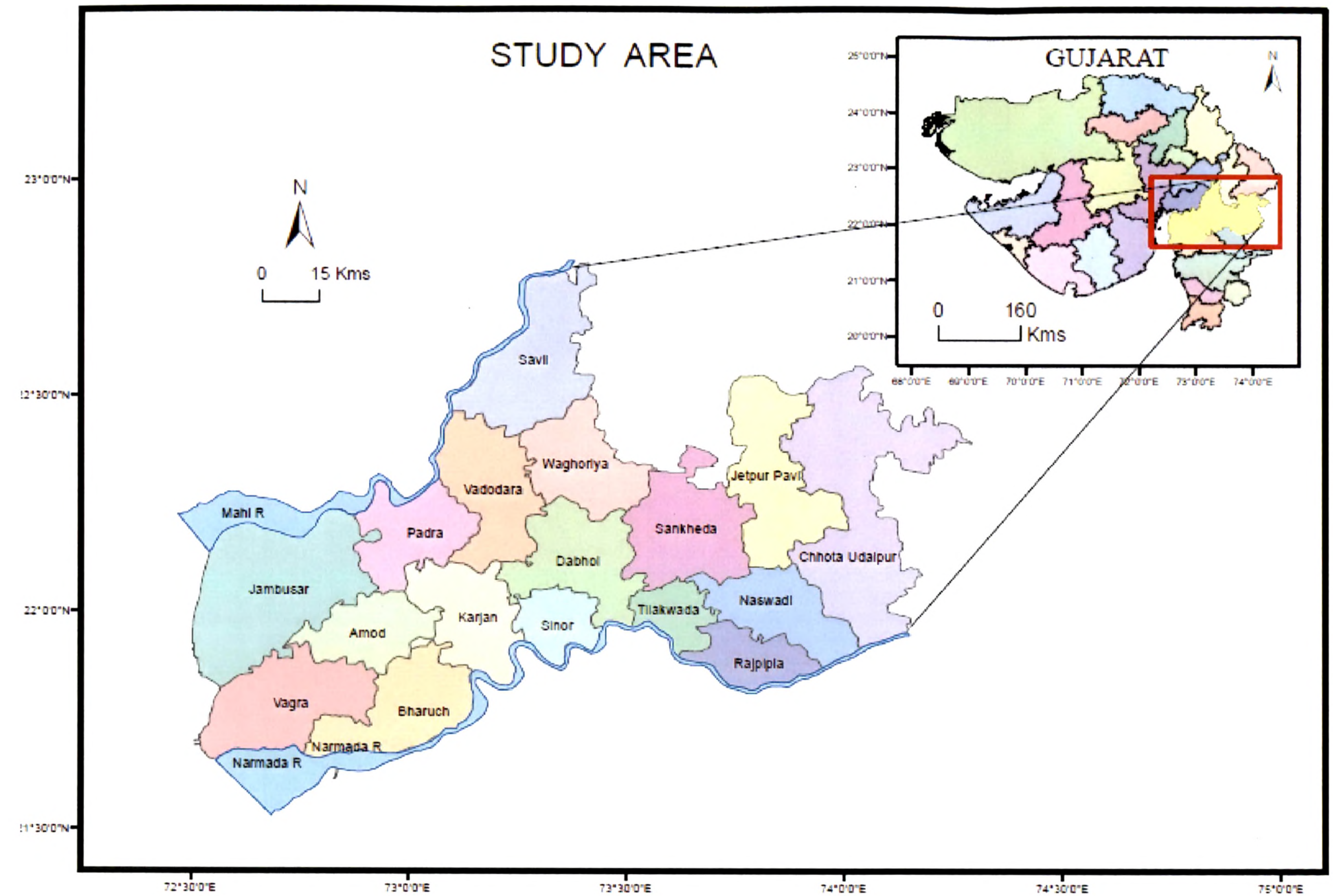


Fig-1.5 Location of Study Area

1.5 Objective and Scope:

The study aims at carrying out an in-depth study on hydrogeological aspects of Mahi-Narmada interstream area with the following objectives:

1. To work out the various hydrogeological environs.
2. Hydrogeochemical study of the groundwater with special reference to seasonal changes in ionic content and its characterization in terms of potability and toxicity.
3. Isotopic study of the groundwater to delineate the regions of groundwater recharge and its pattern.
4. To work out various geochemical facies and establishing correlations with the source (recharge) area.
5. Quantitative assessment of water resources and analysis of demand supply scenario.
6. To workout water resource management model using on Remote Sensing and Geographical Information System (RS & GIS) tools.

1.6 Approach and Methodology

The defined objectives fall in varied domains therefore author has adopted a multidisciplinary approach to accomplish the various tasks. The entire investigation has been carried out in three phases mainly encompassing following activities.

Phase-1

- Literature survey and collection of secondary data pertaining to geology, hydrogeology, hydrometeorology, geomorphology aspects.
- Critical appraisal, evaluation and compilation of secondary data and development of various thematic maps based on Survey of India toposheets and ancillary data.
- Carrying out reconnaissance field work to identify sites for establishing observation wells, groundwater sampling and other attributes.

Phase-II

- Seasonal collection of water samples for estimation of oxygen isotopes and analyzing their hydrochemical contents.

- Study of aerial photographs and satellite imageries of the study area to work out various thematic maps hydrogeologic attributes viz.hydrogeomorphology, hydrogeology, lineament features, drainage, land use etc. at 1:50,000 scale in GIS environment.

- Preparation of various well hydrographs using primary and secondary data and their analysis.

- Evaluation of hydrometerological data for quantitative estimation of water resources.

Phase-III

- This phase includes analysis and interpretation of various data collected in Phase-I and II leading to area characterization from groundwater feasibility point of view.

- Groundwater quality assessment using existing standards and plots from the point of view of its potability, uses and genesis.
- Characterization of the various aquifers using bore hole data and developing sub-surface profiles.

- Integration of groundwater chemistry with geological environment and its spatial distribution patterns.

- Quantitative assessment of groundwater resource using standard approach.

- Integration of various information on GIS environment with a view to generate various thematic maps on recharge and discharge zones, ground water potential map, water resource management map siting recharge zones etc.

- Syntheses of an overall water resource management model for the study area.

1.7 Communication

The study area is very well connected to the other parts of the country by air, rail and road networks. Broad and narrow gauge rail lines are passing through the study area. One domestic airport at Vadodara provides air connectivity to other parts of the country. The National Highway No. 8 passes through the study area. Moreover, the study area has good network of state highways and district roads. All the cities, town and villages within the study area are connected with the motorable roads and as a mode of conveyance state transport buses and private vehicles ply on regular basis.

1.8 Climate

The study area falls in the semi-arid climatic zone of the Gujarat state and lies between 35º & 45º C isotherms. The area receives rainfall from SW monsoon during the months from June to September. From November onwards and upto the March is the period of winter seasons wherein temperature ranges from a minimum of 5º C to a maximum of 20º C. It is followed by summer months of high temperature which at times reaches to 45º C. The average annual range of temperature falls within 20-34º C (CGWB, 2003). The area receives rainfall from South West monsoon and the mean annual rainfall is around ~ 900mm for the central portion and 700mm along the coastal track (Fig-1.5). Based on the variability in rainfall, potential and actual evapotranspiration relation and length of growing period for normal cropping, the study area falls in the semi-arid central agro-ecological sub region of Gujarat (NBSS & LUP, 1994).

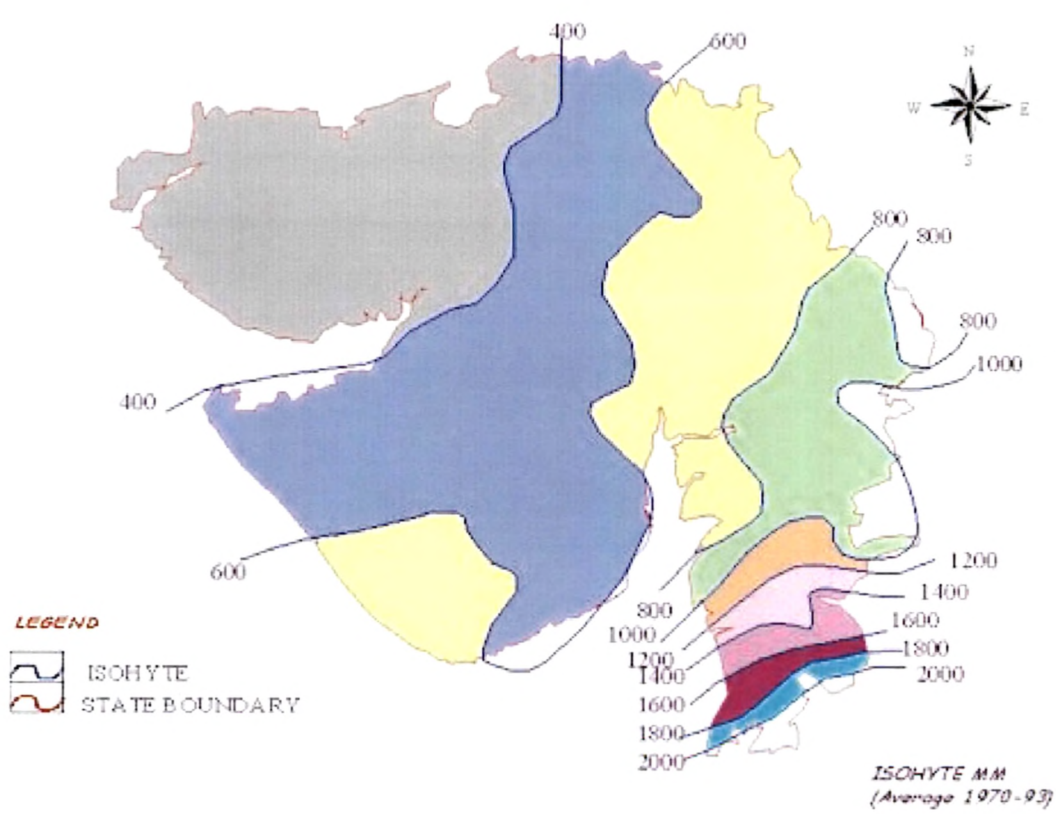


Fig-1.6 Rainfall Distribution Pattern in Gujarat State.

1.9 Population and Land use

The study area inhabitates sizable population. As per 2001 Census, population of the 18 Talukas falling within 03 districts was 25.61 lakh. Population density for this area is 243 person/km². The study area is characterized by poor land use pattern with almost 50% of the land fall under un-irrigated area and less than 7% area as forest land. Only 19% area is benefited by irrigation facility. The land use classification according to the different uses for the rural areas is given as under.

Table 1.2 Population Status and Land use Pattern in the Study Area

District	Rural Area (Km^2)	Total Population (Persons)	Forest land (Km^2)	Total Irrigated area (Km^2)	Unirrigated area (Km^2)	Culturable waste (Km^2)	Area not available for cultivation (Km^2)
Vadodara	7264.1	3,641,802	703.20	1756. 1	3403.2	573.5	827.9
Narmada	545.99	121,871	119.33	22.13	281.66	48.87	80.30
Bharuch	3028.72	735873	1.803	180.94	383.85	121.71	221.60
Grand Total	**10,834.9**	**4499546**	**710.1566**	**1959.16**	**4068.07**	**744.05**	**1129.79**

(Source: Census of India, 2001)

1.10 Brief Geology

The study area display considerable heterogeneity in its geological environment. Area is characterized by rock formations ranging in age from Precambrian to Recent. The basement gneissic complex, phyllite, schist, quartzite and post Delhi granites belonging to Precambrian Formation and are exposed in the eastern parts of the study area. The Precambrian rocks are unconformably overlained by the rocks of Bagh sedimentary sequence consisting of sandstone, shale and limestone of Cretaceous age. These are further intruded by extensive Deccan trap volcanics of Cretaceo-Eocene age.

The western side being part of "Gujarat Alluvial Plains" comprises huge thickness of marine, fluvial and aeolian sediments deposited during the Quaternary period *(Merh and Chamyal, 1997)*. These sediments consist of intercalations of sand, silt, clay and gravel fractions with the perceived development of clacretised bands. These unconsolidated sediments serve as an ideal repository for groundwater in unconfined, semi-confined and confined conditions.

The occurrence, distribution and sustainability of groundwater reserves in the study area is largely depend upon the geological environment. i.e. fluvial, marine and aeolian the groundwater facies also varies accordingly. The geological setup has produced aquifers in two different conditions i.e. in hard rock and unconsolidated formation. As a result of these boundaries the quality and quantity aspects vary considerably.

1.11 Physiography and Geomorphology

Geomorphologically, the study area may be divided into four geomorphic zones viz.

a) The eastern uplands zone,
b) The intermediate pediment zone,
c) The central alluvial zone and
d) The low coastal zone.

The eastern upland zone is marked by the Aravalli and Shyadri range having steep gradient. The Pediment zone is characterized by colluvial deposits overlying basement rock. The landscape of the pediment zone is marked by both erosional (e.g. cliffs, scarps, residual bedrock terraces, cascades, rapids etc) and depositional features (valley fills, low terraces, badland etc). The central Alluvium zone comprises predominantly Quaternary deposit and forms the major part of the study area. Important features of the alluvial plains are flood plains, ravines, natural levees, point bars, buried channels, gullies, cliffs and scarps etc. The western coastal zone is characterized by flat terrain inhibiting recent mudflats, river mouth bars, beach sand ridges, raised mudflats, older alluvial plains, and bets that are formed under fluvial marine environment. The coastal belt also shows development of ravines which also continues along the banks of Mahi and Narmada rivers in upper reaches. The general trend of slope in the study area is due WSW.

1.12 Water Resources

The surface and groundwater together constitute water resource of the study area. The area is covered under the watershed basins of perennial rivers like Mahi and Narmada and ephemeral river like Dhadhar and Bhukhi. The study area falls in the lower reaches of drainage basin of these rivers hence their cumulative discharge can be taken as a surface potential. Annual average discharge from these basins stand at 49,895 MCM (Yusuf, 1989). The coastal tracks of the study area inhibiting sizable population subsist its potable water demand through innumerable surface ponds constructed on paleo channel courses of the earlier rivers.

The groundwater potential varies in the study area depending upon the Hydrogeological conditions. The alluvial plains constitute the most potential zones for groundwater. The groundwater occurs as shallow phreatic aquifers and deeper semi-confined to confined aquifers. The quality of groundwater varies and tends to deteriorate down gradient.

A broad litho-stratigraphy of the study area is given as under

Epoch/Age	Formation	Depositional Environment
Holocene Recent 2000 Yrs B.P. Depth 10-25m Sub-Recent 10,000 Yrs B.P. Depth 50-450m	Surfacial Deposits River sands, gravel, Coastal mud, Beach Sand, Modern soils etc Newer Alluvium Inter layering of thick sand gravel and thin clay silt with calcareous nodules	Subaerial deposition under marine and fluvial conditions. Late semiarid to arid phase (fluvial & Aeolian) and early wet phase predominantly marine
Pleistocene 1.5 – 2 M.Y. Depth 450-750m Tertiary (<40 M.Y.) Cretaceous - Eocene (40-55 M.Y.) Cretaceous (>55 M.Y.)	Older Alluvium Interbedding of thick silty clay and thin gravelly sands Deccan Trap (Basalt, Dolerites, Rhyolites etc.) Bagh Formation (Sand stone, Shale, Limestone)	Fluvio-Marine Volcanic Marine
----------Unconformity----------		
Precambrian (>1500 M.Y.)	Champaner Group (Aravalli Super Group) Quartzite, Phyllites, Slates and Schists ,Limestone and intrusive	Metamorphic and Magmatic
Basement (>2000 M.Y.)	Unclassified Gneisses (Gneisses, Granites and Intrusives)	Metamorphic and Magmatic

(Source: GSI)