Central Ground Water Board

Department of Water Resources, River Development and Ganga Rejuvenation

Ministry of Jal Shakti

Government of India

Report On

AQUIFER MAPPING AND GROUND WATER MANAGEMENT PLAN

Navsari District

Gujarat

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AQUIFER MAPPING AND GROUNDWATER MANAGEMENT PLAN, NAVSARI DISTRICT, GUJARAT STATE

Chapter 1: INTRODUCTION

Navsari district is situated in the southern part of Gujarat State. It is one of the most important districts in Gujarat State, bifurcated from Valsad district. It lies between Latitude 20°32' & 21°05' North and Longitude 72°42' & 73°30' East and falls in Survey of India Toposheet Nos. 46C, 46D, 46G& 46H. It is bounded by Surat district in the north, Dangs district in the east, Valsad district in the South and Arabian sea in the west. Navsari district has a geographical area of about 2210.97 sq. km (Figure 1). The geographical areas of different talukas are given in table- 1

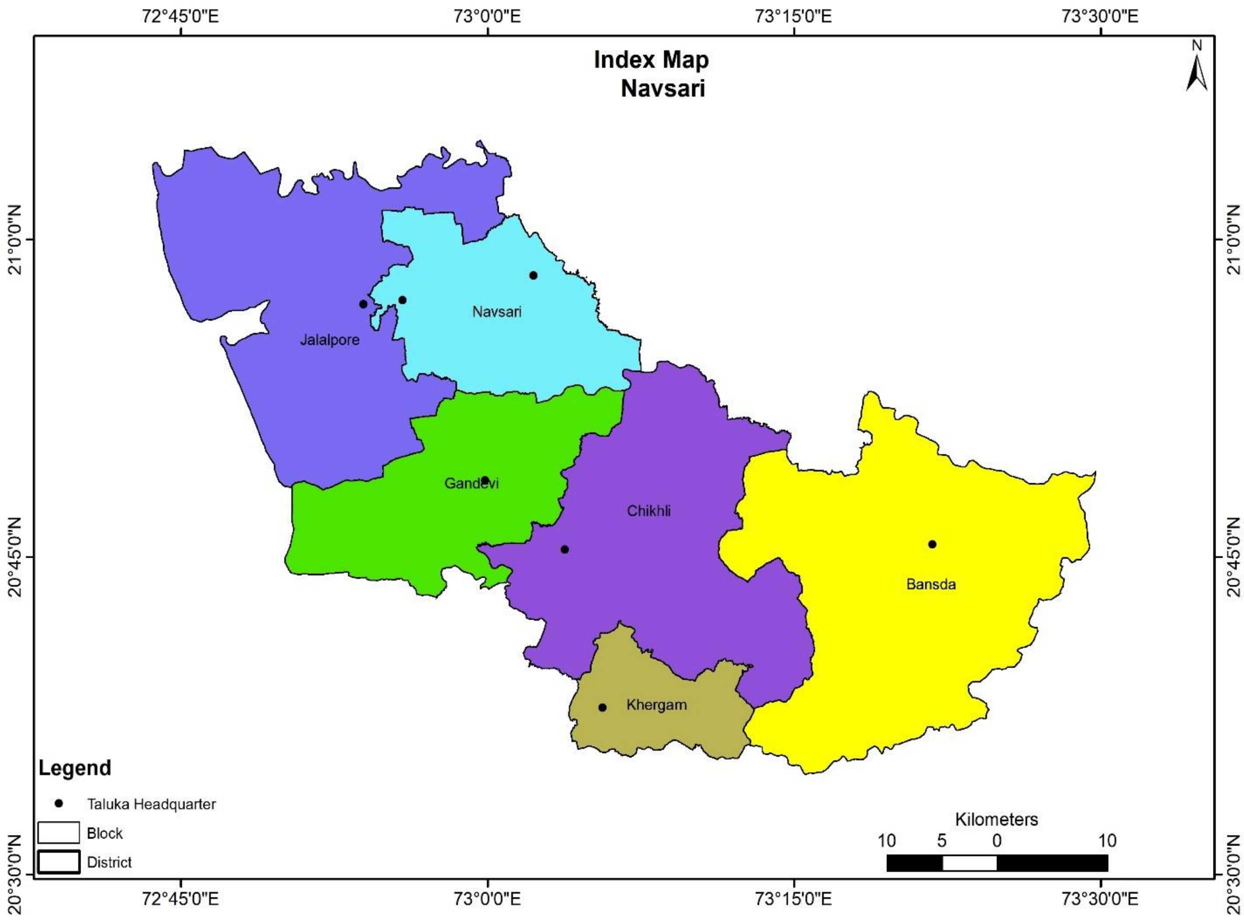

Figure 1: Index map of Navsari district

Table 1 Taluka wise geographical area of Navsari district

S. No	Taluka	Geographical Area (Sq. Km.)
1	Bansda	599.34
2	Chikhli	574.61
3	Gandevi	294.75
4	Jalalpore	492.82
5	Navsari	249.45
	Total	**2210.97**

The district comprises of five Talukas, i.e., Navsari, Jalalpore, Gandevi, Chikli, and Bansda. The administrative divisions of the district have been reconstituted recently by dividing Valsad district into two district such as Navsari in the north and Valsad in the south. There are 374 villages and 09 towns in the district. Index Map shows administrative boundaries, drainage, topography, and ground water structures (Figure-1)

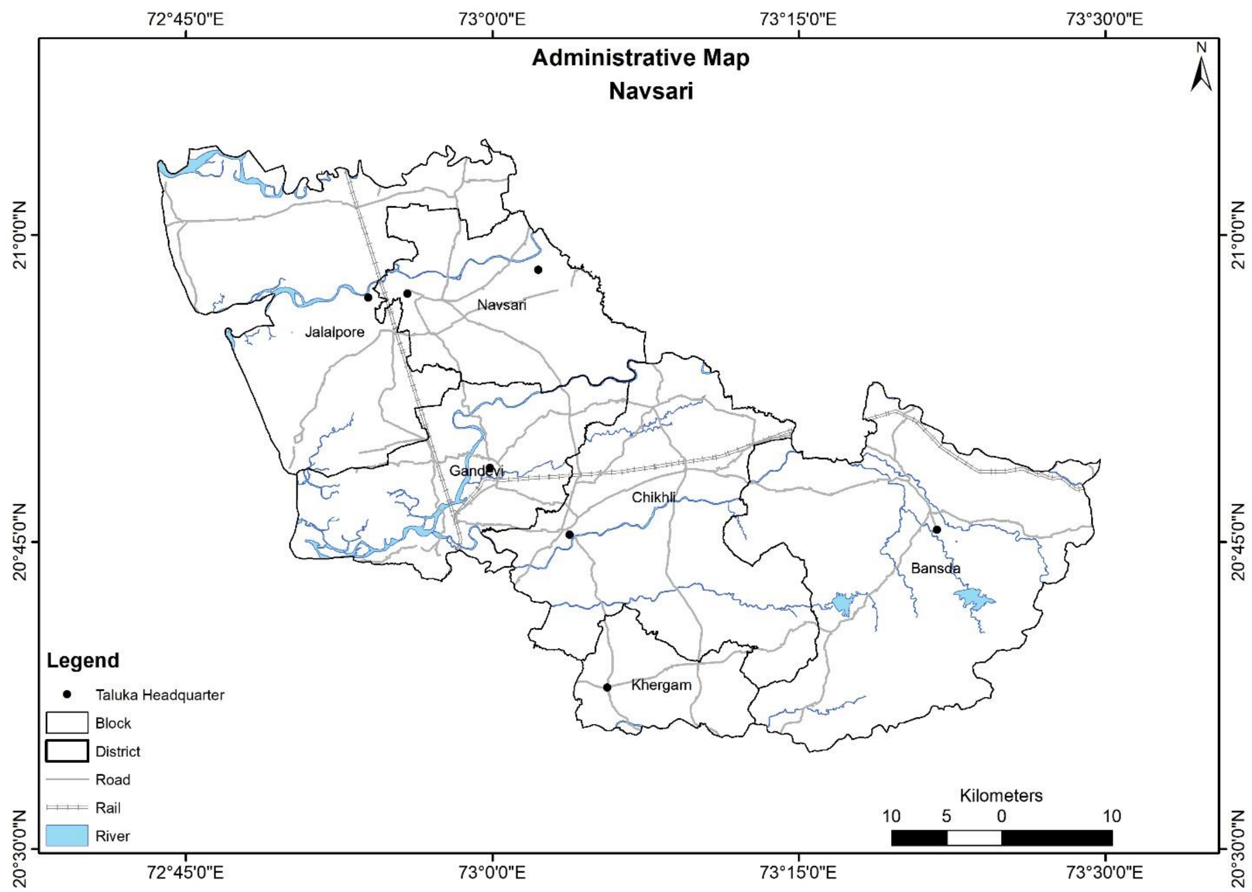

Figure 2 Administrative map of Navsari district

1.1 Objective:

The primary objective of the Aquifer Mapping Exercise can be summed up as "Know your Aquifer, Manage your Aquifer". Demystification of Science and thereby involvement of stake holders is the essence of the entire project. The involvement and participation of the community will infuse a sense of ownership amongst the stakeholders. This is an activity where the Government and the Community work in tandem. Greater the harmony between the two, greater will be the chances of successful implementation and achievement of the goals of the Project. As per the Report of the Working Group on Sustainable Ground Water Management, "It is imperative to design an aquifer mapping programme with a clear-cut groundwater management purpose. This will ensure that aquifer mapping does not remain an academic exercise and that it will seamlessly flow into a participatory groundwater management programme. The aquifer mapping approach can help integrate ground water availability with ground water accessibility and quality aspects.

1.2 Methodology:

Methodology involves creation of database for each of the principal aquifer. Delineation of aquifer extent (vertical and lateral). Standard output for effective presentation of scientific integration of Hydrogeological, geophysical, geological, hydro chemical data facts and on GIS platform, identification of issues, manifestation of issues and formulation of strategies to address the issues by possible interventions at local and regional level.

The activities of the Aquifer Mapping can be grouped as follows.

1.2.1 Data Compilation & Data Gap Analysis:

One of the important aspects of the aquifer mapping programme was the synthesis of the large volume of data already collected during specific studies carried out by Central Ground Water Board and various Government organizations with a new data set generated that broadly describe an aquifer system. The data were assembled from the available sources, analyzed, examined, synthesized and interpreted. These sources were predominantly non-computerized data, which was converted into computer-based GIS data sets and on the basis of available data, data gaps were identified.

1.2.2 Data Generation

There a strong need for generating additional data to fill the data gaps to achieve the task of aquifer mapping. This was achieved by multiple activities such as data gap analysis, site selection, exploratory drilling, PYT, pumping test, geophysical techniques, hydro-geochemical analysis, remote sensing, and hydrogeological surveys to delineate multi aquifer system to bring out the efficacy of various geophysical techniques and a protocol for use of geophysical techniques for aquifer mapping in different hydrogeological environs.

1.2.3 Aquifer Map Preparation:

On the basis of integration of data generated from various studies of hydrogeology & geophysics, aquifers have been delineated and characterized in terms of quality and potential. Various maps have been prepared bringing out details of Aquifers, these are termed as Aquifer maps providing spatial variation (lateral & vertical) in reference to aquifer extremities (i.e., quality & quantity).

1.2.4 Aquifer Management Plan Formulation:

Aquifer response Model has been utilized to identify a suitable strategy for sustainable development of the aquifer in the area.

All the above activities under the ground National Aquifer Mapping programme are depicted/elaborated and presented in figure 3.

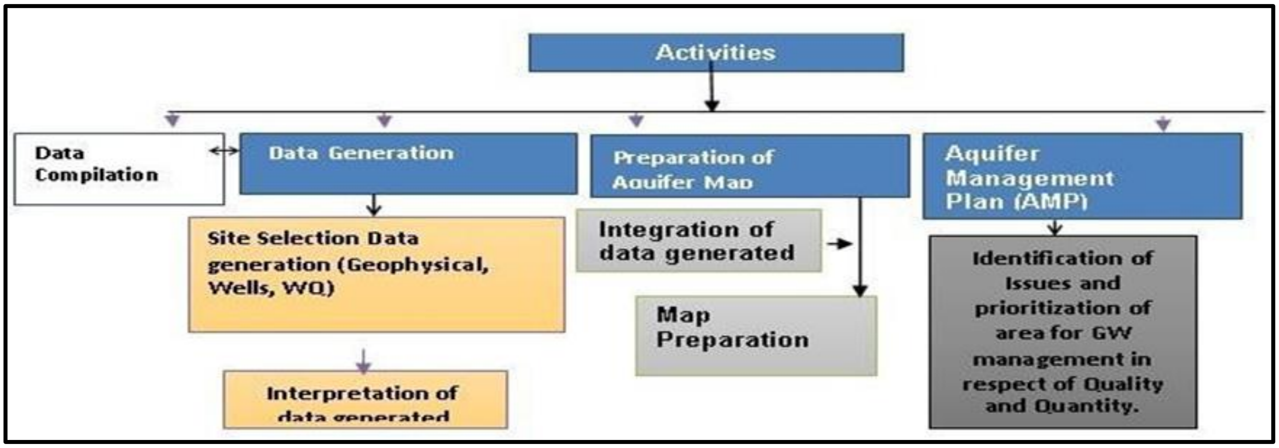

Figure 3 Activities under National Aquifer Mapping Programme

1.3 Demography

As per 2011 census, Navsari had population of 1,329,672 of which male and female were 678165 (51%) and 651507 (49%) respectively (Table 2 and Figure 4). The population of children between age 0-6 is 135170 which is 10.17% of total population. The sex-ratio of Navsari district is around 961 compared to 919 which is average of Gujarat state. The literacy rate of Navsari district is 75.35% out of which 79.55% males are literate and 70.98% females are literate. Population density of the district is 592 per sq.km. Out of total population, 69.23% of population lives in Urban area and 30.77% lives in Rural area. There are 2.67% Scheduled Caste (SC) and 48.11% Scheduled Tribe (ST) of total population in Navsari district.

Table 2 Taluka wise demography table of Navsari Taluka

Sr.No.	Taluka	Male	Female	Total	Male (%)	Female (%)
1	Bansda	115,529	115,699	231,228	49.96%	50.036%
2	Chikhli	156,516	153,361	309,877	50.50%	49.50%
3	Gandevi	90,729	88,521	179,250	50.62%	49.38%
4	Jalalpore	75,048	71,772	146,820	51.12%	48.88%
5	Navsari	76,736	73,561	150,297	51.05%	48.95%
6	Total	678165	651507	1,329,672	51%	49%

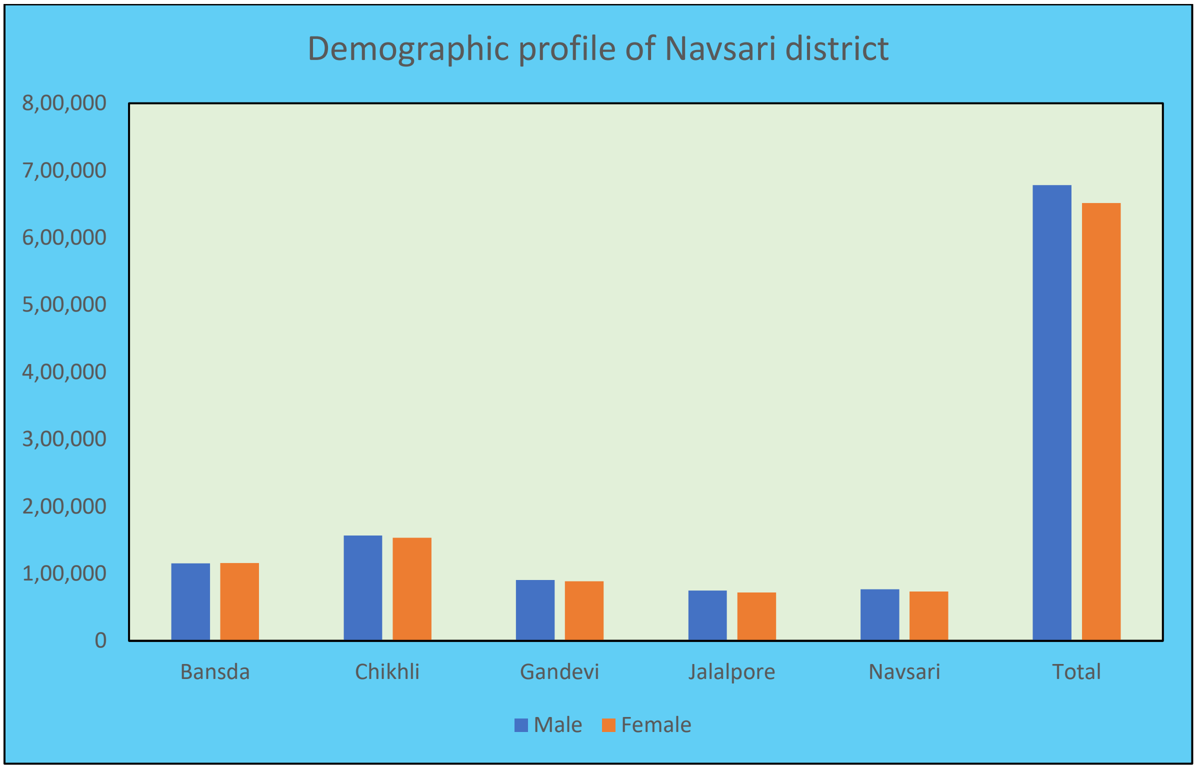

Figure 4: Demographic profle of Navsari district

1.4 Studies/Activities by CGWB

Systematic hydrogeological surveys were carried out by S/ Shri P.C. Rai and Kailash Chander during the year 1976-77. During 1977-78 systematic hydrogeological surveys were carried out by Shri G S Mittal Jr. Hydrogeologist. Shri K. Balakrishan (1993-94 &1994-95) carried out reappraisal hydrogeological surveys in Auranga, Ambika, Purna and Mindhola river basin of Gujarat State. Ground water exploration was carried out during 1993-94 &9 94-95

1.5 Hydrometeorology

Navsari District is sharing border with Surat District to the North, Valsad District to the South. It's in the 96 meters to 14 meters elevation range. It is a Coastal district and beaches also there. Navsari District is sharing border with Arabian sea. General climate of the district is sub-tropical and is characterized by three well- defined seasons, i.e., summer - from April to June, monsoon - from July to September, and winter - from October to March.

1.5.1 Temperature

Mean maximum daily temperatures range from 30° to 37°C and mean minimum daily temperatures from 14 to 26 °C. April and May are the hottest months when the temperatures may exceed 44°C. The winters are generally pleasant with minimum temperatures around 09°C., however, at times temperatures may further drop down.

1.5.2 Humidity

The relative humidity is highest in the early morning, which reduces as the day advances. In the monsoon season the humidity is high reaching up to 84%, during winters it may drop down to 47%.

1.5.3 Wind

Light winds, mainly from southern and south- western directions blow during summer. In winter light winds blow from north-west and north-east. During monsoon however, moderate to heavy wind prevail from south and south-western directions. Mean wind speed ranges from 108 km/d during winters to more than 220 km/d during summer and monsoon.

1.5.4 Rainfall

District receive rainfall mainly from Southwest monsoon. The rainfall is confined between June to October months. As such The Surat IMD station is more representative of climatological conditions for the Navsari district, therefore, the climatological data of Surat IMD station is taken into consideration for discussion. The average rainfall (1987 to 2022) of the district is 1856 mm Taluka wise rainfall data is given in Table 3. An isohyet Map of Navsari district showing that average precipitation is higher in Eastern part of the district (Figure 5).

Table 3 Taluka wise Rain Fall Data of Navsari District (mm.)

Year	Chikhli	Gandevi	Jalalpor	Khergam	Navsari	Vansda
1987	848	750	932	848	932	1036
1988	2423	1563	2767	2423	2767	2390
1989	2087	1534	1412	2087	1412	1563
1990	1268	1205	1924	1268	1924	1869
1991	1412	921	1407	1412	1407	1305
1992	1788	1689	1982	1788	1982	2299
1993	1826	1516	1058	1826	1058	2598
1994	3732	2411	2822	3732	2822	3051
1995	1495	1118	1206	1495	1206	1429
1996	1788	1243	1119	1788	1119	2364

1997	1968	1027	1060	1968	1060	1587
1998	2401	1645	1524	2401	1547	1960
1999	1781	1517	1041	1781	973	2117
2000	1685	1575	1194	1685	1250	1301
2001	1842	2033	1799	1842	2006	1601
2002	1302	1485	1082	1302	1396	1604
2003	2051	2992	2547	2051	2933	1932
2004	1759	2059	2112	1759	2492	2086
2005	2840	3293	2427	2840	2584	3183
2006	2090	2348	1893	2090	1857	2222
2007	1479	2036	1849	1479	1599	1700
2008	2241	2607	2056	2241	1785	2289
2009	1301	1591	1619	1301	1447	1315
2010	1719	2024	2147	1719	2060	1857
2011	1843	1962	1593	1843	1936	2216
2012	1044	1124	1256	1044	1300	1151
2013	1898	2140	2445	1898	2462	2296
2014	1407	1538	1459	1445	1348	1434
2015	1031	1102	1219	1222	1185	1046
2016	1544	1442	1432	1900	1590	1632
2017	2076	1472	1321	1836	1331	2004
2018	2113	1813	1675	2330	1793	2190
2019	2661	2288	2165	2892	2202	2760
2020	1850	2026	2071	1703	2204	1526
2021	1840	1846	1517	2066	1859	1662
2022	2461	2289	2420	3095	2625	2758
Average	**1902**	**1852**	**1704**	**1952**	**1768**	**1962**

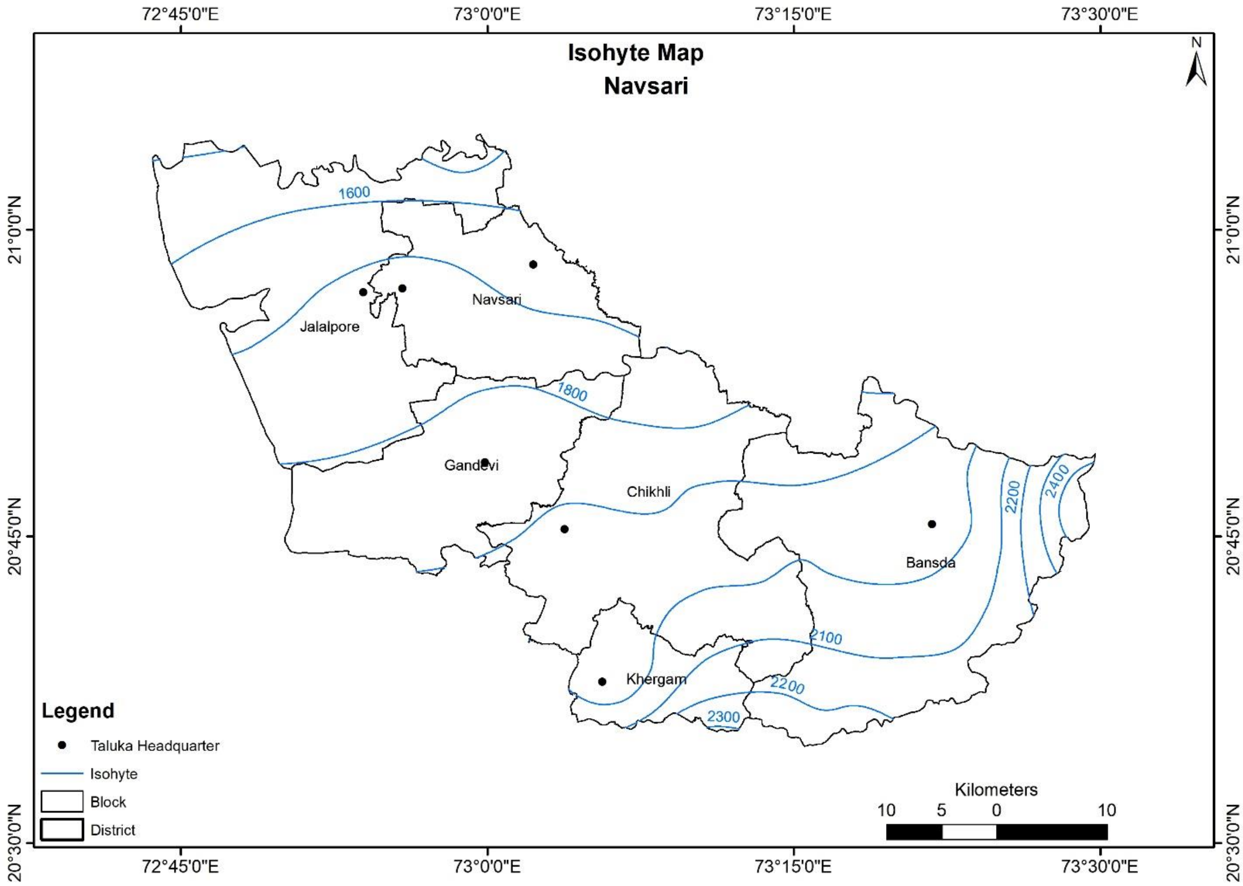

Figure 5: Map showing isohyetal line in Navsari disrict.

1.6 Geomorphology

Navsari district is situated in the southern part of the state. Four physiographic units have been established in the area (Figure 6).

1) High Relief Zone
2) Piedmont Zone.
3) Alluvial Plain.
4) Coastal Plain.

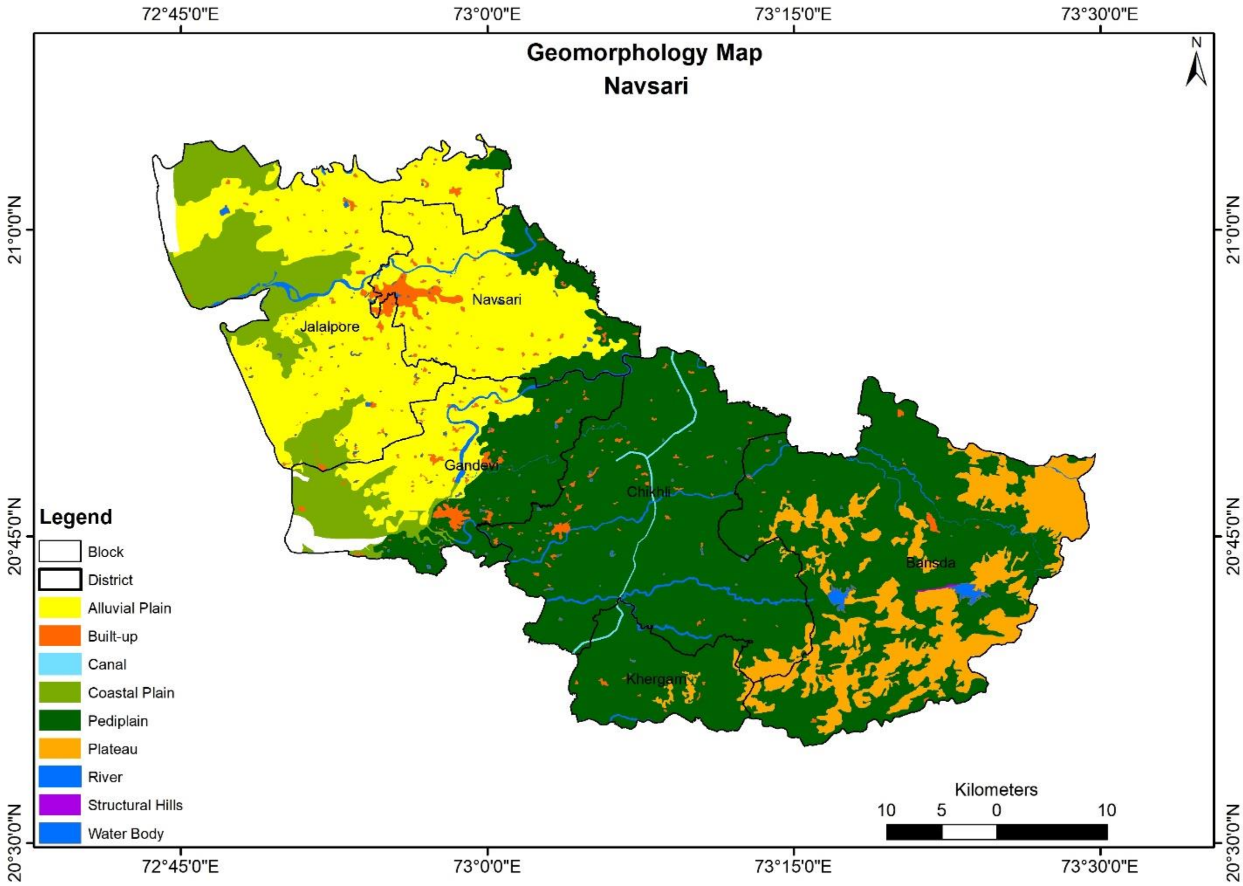

Figure 6 Geomorphological map of Navsari district in Gujarat state

The High relief zones are observed in the eastern part of the district which forms part of Sahayadri hills (Western Ghat). The general disposition is in the North-South direction. The ridges are flat topped and step like in its disposition. They are dissected by all rivers flowing east to west. The valleys are narrow and have plenty of detrital materials.

Piedmont Zone is located in the eastern part of area adjacent to foot hills. The unit is characterised by assorted clastic sediments and gradually graded into alluviual plain toward west. The plains are extensively cultivated.

The central and western parts are covered by extensive **alluvial plains** formed the different geomorphic processes. The general slope is gentle toward west. It has low moderate infiltration characteristic. It forms the recharge zone in the east and discharge zone in the west.

Coastal Plain includes barren and sandy strips bordering the alluvial plain. The areas are subjected the frequent submergence during rainy season resulting the water logging conditions. Mudflats are characteristic geomorphic units in these areas.

The present physiographic set-up is combined result of diversified lithology (Deccan tap and Alluvium).

1.6.1 Drainage

The drainage in the district is controlled by the topography and the lineaments. The major rivers draining the district are Purna, Ambika, Kaveri and Khapar and their tributaries. The rivers are ephemeral toward hilly area toward east and gradually tends to become perennial toward west. All the river basin are east-westward stretching basins The river originates from Sahyadri hills and flow toward west.

The drainage Pattern is mainly dendritic and drainage density is fine. Radial pattern is locally developed around the hills. In piedmonts drainage density is courser and sub- parallel and are characterized by broad stream course. In alluvial terrain the drainage density is characteristically course and sub-parallel to parallel (Figure 7 and 8).

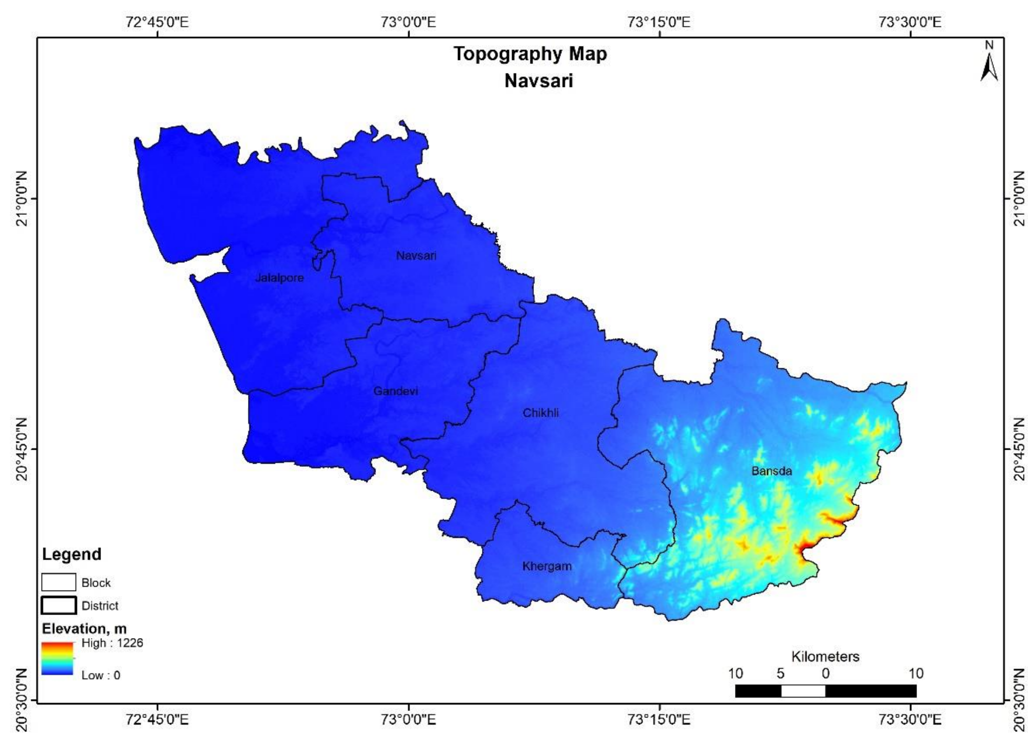

Figure 7: Map showing topography of the Navsari district

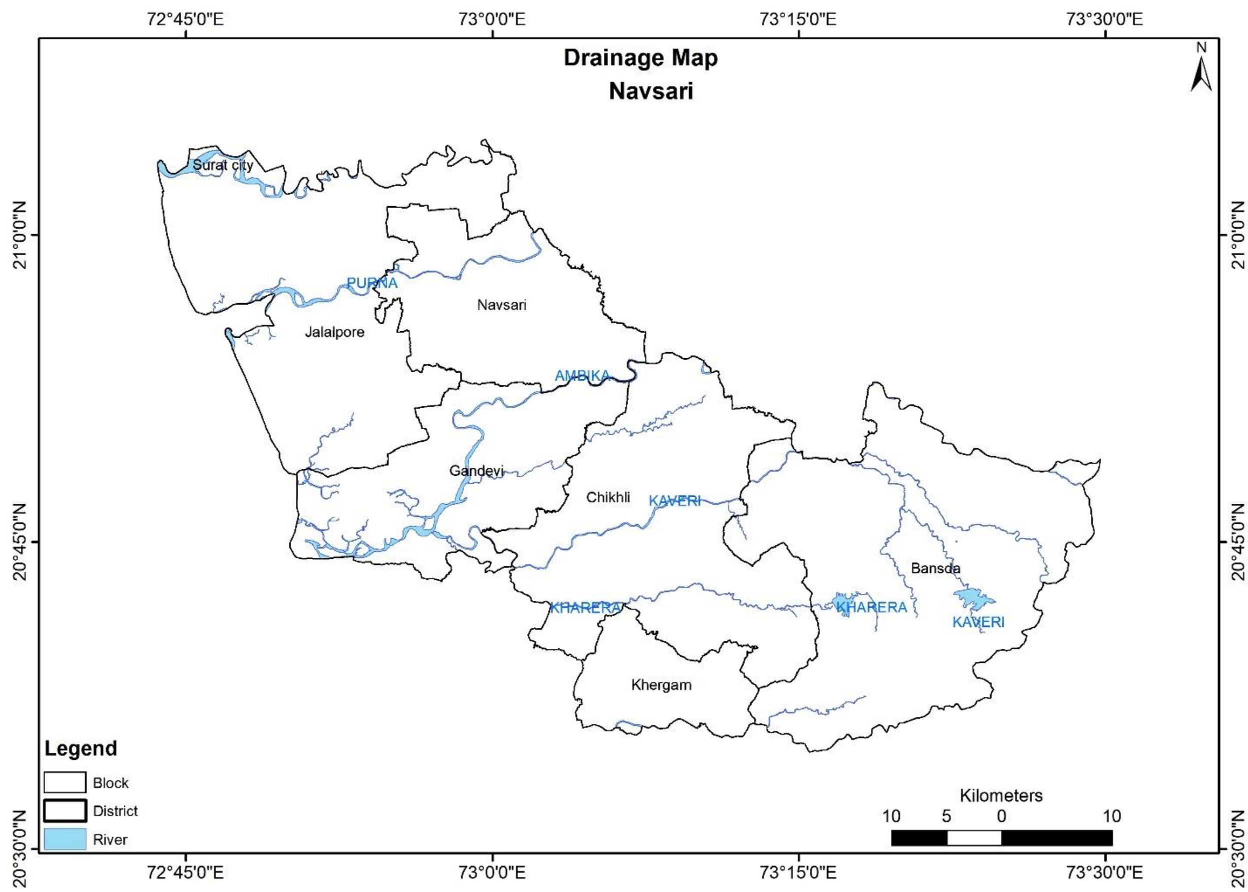

Figure 8: Drainage map of Navsari district

1.8 Soil Types

The soils derived their characteristics from the basaltic rocks as parts of the district. The basaltic lava flows are covered by black clayey to loamy soil. It is in general ranges in thickness up to one meter. The color of the soil turns brown due to high iron content at places. In the piedmont slope area, the soil is shallow to moderately deep, moderate to severely eroded and non-calcareous in nature. The texture is silt clay loam to clay loams. The clay content varies from 30 to 60%. The water holding capacity of the soil is moderate. In the midland and flood plain areas, the soil is deep to very deep, light greyish to yellowish brown in color. The texture is fine clay loam to sandy loam. The clay content varies from 25 to 60%. In coastal region the soil is deep to very deep dark grey to black color. The texture is clay loam to silty loam. The area is affected by tide as well as leaching of salts from up land forming saline alkali soils. The content of clay in this is high and permeability is low (mud flats) (Figure 9).

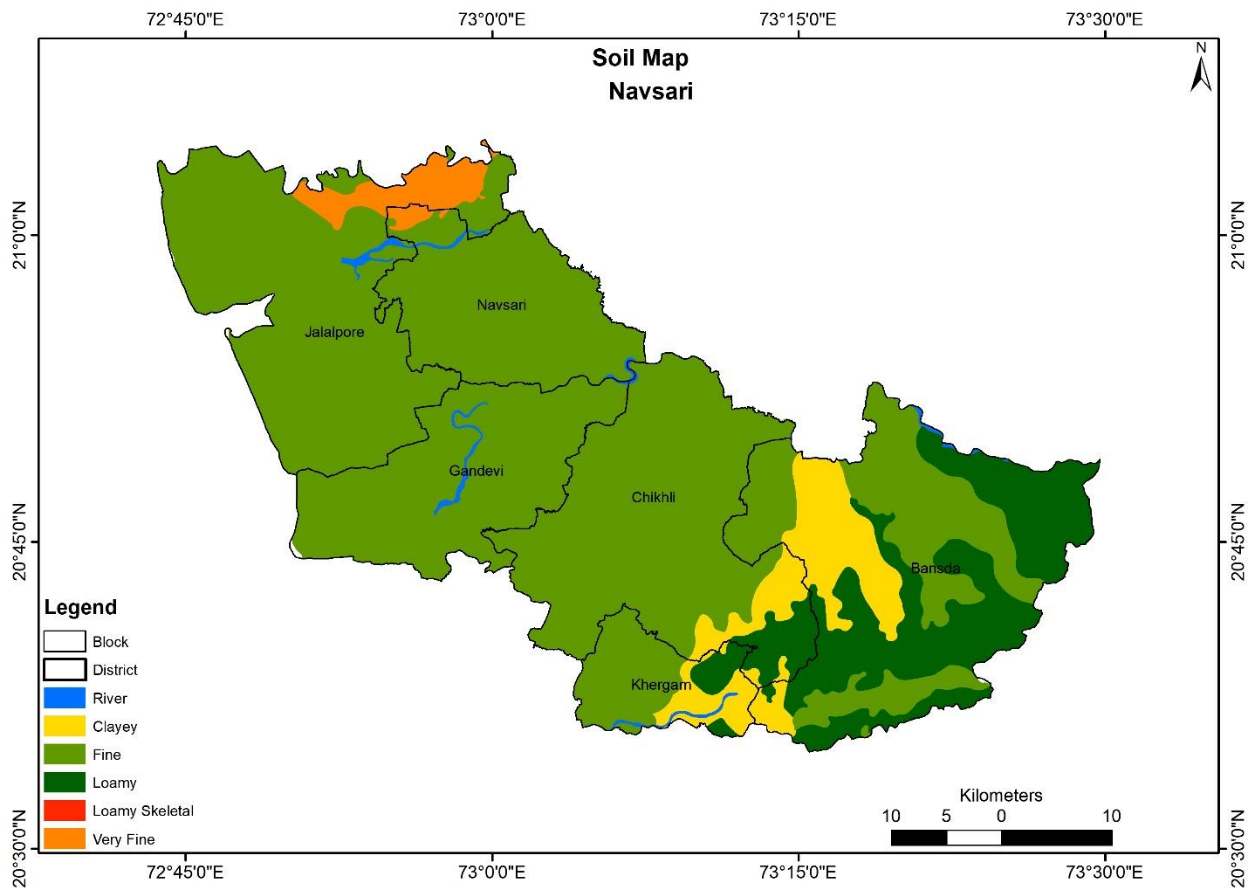

Figure 9: Map showing the soil texture in Navsari district of Gujarat state

1.9 Land Use Pattern

The total geographical area of the district is 220077 Ha, out of which nearly 131096 Ha (59.57%) is under agriculture (Figure 10). The land under forest cover is 25098 Ha which is 11.4 % of the total geographical area of the district. The area which is not available for agricultural use is about 16063 Ha (7.3%).

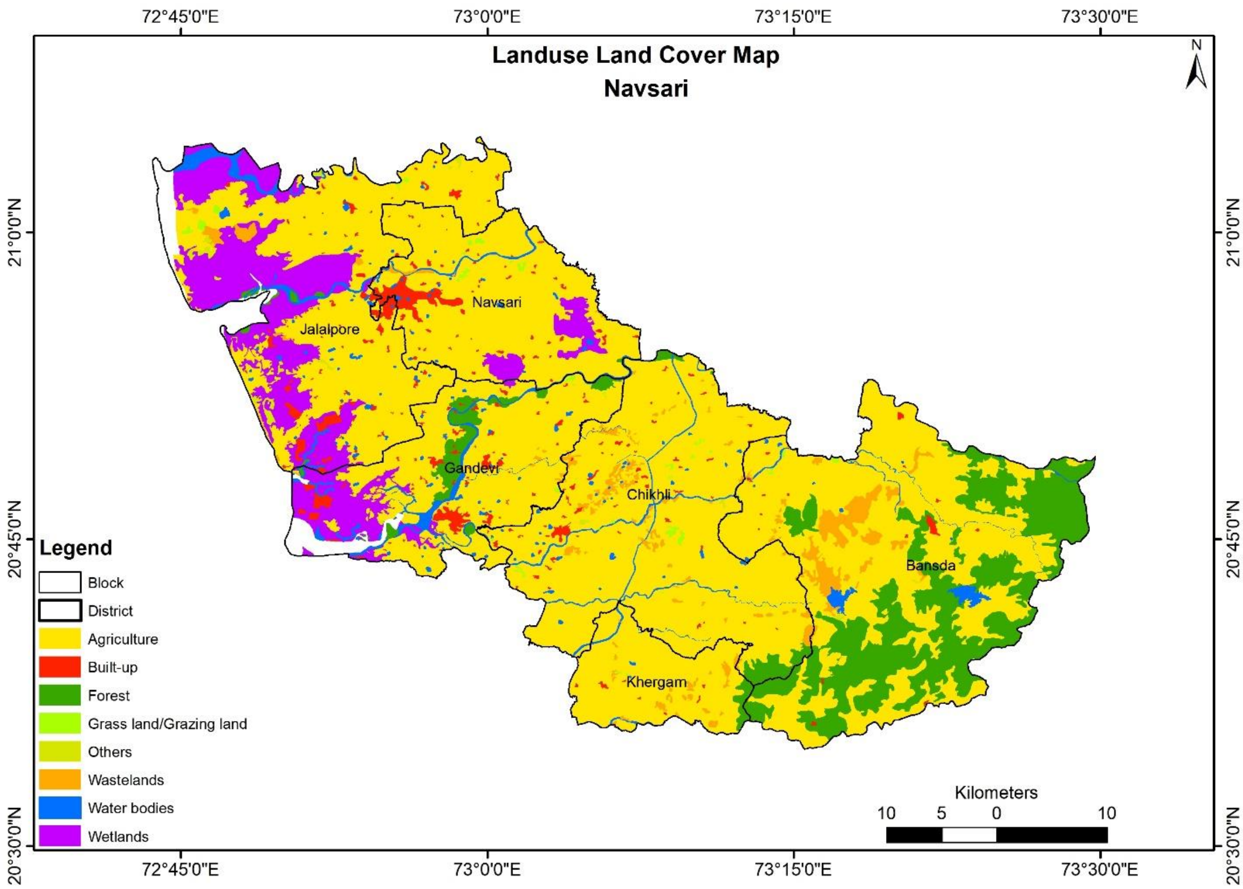

Figure 10: Map showing the land use/ land cover in Navsari district of Gujarat district

Chapter 2: Geology

There are mainly two types of geological formation in the district

1). Deccan Trap

2). Alluvium

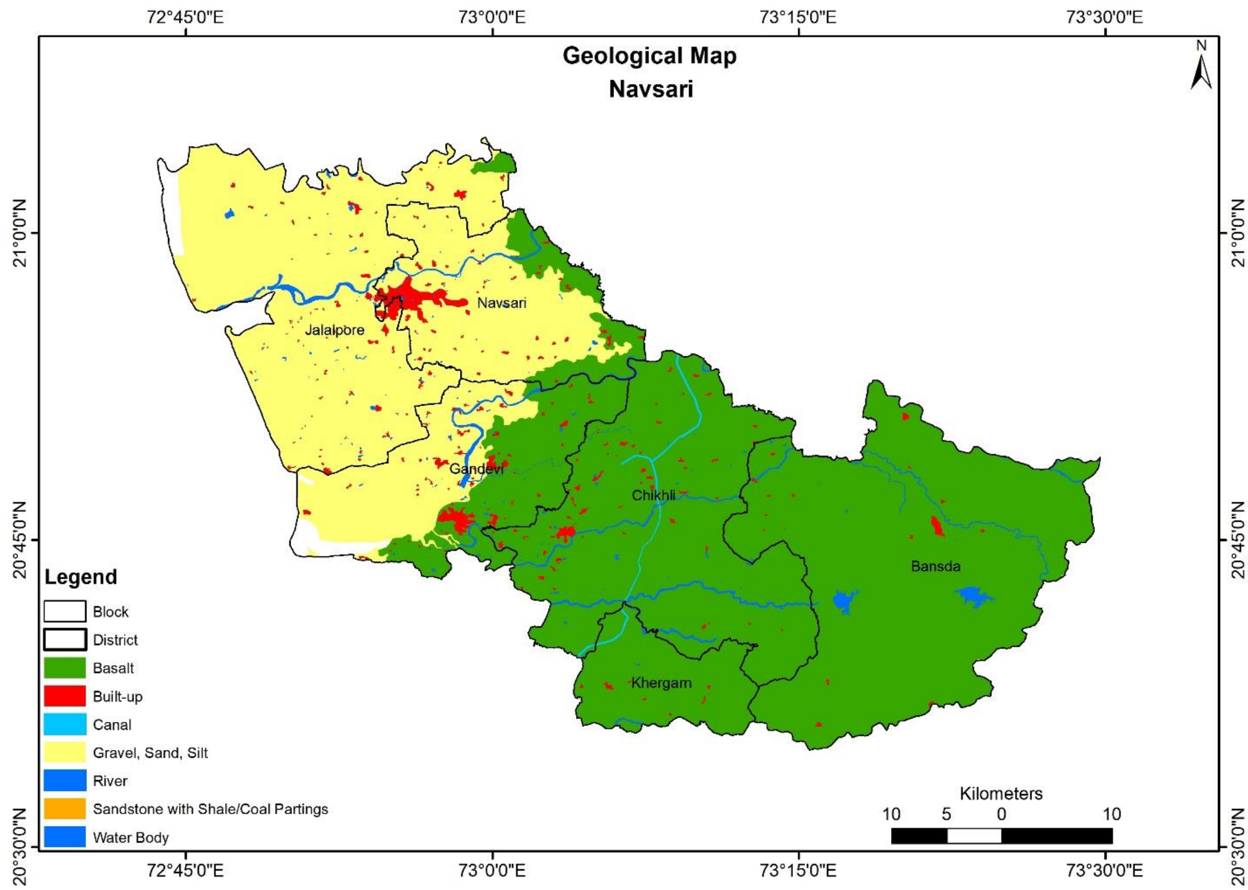

Figure 11: Map showing the geological units in Navsari district of Gujarat district

Deccan trap basalt occupies a major part of the district and comprises of basaltic lava flows and numerous cross cuttings of dykes of basaltic and dolerite composition. The porosity subsequently is developed by weathering, fracturing and faulting in the basaltic rocks. In lava flows the vesicles are formed by escaping of gases which results the upper part of the lava flow porous and these vesicles seldom are interconnected to allow any flow of ground water (Figure 11).

Alluvium consists of gravel, sand, silt clay and kankar. The ground water occurs mainly under unconfined conditions but at places semi-confined conditions are also observed. The occurrence and movement of ground water in alluvium is controlled by primary porosity (interstitial pore spaces) of the alluvial material (Table 4).

Table 4 Geological succesion of Navsari district

Age	**Formation**	**Lithology**
Pleistocene to Recent	Soil	Thin soil cover
	Alluvium	Gravel, sand, clay and Kankar
--Unconformity--		
Upper Cretaceous to Lower Miocene	Deccan Traps and related intrusive	Basalts, volcanic tuff, porcellanitic, Dolerite dykes, & related volcanic rocks

Chapter 3: DATA INTERPRETATION, INTEGRATION AND AQUIFER MAPPING

Collection and compilation of data for aquifer mapping studies is carried out in conformity with Expenditure Finance Committee (EFC) document of XII plan of CGWB encompassing various data generation activities (Table-5).

Table 5 brief activities showing data compilation and generation

S.No.	Activity	Sub-activity	Task
1	Compilation of existing data/ Identification	Compilation of Existing data on groundwater	Preparation of base map and various thematic layers, compilation of information on Hydrology, Geology, Geophysics, Hydrogeology, Geochemical etc. Creation of data base of Exploration Wells, delineation of Principal aquifers (vertical and lateral) and compilation of Aquifer wise water level and draft data etc.
		Identification of Data Gap	Data gap in thematic layers, sub-surface information and aquifer parameters, information on hydrology, geology, geophysics, hydrogeology, geochemical, in aquifer delineation (vertical and lateral) and gap in aquifer wise water level and draft data etc.
2	Generation of Data	Generation of geological layers (1:50,000)	Preparation of sub-surface geology, geomorphologic analysis, analysis of land use pattern.
		Surface and sub-surface geo-electrical and gravity data generation	Vertical Electrical Sounding (VES), bore-hole logging, 2-D imaging etc.
		Hydrological Parameters On groundwater recharge	Soil infiltration studies, rainfall data analysis, canal flow and recharge structures.

		Preparation of Hydrogeological map (1:50, 000 scale)	Water level monitoring, exploratory drilling, pumping tests, preparation of sub-surface hydrogeological sections.
		Generation of additional Water quality parameters	Analysis of groundwater for general parameters Including fluoride.
3	Aquifer Map Preparation (1:50,000 scale)	Analysis of data and preparation of GIS layers and preparation of aquifer maps	Integration of Hydrogeological, Geophysical, Geological and Hydro-chemical data.
4	Aquifer Management Plan	Preparation of aquifer management plan	Information on aquifer through training to Administrators, NGO's, progressive farmers and stakeholders etc. and putting in public domain.

3.1 Data Generation

In order to establish the three-dimensional disposition of aquifer system in the area, the existing data of lithological logs and Electrical logs of Exploratory wells studies carried out and used in prepare a hydro geological cross section, Fence diagram and 3D Model. The data has been analyzed using Rockworks 16 software and is presented below in the Hydrogeological cross sections A-A' to F-F' and Solid Model of the district showing the depiction of Aquifer Groups and Aquitard up to 200 m. The stratigraphic sections depicting unconfined aquifer, Confined Aquifer for alluvium and weathered aquifer & fractured aquifer for Basaltic rock are placed at Figure (13 to 17). Fence Diagram and 3D Solid Model of district is depicted in Figure 18 and 19, respectively.

Table 6: Data integration in respect to Navsari district

Type of Data & source	No of Wells
Aquifer Disposition	
CGWB+ GWRDC	**21**
Long term Fluctuation	
CGWB+GWRDC	**25+47**
Decadal Analysis water Level	
CGWB+GWRDC	**25+47**
Analysis of water Quality	
CGWB	**55**

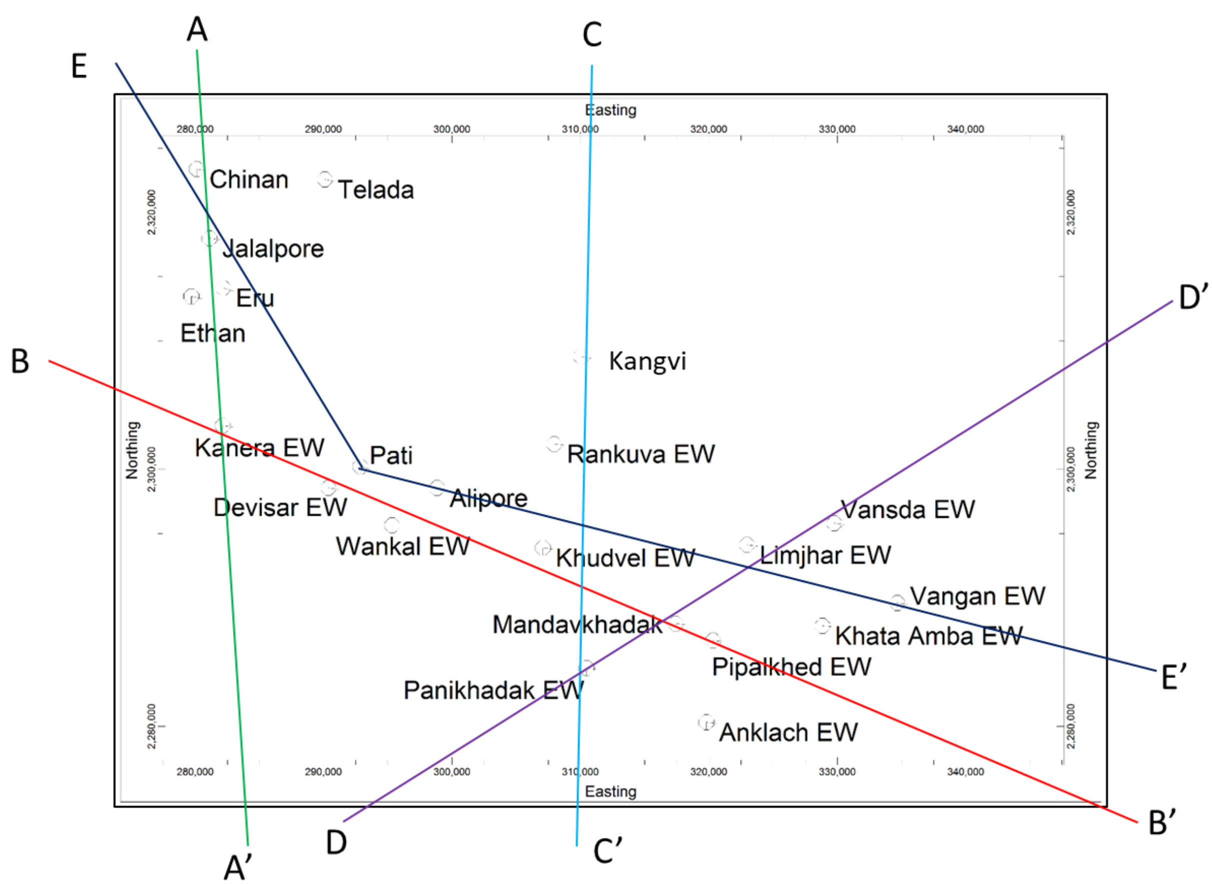

Figure 12: Map showing drawn section lines

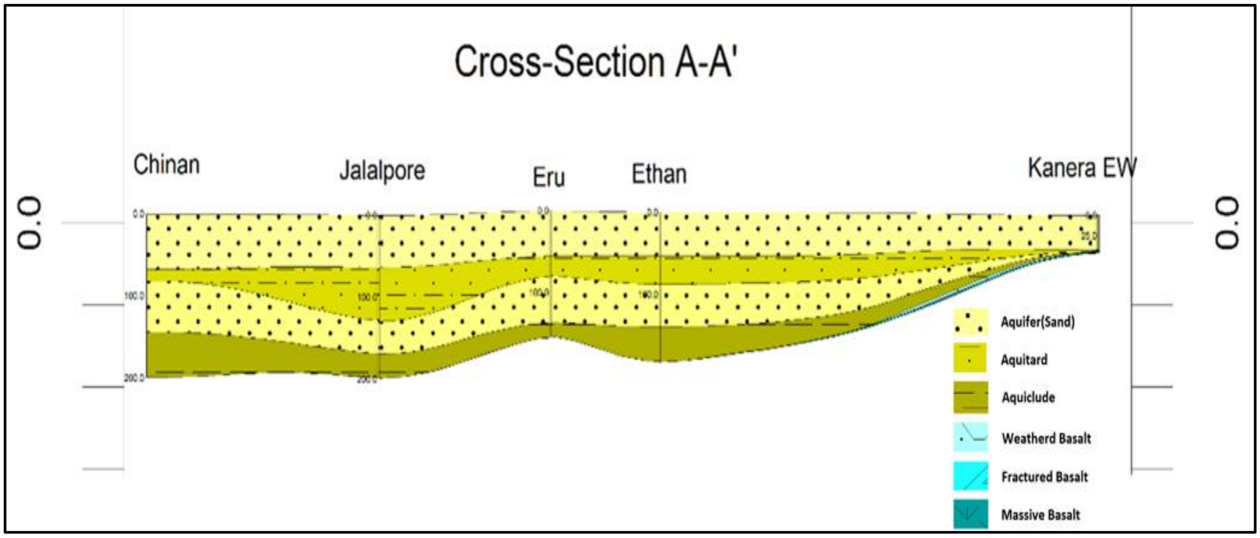

Figure 13: Hydrogeological cross section between Chinam and Kanera(A-A')

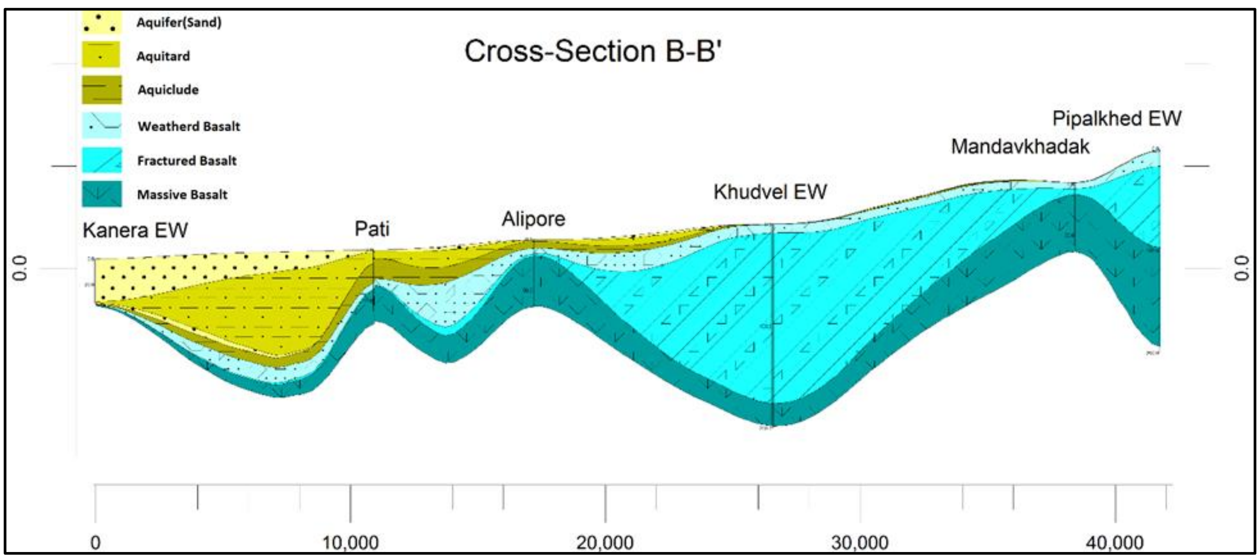

Figure 14:Hydrogeological cross section between Kanera and Pipalkhed(B-B')

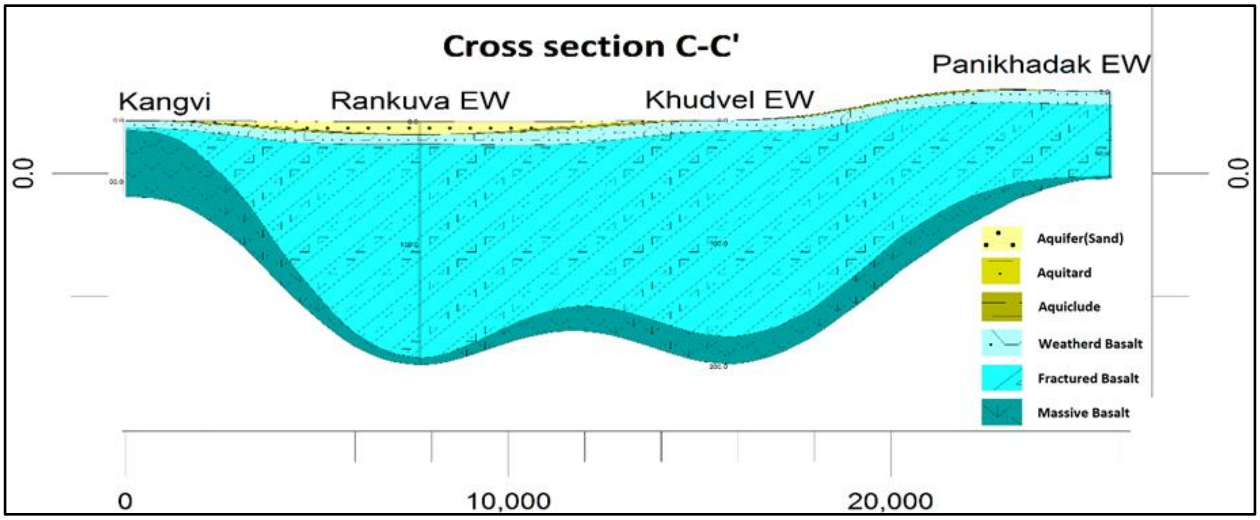

Figure 15: Hydrogeological cross section between Kangvi and Panikhdak(C-C')

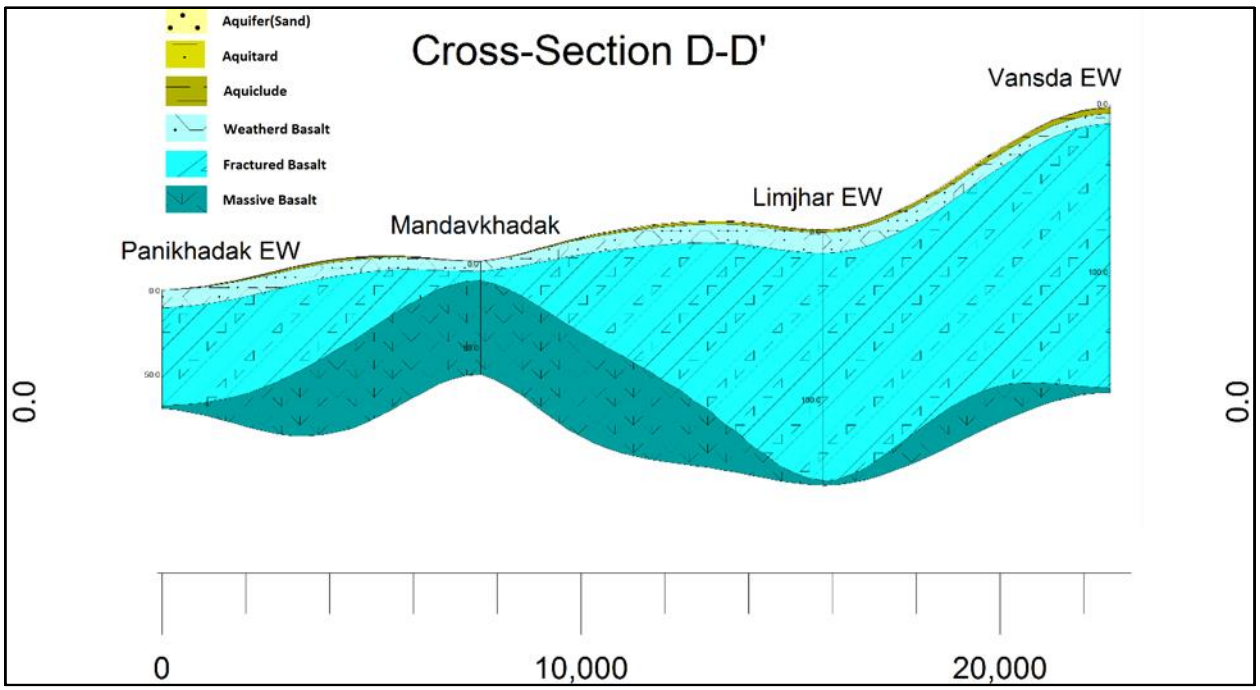

Figure 16: Hydrogeological cross section between Panikhadak and Vansda(D-D')

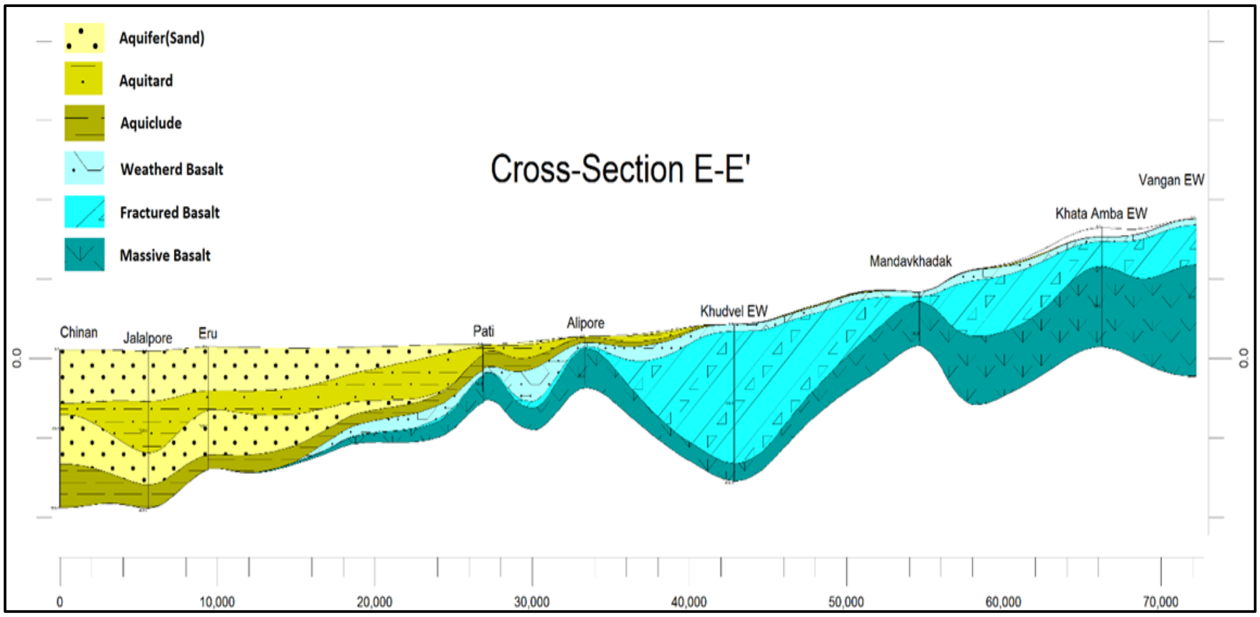

Figure 17: Hydrogeological cross section between Chinam and Vangan(E-E')

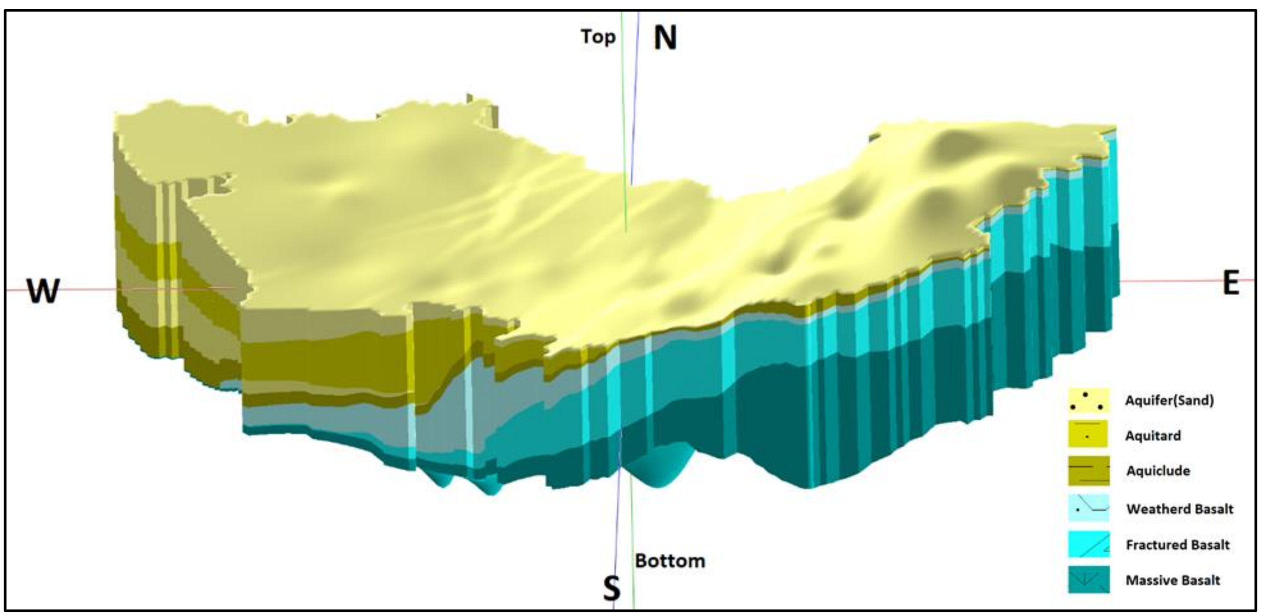

Figure 18: 3D- Aquifer disposition/ model of Navsari district

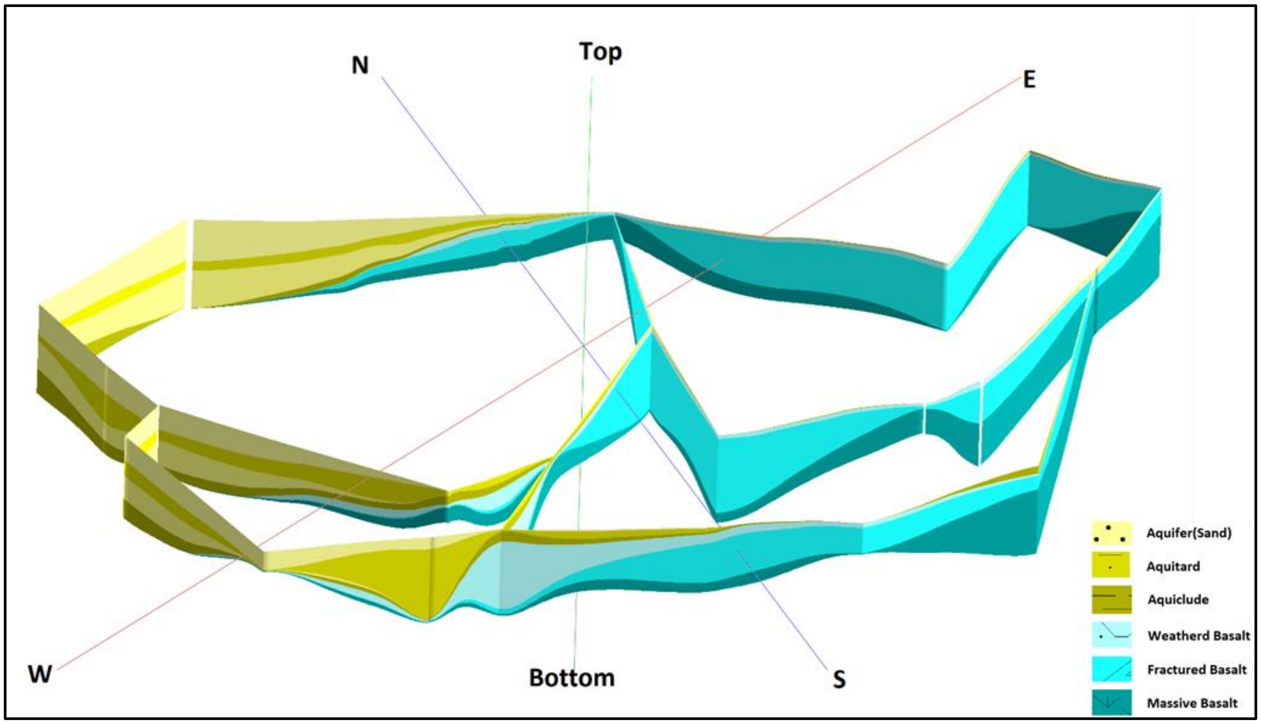

Figure 19: Fence diagram of Navsari district

Table 7 Aquifer Charecterization of Navsari District

Aquifer Characterization and Disposition (Navsari)										
Stratigraphy	Aquifer Nomenclature	Lithological Characteristics	Depth of occurrence Aquifer (mbgl)	Thickness Range (m)	Water Level (mbgl) Range (mbgl)	Quality (TDS) Range Mg/l	Discharge Range lps	Transmissivity Range m2/day	Nature of Aquifer	Remarks
Pleistocene to Recent	Aquifer I	Gravel, sand, clay and Kankar	0 to 95	10.6 to 95	3.22 to 4.05	330 to 4654	0.24 to 1.04	23 to 344	Phreatic	Fresh to moderaterly saline
	Aquitard	Clay with fine sand	10 to 115	13 to 171						
	AquiferII	Sand	81 to 200	11.6 to 85	5.6 to 8.2	450 to 5658	0.2 to 1.8	NA	Semi-confined	Moderately saline to saline
	Aquiclude	Clay	135 to 200	2 to 45						
Cretaceous to Upper Proterozoic	Weathered Basalt	Basalts, volcanic tuff, pocellanites, Doleritedykes, & related volcanic rocks	0 to 188	1.84 to 164	1.35 to 4.60	270 to 598	0.08 to .27	18-120	Phreatic	Fresh to moderately saline
	Fractured Basalt		5.44 to 200	28 to 177	4.95 to 11.10	281 to 663	0.05 to 0.27	48 to 88	Semi confined	Fresh to moderately saline
	Massive Basalt		544 to 200	5 to 177						

3.2 Conceptualization of Aquifer system in 2D

A total of 21 exploratory wells and piezometers lithologs are utilized to decipher the subsurface geometry of the aquifer by using Rockworks 16 software prepared hydro geological cross sections, Fence diagram and 3D Model up to the depth of 200 mbgl. And three hydrogeological cross sections (2D) are drawn in different direction to cover entire area as per the availability of data point in the district and represented in figure 13 (A-A') to figure 17 (E-E').

1. Section A-A' (Fig. 13)- Section is drawn roughly N-S direction and in between Chinnam and Kanera, passing through Jalalpore, Eru and Ethan. Stratigraphicaly from Section, it is deciphered that sandstone, intercalation of Shale and sandstone and alluvium forms the major aquifer system in the district.

2. Section B-B' (Fig. 14)- Section is drawn roughly W-E direction and in between Kanera and Pipalkhed passing through pati, Alipore, Kudvel and Mandavkhadak. Section is represented Stratigraphicaly, from section it is deciphered that that Alluvium and Hard rock formation (weathered & fractured), forms the major aquifer system in the district along drawn section line
3. Section C-C' (Fig. 15)- Section is drawn roughly N-S direction and in between Kangvi and Panikhadak passing through Rankuva and Kudvel. Section is represented Stratigraphicaly, from section it is deciphered that that Hard rock formation (weathered & fractured) forms the major aquifer system in the district along drawn section line

4. Section D-D' (Fig. 16)- Section is drawn roughly N-S direction and in between Panikhadak and Vansda passing through Mandavkhadhak and Limjhar. Section is represented Stratigraphicaly, from section it is deciphered that that Hard rock formation (weathered & fractured) forms the major aquifer system in the district along drawn section line.

5. Section E-E' (Fig. 17)- Section is drawn roughly NW-SE direction and in between Kanera and Pipalkhed passing through pati, Alipore, Kudvel and Mandavkhadak. Section is represented Stratigraphicaly, from section it is deciphered that that Alluvium and Hard rock formation (weathered & fractured), forms the major aquifer system in the district along drawn section line

Chapter 4: Ground Water Scenario

4.1 Hydrogeology

The hydrogeological frame work of the area is essentially governed by geological setting, distribution of rainfall and facilities of circulation and movement of water through inter connected primary and secondary porosity of the geological units forming the aquifers. The Hydrogeological Map of the district is given in Figure 20.

4.1.1 Aquifer System

Based on the geological formation the area can be divided broadly into two hydrogeological units:

Deccan Trap (Fissure Formations):

Alluvium (Porous Formation):

Deccan Trap:

Deccan trap basalt occupies a major part of the district and comprises of basaltic lava flows and numerous cross cuttings of dykes of basaltic and dolerite composition. The porosity subsequently is developed by weathering, fracturing and faulting in the basaltic rocks. In lava flows the vesicles are formed by escaping of gases which results the upper part of the lava flow porous and these vesicles seldom are interconnected to allow any flow of ground water.

The phreatic aquifers are formed by weathered of basalt. The depth of weathering varies from surface to about 15 meters below ground level. It also varies from place to place depending upon the geomorphology of the area. The deeply weathered zones form good area for storage and movement of ground water. The second type of aquifer found in the area is fractured well jointed and faulted basalts. The fractured developed at the time cooling of lava flows which unique to each flow units and by the later tectonic activity deepest water bearing fracture zones encountered in each basin by exploratory drilling is as follows;

1. Ambika Basin Wangan EW depth 192m. (20°41’55”; 73°24’45”)
2. Purna Basin Gunkhadi EW depth 181m. (21°02’36”; 73°35’32”)

The aquifer formed by later tectonic activities support shallow and deep aquifer system. Combination of weathering and fracturing can enhance the hydrogeological parameters of the aquifers.

The third type of aquifer is formed by paleo weathering. Significant time lapse has taken in between successive lava flows. During this period weathering takes placed may reach to a considerable depth. The ground water yield potential is shown in figure 20.

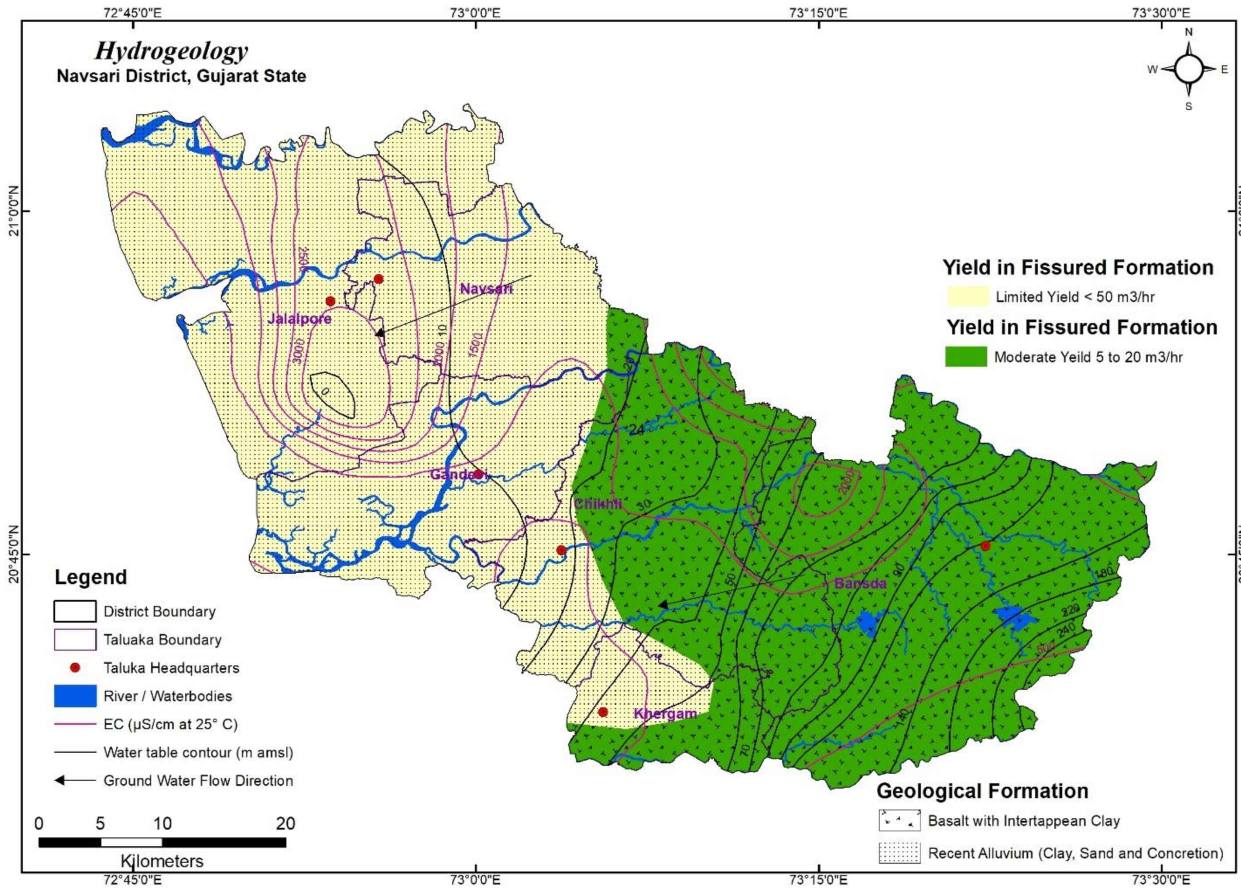

Figure 20: Hydrogeological map of Navsari district of Gujarat state

The weathering causes development of porosity, permeability and inter connection of vesicles. Each individual flow is amygdaloidal / vesicular zones in its upper part and massive at the bottom which covers amygdaloidal zone of the older lava flows. The massive zone acts as aquiclude if not fractured. The vesicular and massive zone of successive lava flows forms multiple aquifer system. Massive zones also act as confining layer. The deep aquifers are recharged by some deep fracture system. There are twelve lava flows are encountered in the bore hole drilled down the depth of 200m ranging in thickness from 6m to 35m. The ground water exploration carried out in the district revealed that yield of wells drilled in Deccan trap area ranges between 42 lpm (Wankel 20°45’47”; 73°10’51”) to 300lpm (Pipalkhed 20°40’15”; 73°16’30”) whereas the Co-efficient of transmissivity ranges between 10 m2/day (Unai 20°50’47”; 73°20’20”) to 31.64 m2/day (Pipalkhed 20°40’15”; 73°16’30”) (Broacher Navsari).

Alluvium:

This consists of gravel, sand, silt clay and kankar. The ground water occurs mainly under unconfined conditions but at places semi-confined conditions are also observed. The occurrence and movement of ground water in alluvium is controlled by primary porosity (interstitial pore spaces) of the alluvial material. The ground water exploration carried out in the district revealed that yield of wells drilled in alluvial area ranges between78lpm (Devisar 20°46’30”; 73°59’10”) to 2744 lpm (Ethan) whereas the Co-efficient of transmissivity ranges between 300 m2/day (Kothavasan) to 2261 m2/day (Ethan).

4.1.2 Behavior of Water Levels

The behavior of water levels was studied based on the water level data collected from the National Network of Hydrograph Stations (NNHS) established by CGWB and Observation wells established by GWRDC in the district. A composite map combining the data of CGWB & GWRDC (depth to water level map -May -2022) has been prepared (Figure 21).

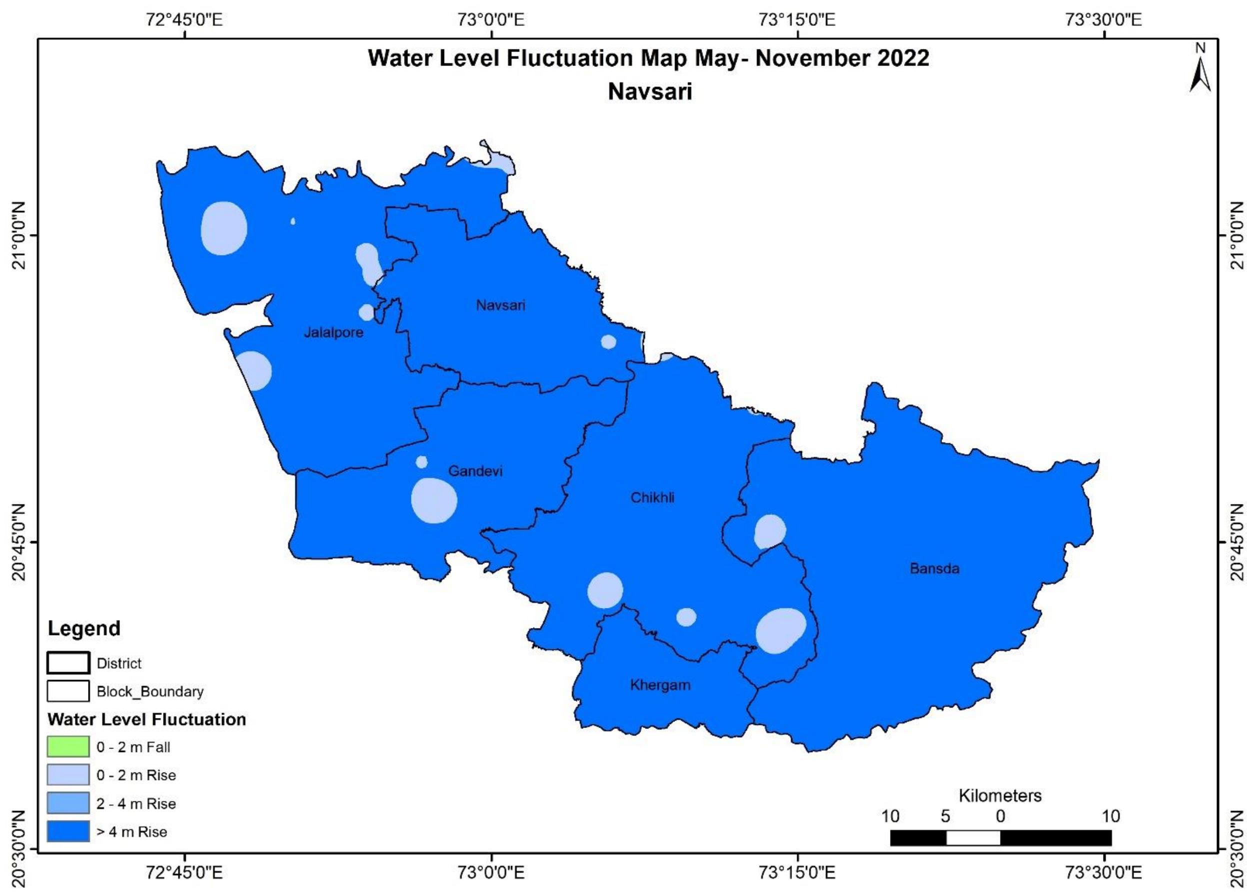

Figure 21: Map showing groundwater fluctuation of pre to post monsoon season 2022

4.1.2.1 Depth to water level (Pre monsoon)

Pre monsoon depth to water levels of Navsari district is shown in the (Figure 22), which depict that water levels in most part of the district ranges in between 5 m bgl to 10 m bgl. Two big patches also showing Water level range of 10 to 20 mbgl in Navsari and Bansda taluka.

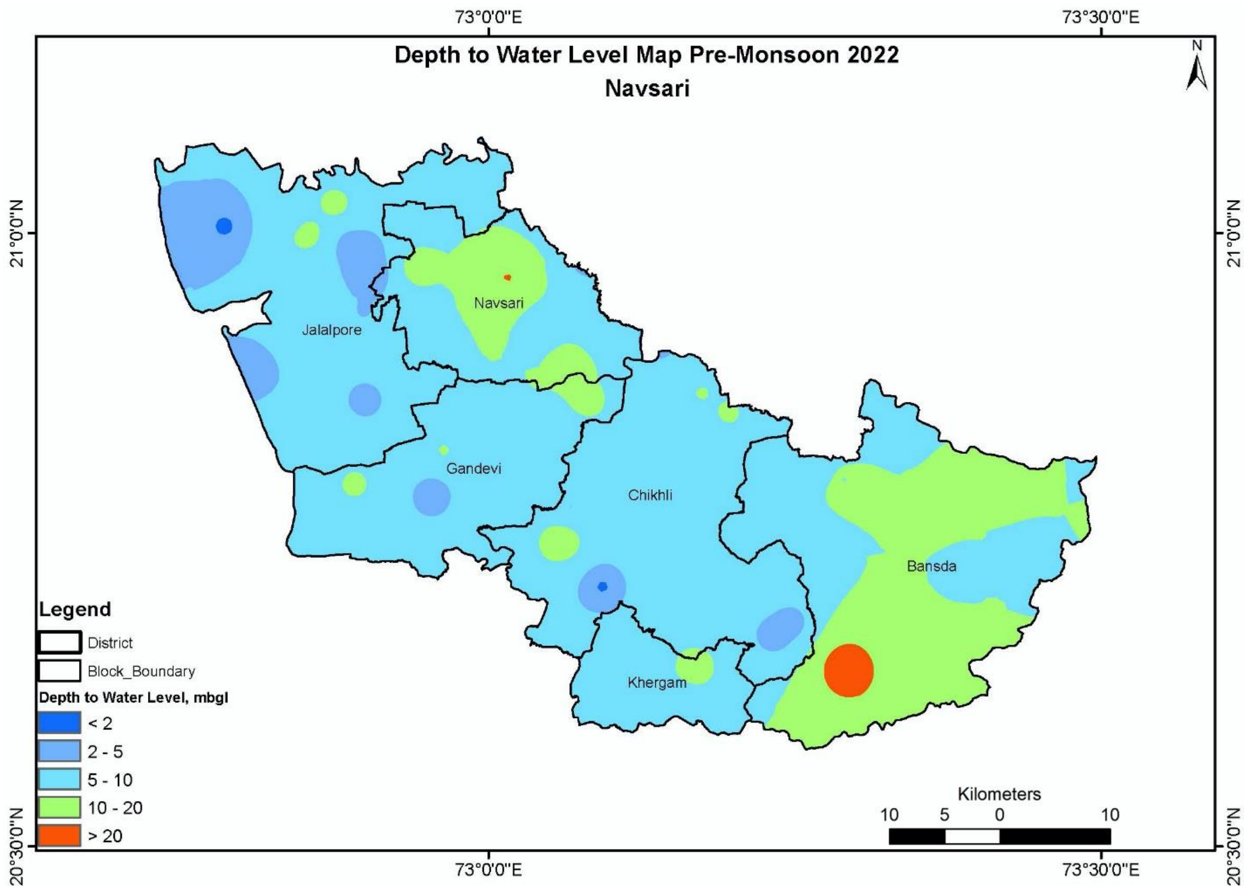

Figure 22: Map showing Pre-monsoon (May 2021) depth to water level of Navsari District

4.1.2.2 Water table and Groundwater movement

The elevation of water table in Pre monsoon 2022 is observed higher along SE (Vansda taluka) adjoining state boundary with Maharastrta state where water table contour ranges in between 180 m amsl to 190m amsl which flowing towards NW direction, with few local domes shaped contour showing radial flow (Figure 23).

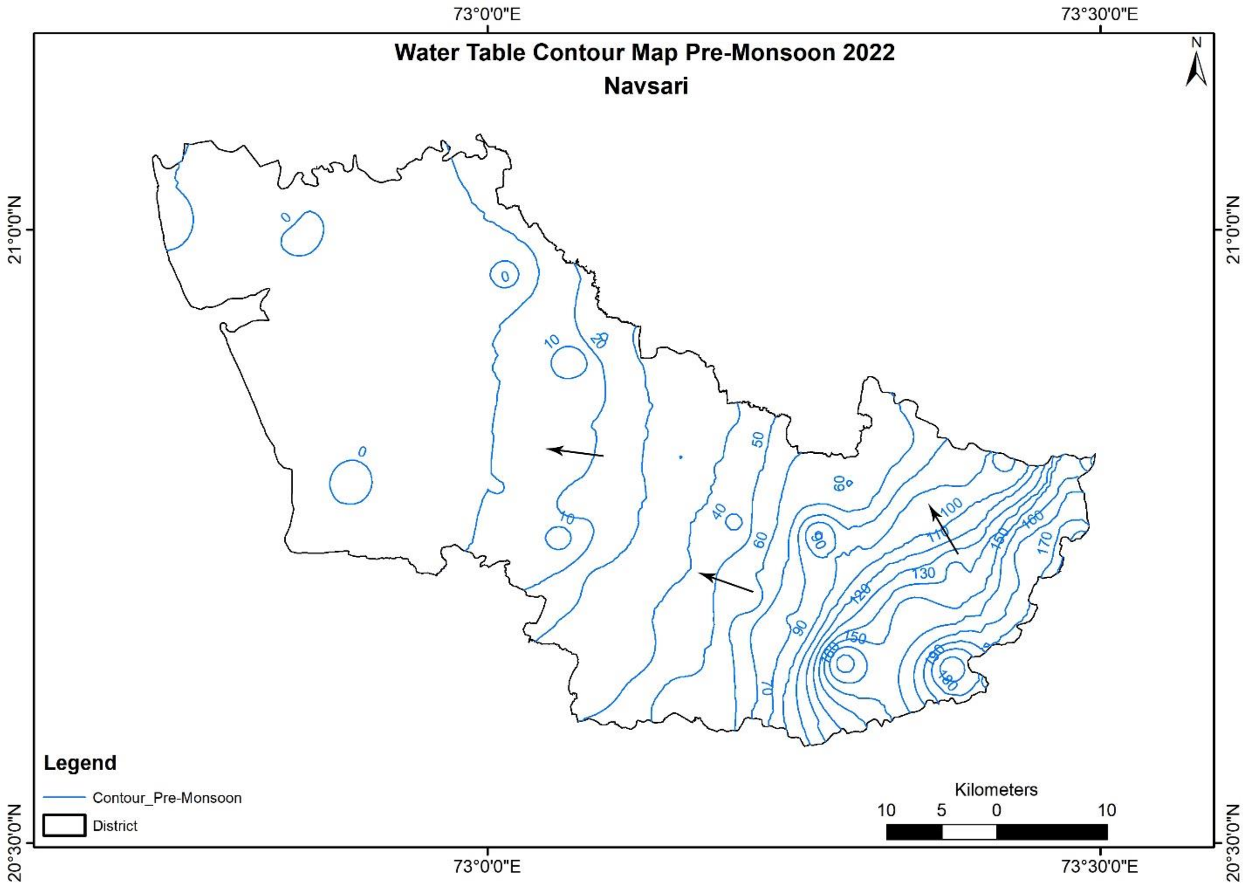

Figure 23: Water level contour map (Pre-Monsoon_2021) of Navsari district district

4.1.2.3 Ground water decadal average depth to water level (2013-2022) Map

Decadal trend of ground water level for the period of 2013 to 2022has been prepared and presented in figure 24 and 25.

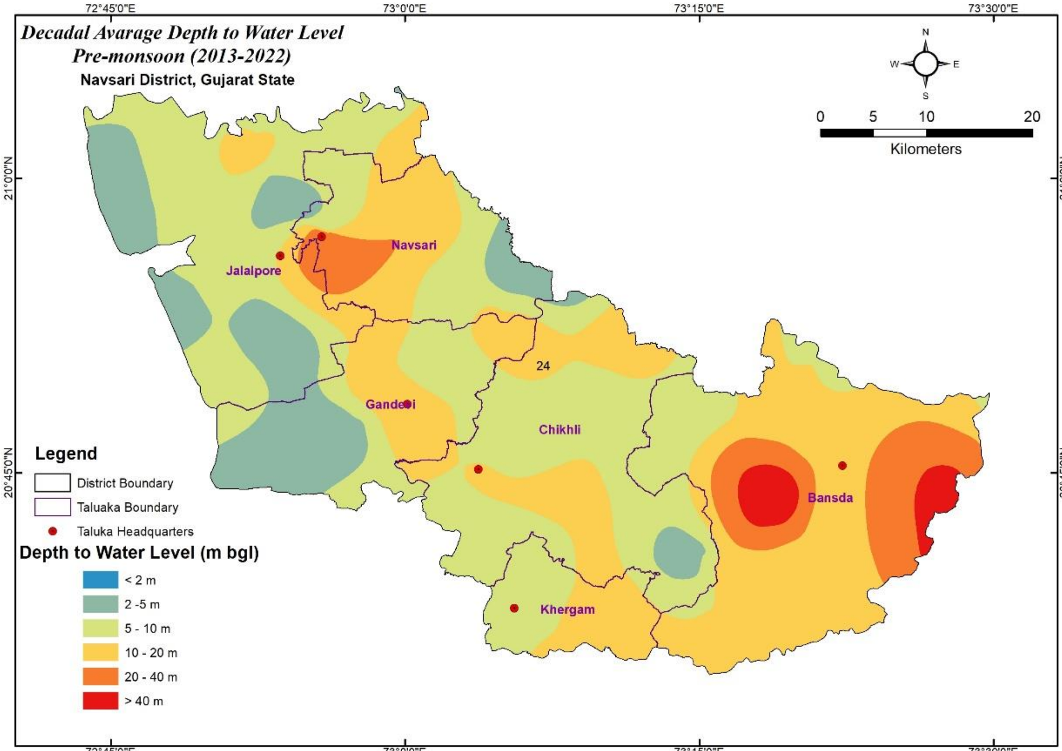

Figure 24 Pre-monsoon decadal deopth to water level map of Navsari district

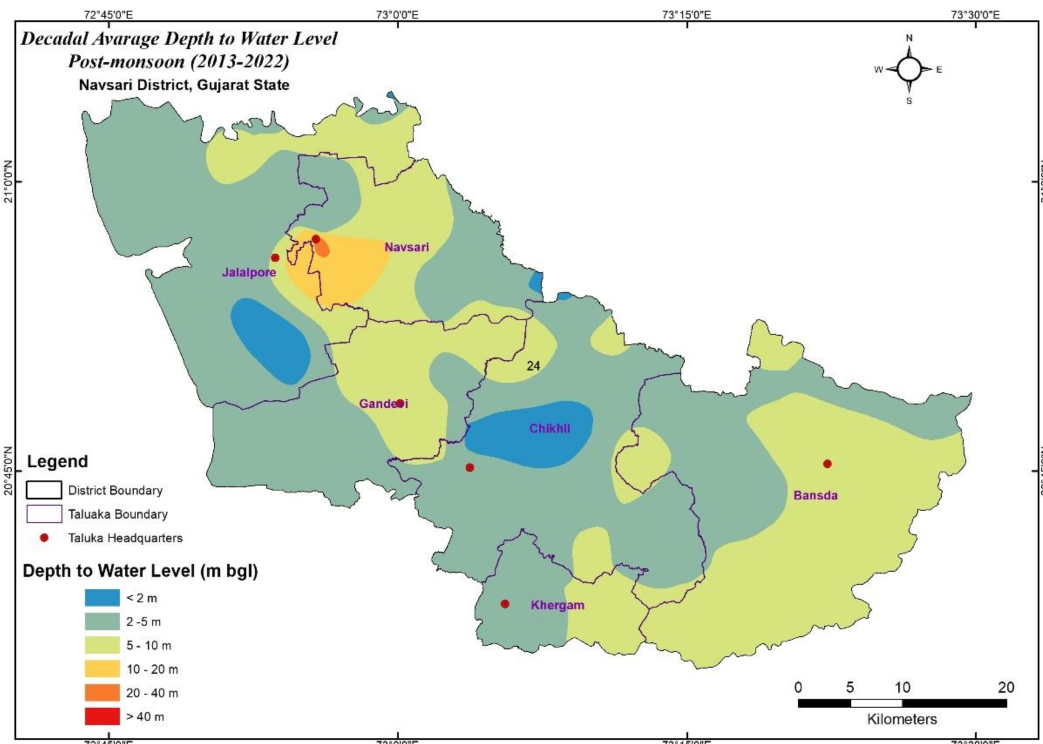

Figure 25:Post-monsoon decadal deopth to water level map of Navsari district

4.1.2.4 Hydrograph and Water Level Trend (2013-2022)

Pre monsoon and Post monsoon long-term rising and decline trend of water level of various hydrograph stations established by CGWB are also studied in graphic form. The hydrographs are showing falling and rising trend in the pre monsoon season (table 8 and Figure 26 to 35).

Table 8 : Long term water level trend of Navsari district

Sr.No.	Location	Taluka	District	Pre-Monsoon			Post Monsoon		
				Data Point	Rise	Fall	Data Point	Rise	Fall
1	Pipalkihed	Bansda	Navsari	9		0.020343	9	0.034230	
2	Hond	Chikhli	Navsari	10	0.005717		10	0.015264	
3	Khergam	Chikhli	Navsari	10	0.026606		9	0.017215	
4	Rankua	Chikhli	Navsari	7		0.012696	6		0.021409
5	Sarikhurd	Gandevi	Navsari	10	0.004538		9	0.005518	
6	Chinam	Jalalpore	Navsari	10		0.010477	9	0.003536	
7	Abrama	Jalalpore	Navsari	10	0.007068		10	0.00659	
8	Dandi	Jalalpore	Navsari	10		0.001333	10	0.005963	
9	Onjal	Jalalpore	Navsari	10	0.001023		10	0.021178	
10	Navsari	Navsari	Navsari	10		0.006375	8	0.016397	

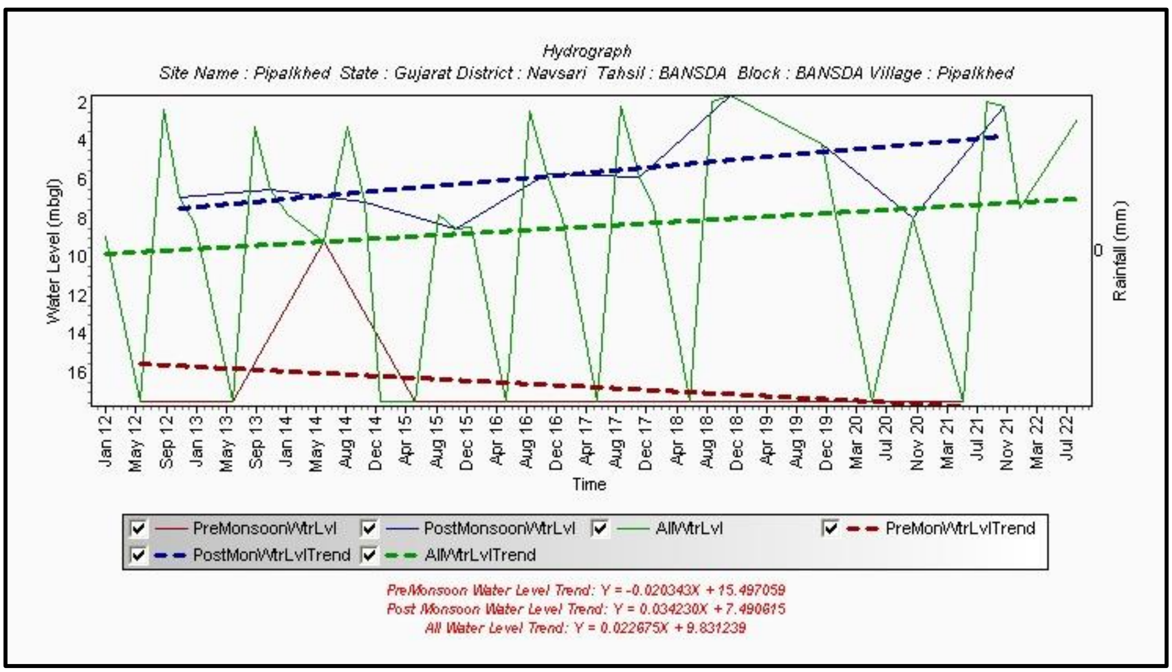

Figure 26 Hydrograph and WL trend of Pipalkhed, Bansda, Navsari.

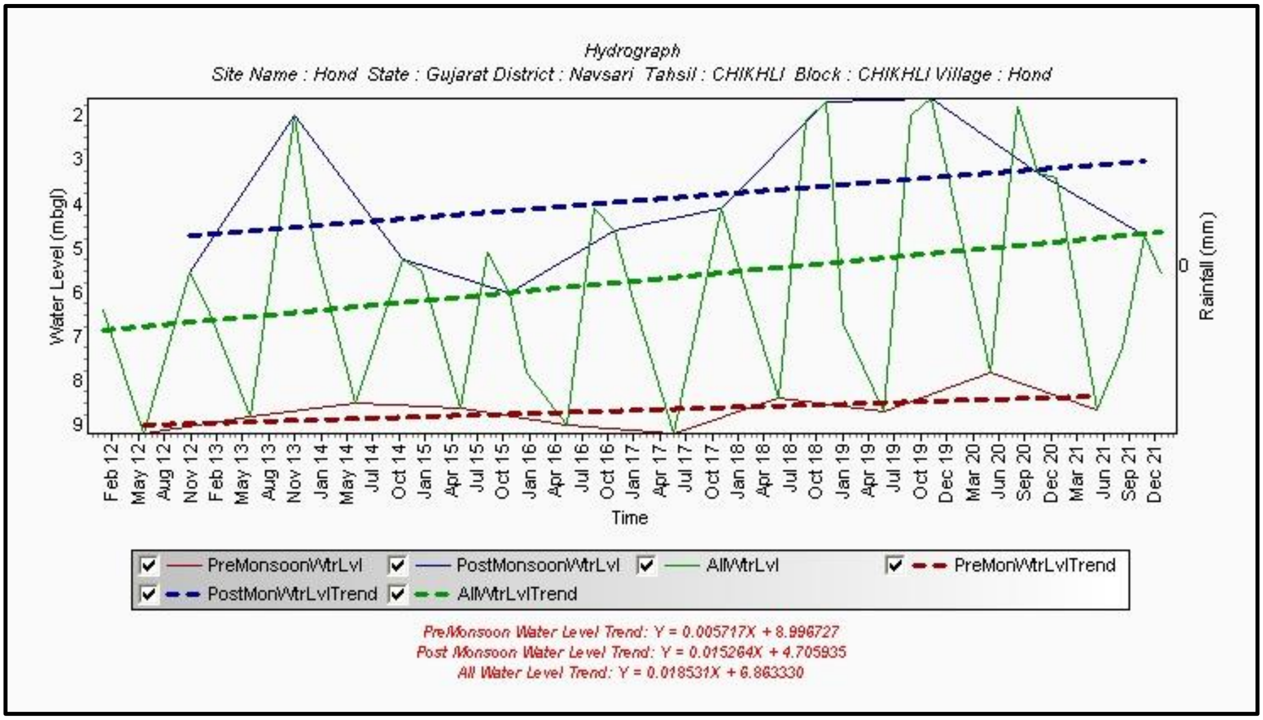

Figure 27 Hydrograph and WL trend of Hond, Chikhali, Navsari

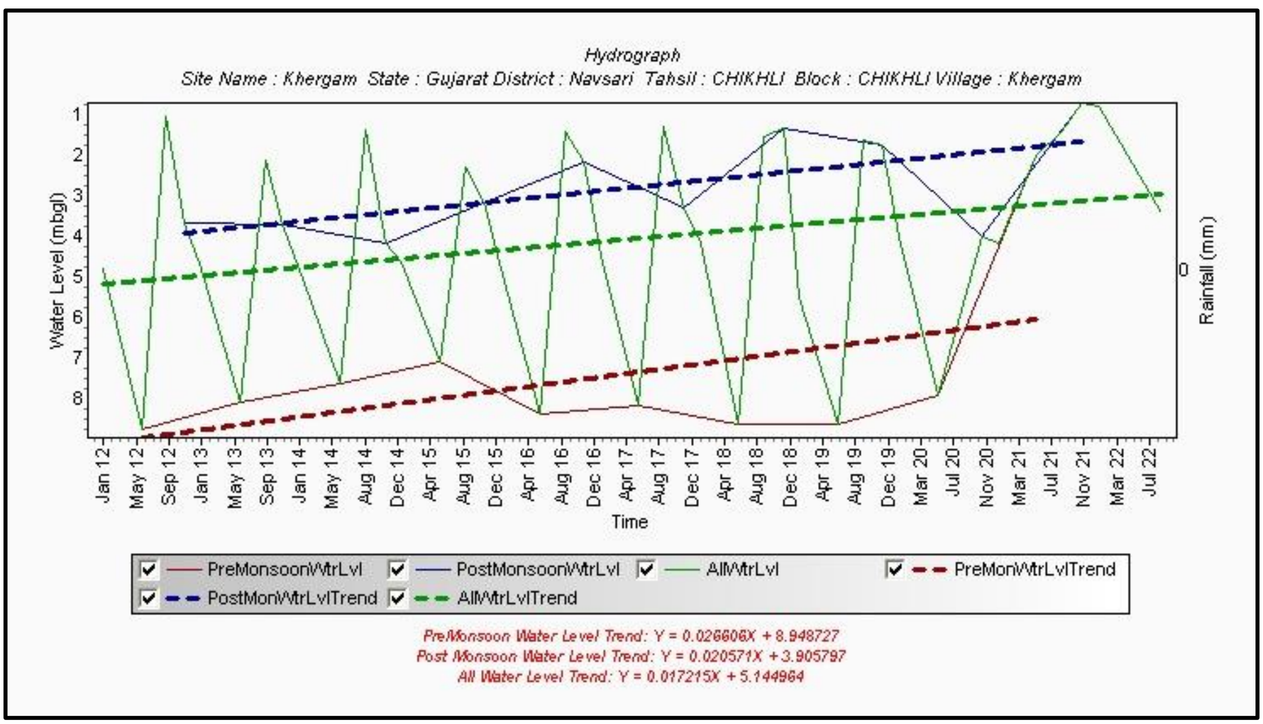

Figure 28 Hydrograph and WL trend of Khergam, Chikhali, Navsari.

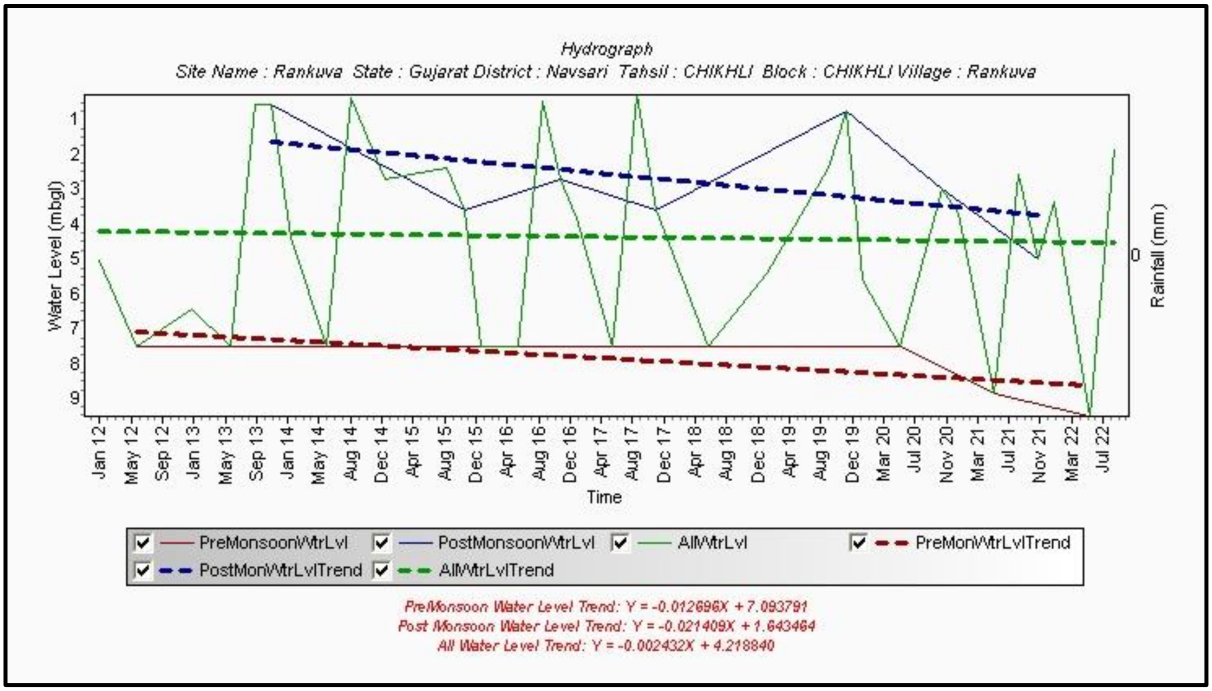

Figure 29 Hydrograph and WL trend of Rankuva, Chikhali , Navsari.

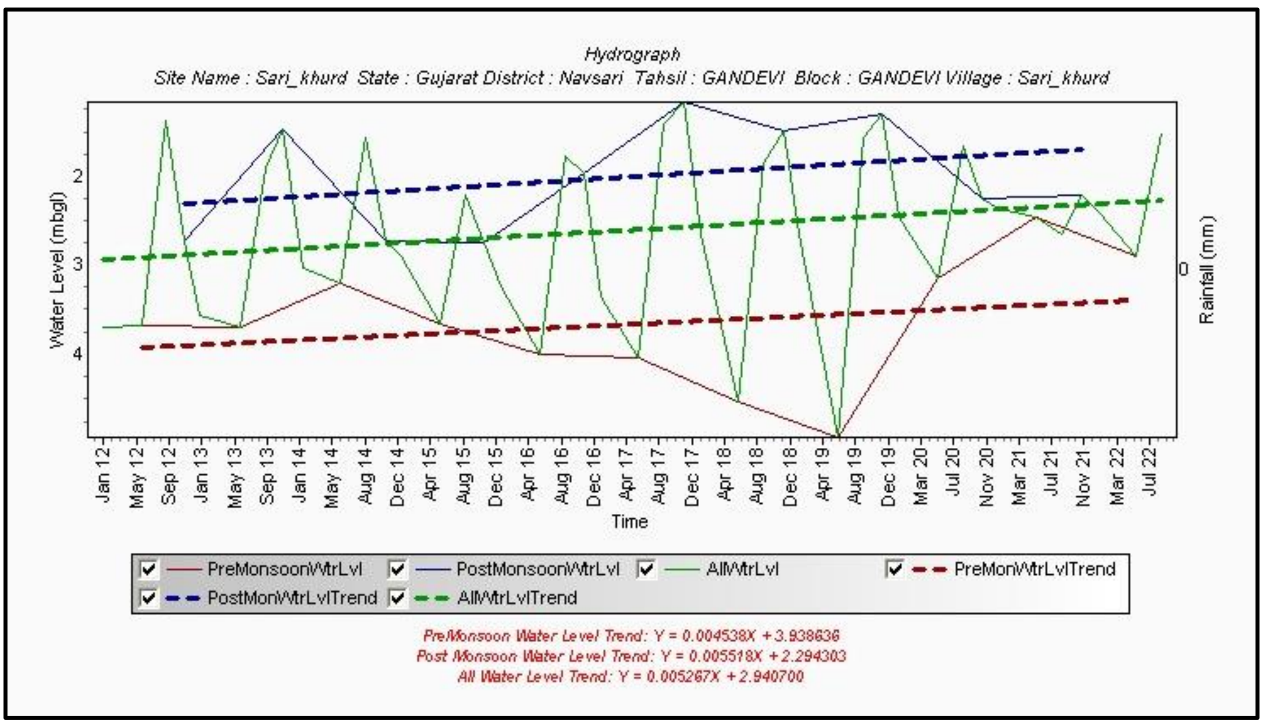

Figure 30 Hydrograph and WL trend of Sarikhurd, Gandevi, Navsari.

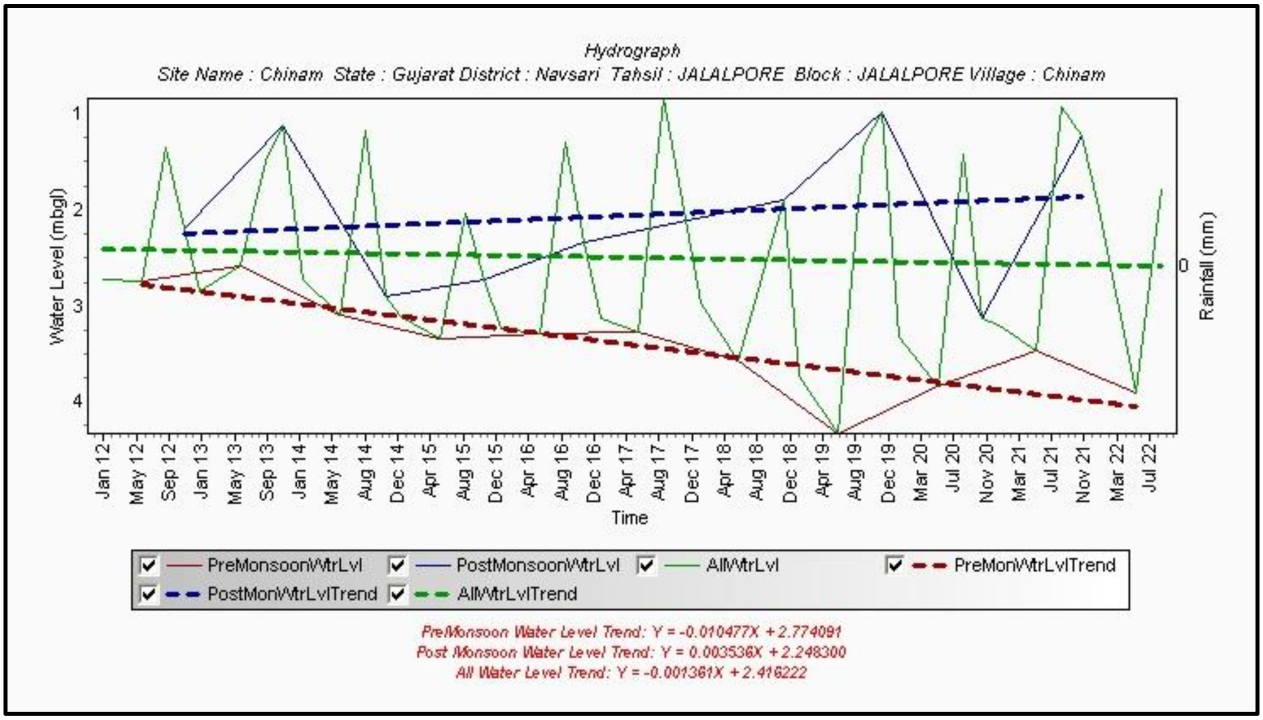

Figure 31 Hydrogrph and WL trend of chinam, jalalpur, Navsari.

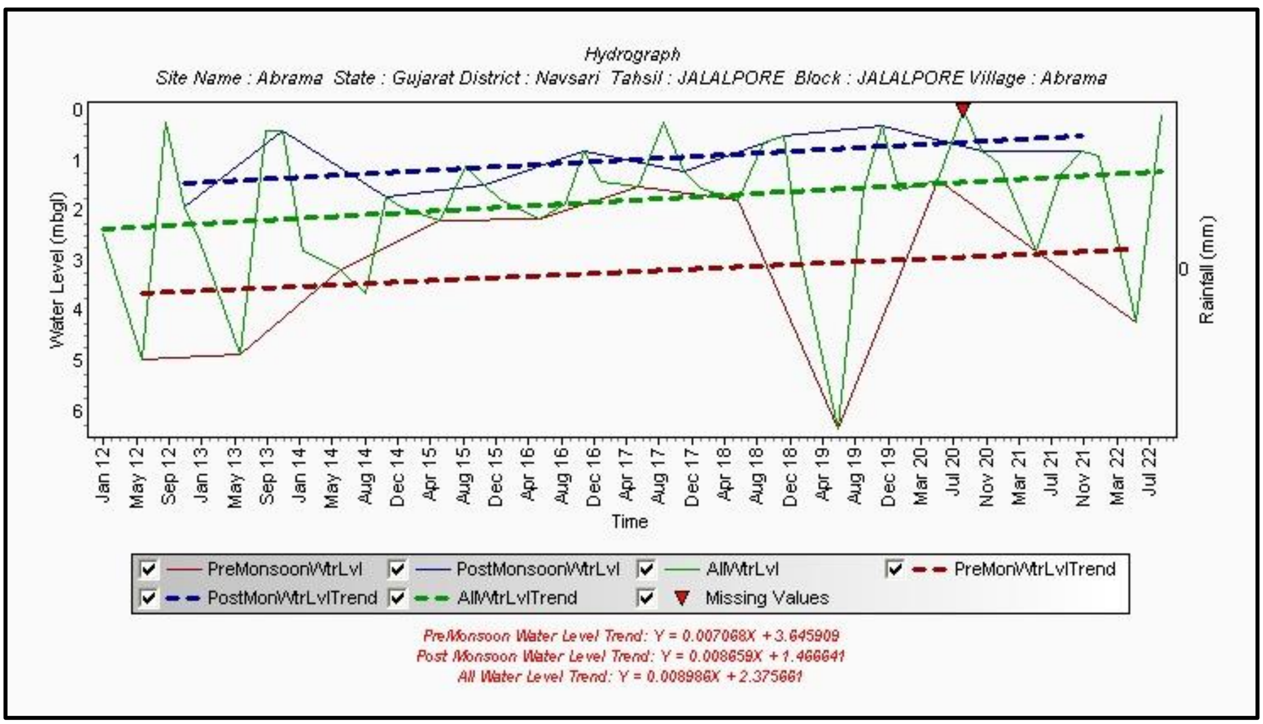

Figure 32 Hydrograph and WL trend of Abrama, Jalalpor, Navsari.

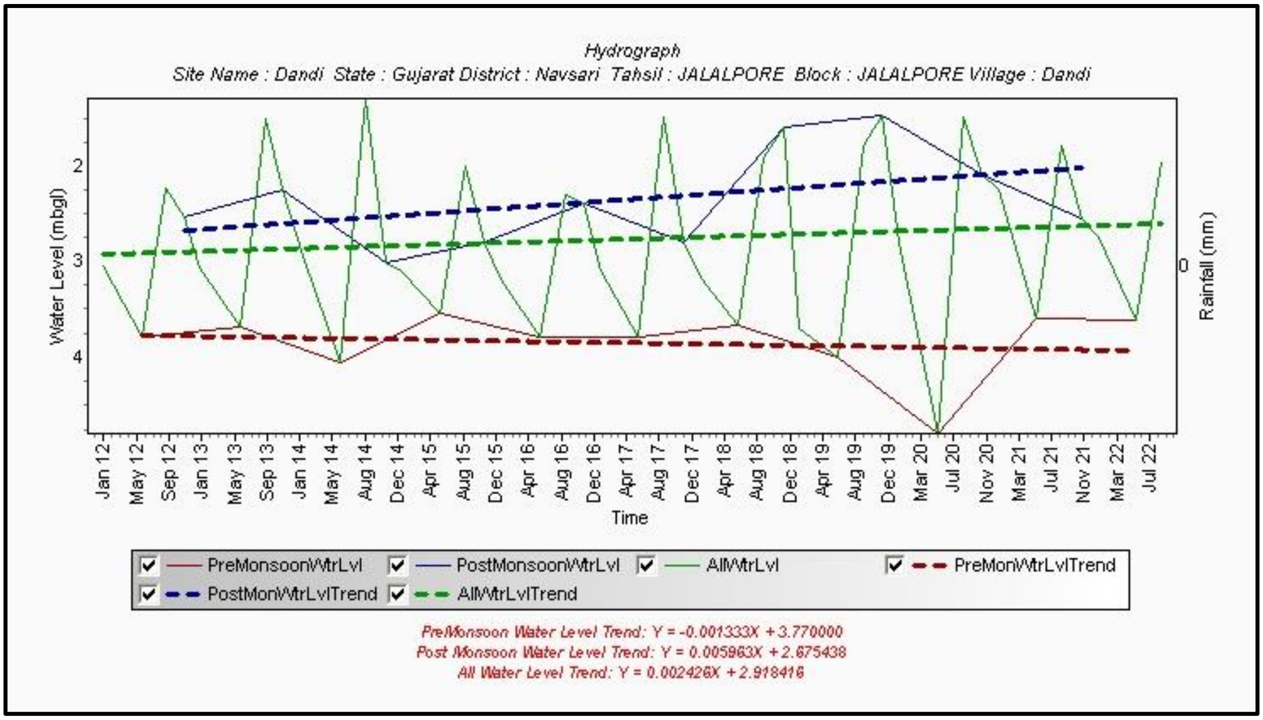

Figure 33 Hrydrogrph and WL trend of Dandi, Jalalpor, Navsari.

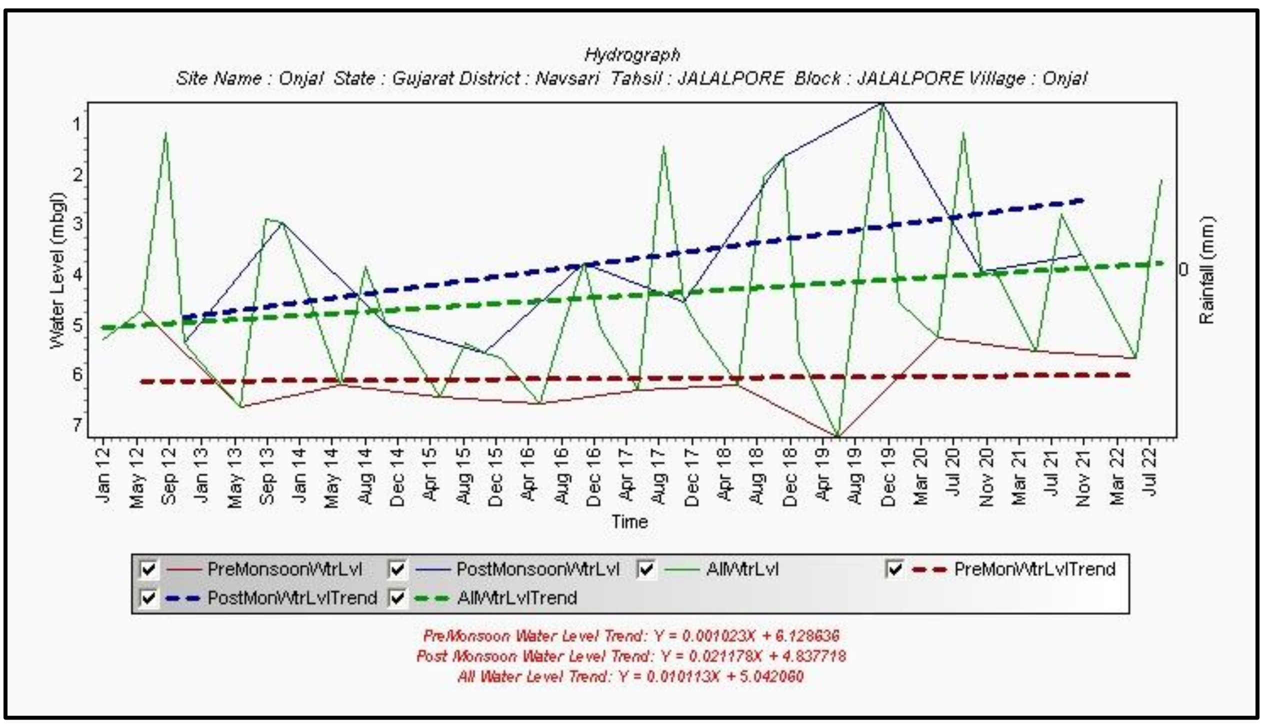

Figure 34 Hydrograph and WL trend of Onjal, Jalalpor, Navsari.

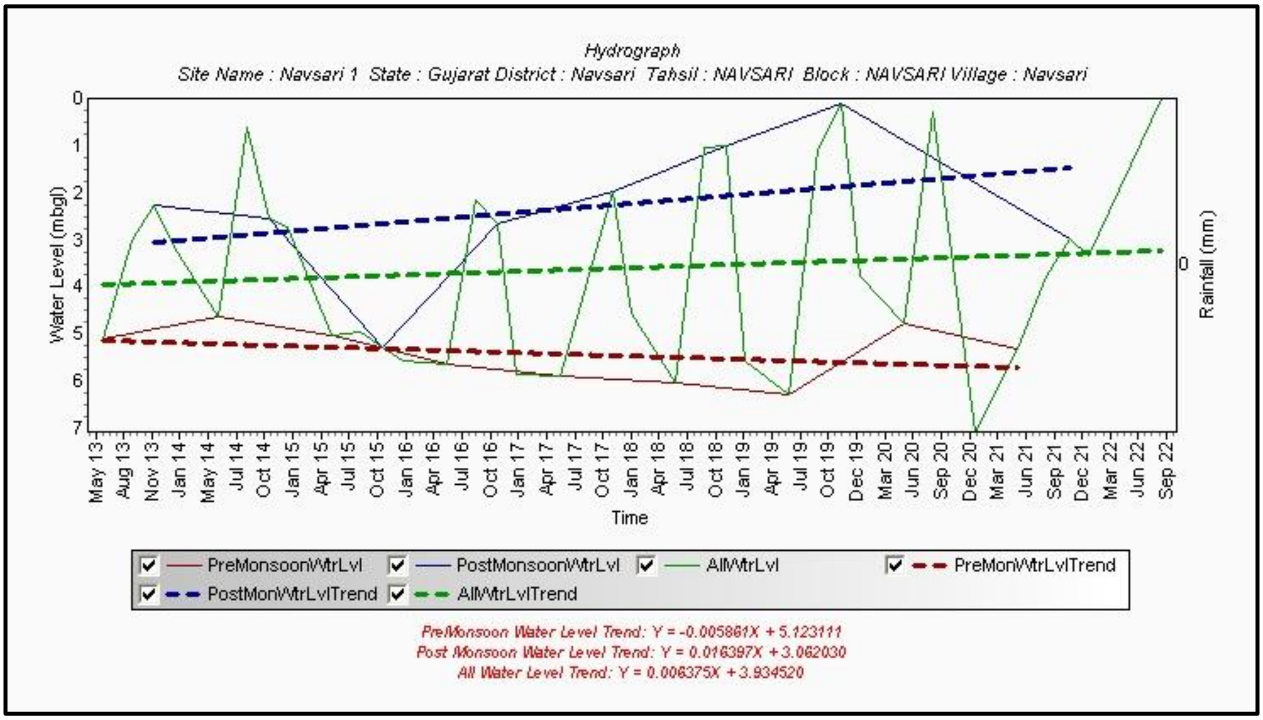

Figure 35 Hydrograph and WL trend of Navsari well.

Chapter 5: GROUND WATER RESOURCE POTENTIAL

The ground water resources of the district were calculated in collaboration with the Government of Gujarat using the GEC-2015 methodology suggested by Ground Water Resource Estimation Committee (GWRE-2022). These resources were computed after reorganization of the districts, talukas of the district are considered as Assessment Unit (AU) and total area of 2210.97 Sq. km are taken as area of assessment of the district including 5 talukas (*Khergam newly created taluka is included in Chikhli taluka). Computed resource is presented in tabulated (table-9)

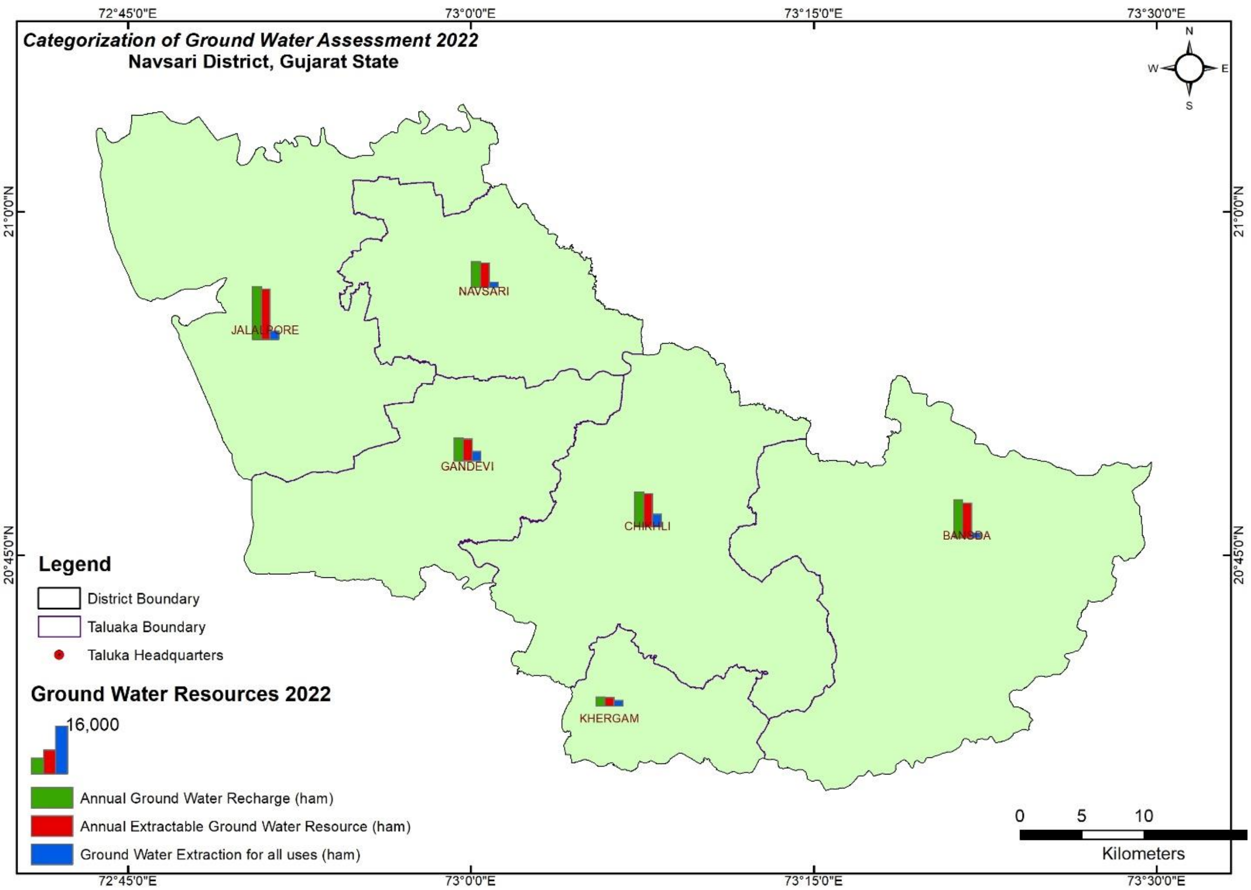

Figure 36:Map showing Dynamic GW resources of Navsari District

Table 9 Taluka Wise Ground Water Resources, Availability, Utilization and Stage of Ground Water Development (2022)

Taluka Wise Ground Water Resources, Availability, Utilization and Stage of Ground Water Development of Navsari District- 2022																
Sr No	Taluka	ANNUAL REPLENISHABLE GROUND WATER RESOURCES (Ham)				Total Annual Ground water Recharge (3+4+5+6)	Environmental Flows (ham) (5% of 7 for WTF & 10% of 7 for RIF)	Annual Extractable Ground water Resource (ham)	ANNUAL GROUND WATER DRAFT (Ham)				Allocation of Ground Water Resource for Domestic Utilisation for projected year 2027 (ham)	Net Annual Ground Water Availability for Future Use (ham)	Stage of Ground Water Extraction (%)	Categorization of Assessment Unit
		Monsoon		Non Monsoon												
		Recharge from Rainfall	Recharge from Other Sources	Recharge from Rainfall	Recharge from Other Sources				Irrigation	Industrial	Domestic	Total Draft (10+11+12)				
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	BANSDA	14904.14	510.06	0.00	1739.87	17154.07	1715.41	15438.66	1675.50	0.00	326.33	2001.83	337.12	13426.04	12.97	safe
2	CHIKHLI	12576.05	1777.76	0	5244.93	19598.74	979.93	18618.81	7337.1	21.06	820.85	8179.01	847.99	10412.66	44.09	safe
3	GANDEVI	7446.53	713.36	0.00	2010.82	10170.71	508.53	9662.18	3555.50	11.58	508.23	4075.31	525.03	5570.07	42.18	safe
4	JALALPORE	19611.36	980.52	0.00	3130.14	23722.02	1186.10	22535.92	3375.50	12.89	476.39	3864.78	492.14	18655.39	17.15	safe
6	NAVSARI	6924.64	1070.34	0.00	3688.47	11683.45	584.17	11099.28	1788.60	94.71	520.17	2403.48	537.36	8678.61	21.65	safe
	District Total	61462.72	5052.04	0.00	15814.23	82328.99	4974.14	77354.85	17732.2	140.24	2651.97	20524.41	2739.64	56742.77	26.53	safe

Chapter 6: HYDROCHEMISTRY

The chemical quality of groundwater in shallow aquifer of the district has been analyzed based on the water samples collected during National Hydrographs Monitoring Stations (NHS) and NAQUIM(Pre-monsoon) in May 2022 from CGWB. Location of the samples are Plotted in the Figure 37 and presented in Table-10. The ground water is in general alkaline in nature.

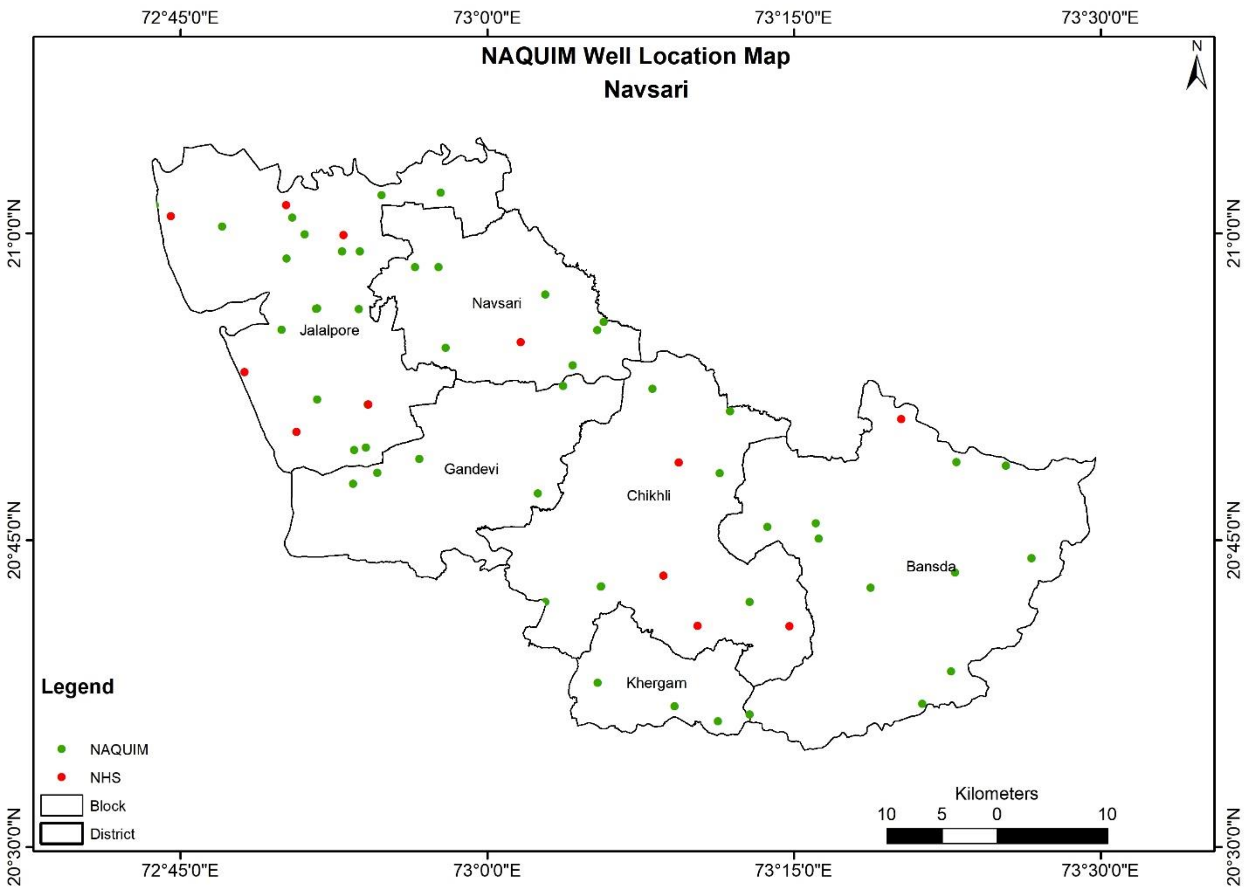

Figure 37:Map showing sample location for chemical analysis in navsari district.

Table 10 Statistical Analysis of Chemical Constituents of Ground Water in Navsari District, May 2022.

Constituents	Minimum	Maximum
pH	7.64	8.72
EC (uS/cm)	403	8446
Alkalinity (mg/l)	50	790
TDS (mg/l)	270	5659
HCO_3 (mg/l)	24	720
Cl (mg/l)	21	2577

SO_4 (mg/l)	11	483
NO_3 (mg/l)	0.07	90.35
Ca (mg/l)	16	240
Mg (mg/l)	2.4	345
Na (mg/l)	11	1341
K (mg/l)	0.1	38.8
F (mg/l)	0	1.48
Fe(mg/l)		

6.1 Hydrogen Ion Concentration (pH)

The pH is an indicator of acidity of the water. The ground water in the district is generally alkaline with pH more than 7. The value of pH ranges between 7.64 (Chorani) & 8.72 (Parujajn) in the district.

6.2 Electrical conductivity

As per the BIS standards [IS 10500: 2012] for drinking water, acceptable limit and permissible limit of Total Dissolve Solid (TDS) are 500 mg/l and 2000 mg/l respectively. The value of EC for the district lies between 403 uS/cm (Jhujh) and 8446 uS/cm (Delwada).

6.3 Total Dissolved Solid (TDS)

As per the BIS standards [IS 10500: 2012] for drinking water, acceptable limit and permissible limit of Total Dissolve Solid (TDS) are 500 mg/l and 2000 mg/l respectively. Total Dissolved Solid (TDS) is an overall parameter indicating salinity of ground water. The Total Dissolved Solid of ground water in the district varies from 270 mg/l (Jhujh) to about 5659 mg/l (Delwada) (Figure 38).

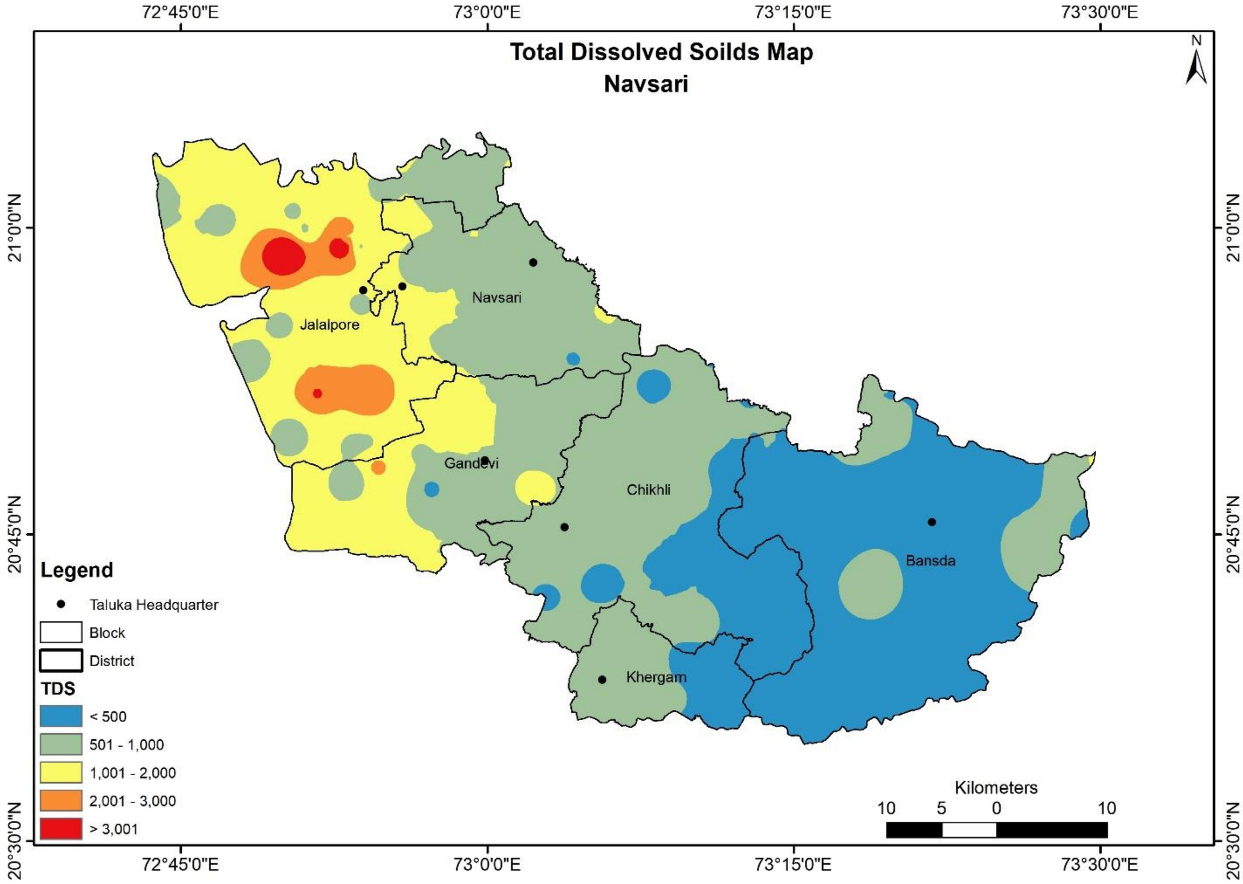

Figure 38: Map showing variation in TDS values in Navsari district of Gujarat State.

6.4 Chloride (Cl)

As per the BIS standards [IS 10500: 2012] for drinking water, Acceptable limit and Permissible limit of Chloride are 250 mg/l and 1000 mg/l respectively. It is depicted from the map shown in figure-37, that except few patches Cl concentration is within permissible limit. The values of Cl concentrations are varying from 21mg/l(Kamadjhari) to 2577 mg/l (Delwada) in the district (Figure 39).

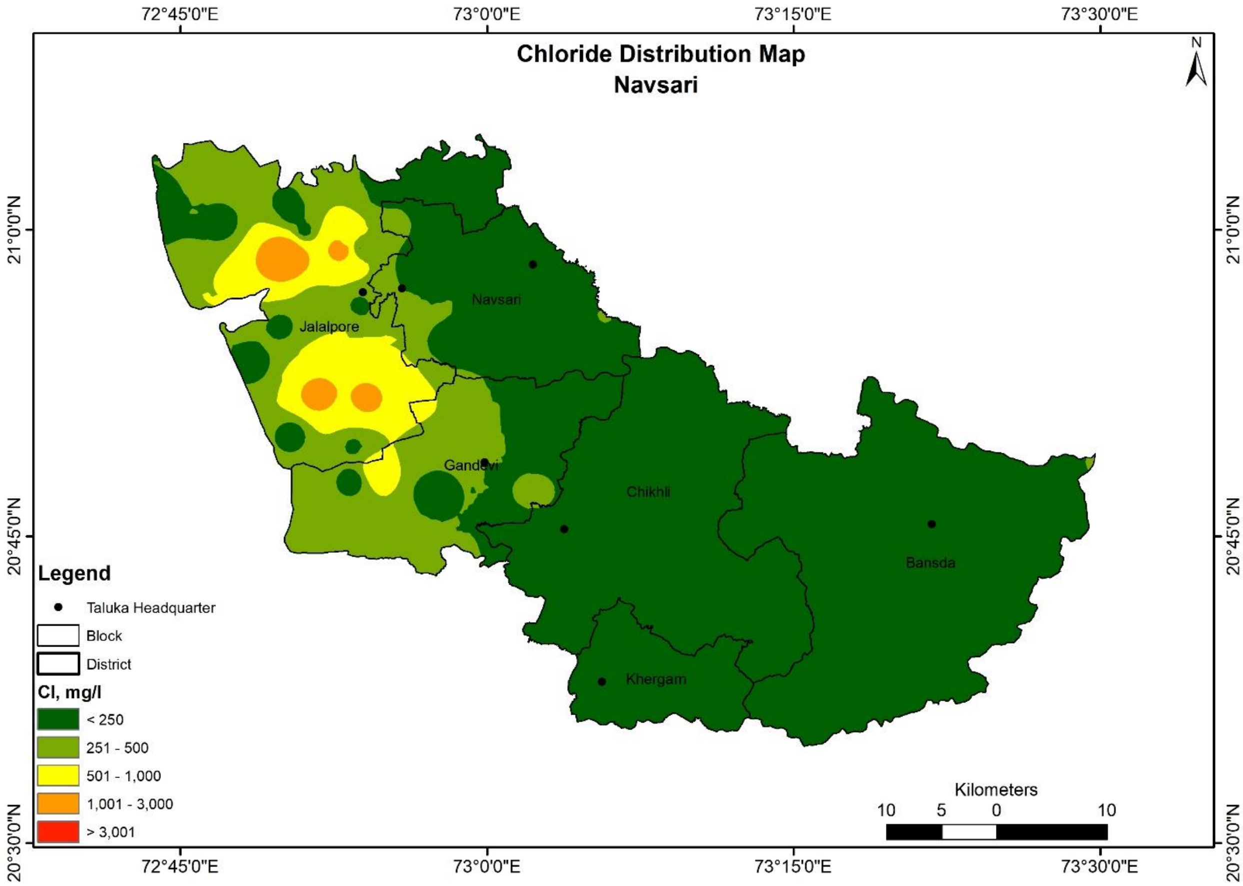

Figure 39: Map showing Variation in Chloride values in Navsari district of Gujarat state.

6.5 Nitrate (NO_3)

As per the BIS standards [IS 10500: 2012] for drinking water, acceptable limit is 45 mg/l (maximum) and there is no relaxation in permissible limit. Nitrate concentration in the ground water in district varies between 0.07 mg/l (Masa) and 90.35 mg/l (Mirjapur) (figure 40).

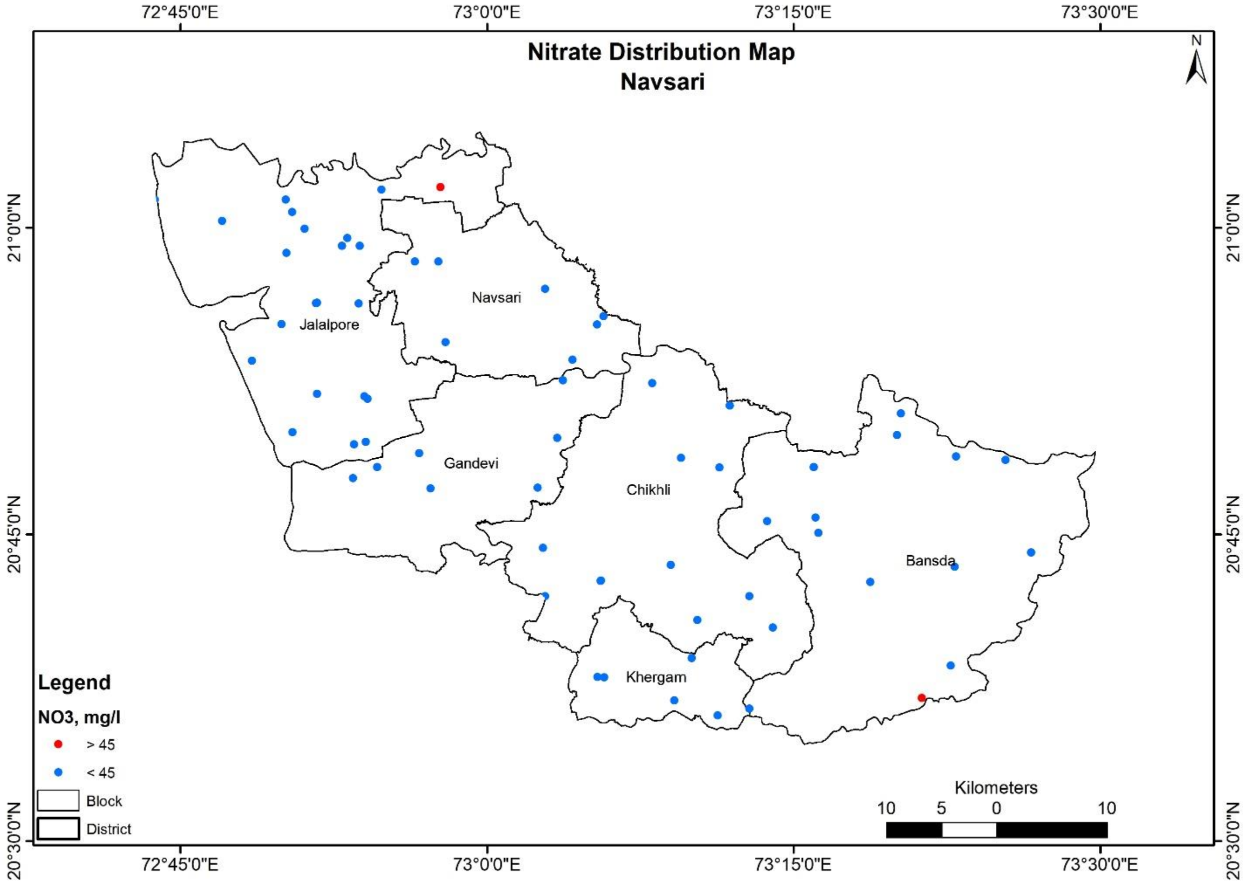

Figure 40: Map showing variation in Nitrate value in Navsari district of Gujarat state.

6.6 Carbonate (CO3) and Bicarbonate (HCO3)

The ground water in Navsari district contain Carbonate which values vary from 0 mg/l to 192 mg/l. The Bicarbonate concentration in district are varies in between 24 mg/l (panar) to 720 mg/l (Mirjapur).

6.7 Sulphate (SO4)

As per the BIS standards [IS 10500: 2012] for drinking water, Permissible limit of Chloride is 400 mg/l. In the district, Sulphate concentration varies from 11 mg/l (Kamadjhari) to 483 mg/l (Mirjapur).

6.8 Calcium (Ca)

Calcium concentration in district varies between 16 mg/l (Pipalbhan) and 240 mg/l (Mirjapur). There are isolated locations where calcium concentration is more than permissible limit (permissible limit as per BIS norms is 200 mg/l).

6.9 Magnesium (Mg)

The Concentration of Magnesium in the district ranges from 2.4 mg/l (Khambhala) to 345 mg/l(Delwala).). There are 7 isolated locations where Magnesium concentration is more than permissible limit (Permissible limit as per BIS norms is 100 mg/l).

6.10 Sodium (Na)

Sodium concentration in the district varies between 11 mg/l (Jhujh) and 1341 mg/l (Mirjapur).

6.11 Potassium (K)

The concentration of Potassium in shallow ground water ranges from 0.1 mg/l (Kukeri) to 38.8 mg/l (Delwada).

6.12 Fluoride (F)

As per the BIS standards [IS 10500: 2012] for drinking water, Acceptable limit and Permissible limit of Fluoride (mg/l) are 1 mg/l and 1.5 mg/l respectively. Fluoride concentration in the district varies in between 0 mg/l (Kamdjhari) and 1.48 mg/l (Mirjapur) (Figure 41).

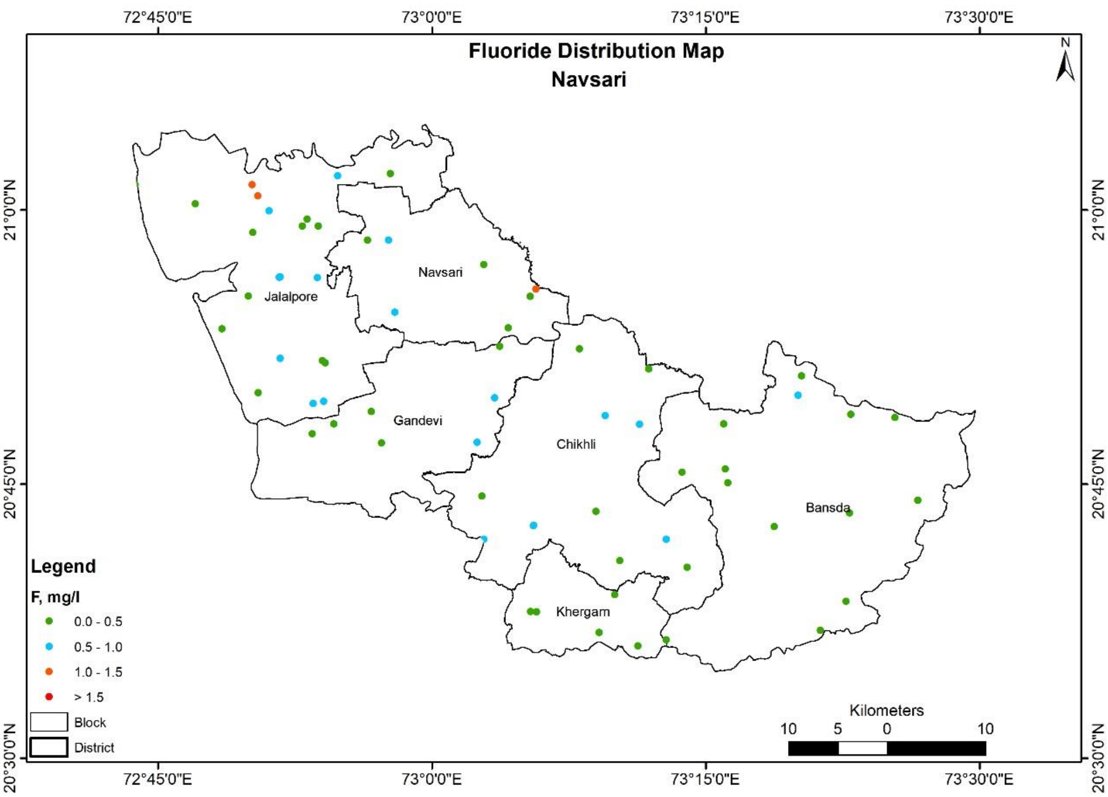

Figure 41: Map showing variation in floride value in Navsari district of Gujarat state.

6.13 Iron (Fe)

As per the BIS standards [IS 10500: 2012] for drinking water, Permissible limit of Fe (mg/l) is 0.3 mg/l. Iron concentration in the district varies between 0.004 mg/l (Kukeri, taluka Jalalpore) and 0.685 mg/l (Kukeri, Taluka Chikhali). Fe concentration in Navsari district is within the permissible limit except 8 locations.

Chapter 7: SUSTAINABLE GROUNDWATER DEVELOPMENT AND MANAGEMENT

7.1 Groundwater related issue:

7.1.1 Low Ground water development

As per GWRE 2022 the total ground water resources of the district are in order of 82328.99 Ham/year and utilizable resources are 77354.85 Ham/year. The net annual drafts of 20524 Ham/year leaves a balance of 56742.77 Ham/year of ground water available for future development. Stage of Ground water development of the district is 26.53 %, however talukas wise it ranges from 12.97% (Bansada taluka) to 44.09% (Chikhali taluka) (Table 9).

*(Newly created khergam taluka is included in Chikhli taluka).

7.1.2 Pollution (Geogenic and Anthropogenic)

We have collected 55 pre-monsoon ground water samples from shallow aquifer for this study. Chemical analysis of these samples is showing that GW of Eastern talukas are potable and fit for domestic, drinking, irrigation and other industrial purposes and and coastal Taluka are not fit for drinking purpose (Mochhiya Vasan, Abrama, Mirjapur, Mandariya, Mirjapur, Amalsar, and Delwada village in Coastal taluka Jalalpur and Gandevi having TDS value more than 2000 mg/l) but may be used for irrigation and other industrial purposes. Fluoride is in permisble limit in the district. Nitrate (3 Locations) beyond acceptable limit (As per the BIS standards [IS 10500: 2012] for drinking water) in Shallow and deep aquifers identified in localized isolated villages.

7.2 Management Strategies

As per the estimate of ground water resources and irrigation potential, there exists a scope for further development of ground water resources in major parts of the district. As per GWRE 2022, all talukas of the district are under safe category Stage of Ground water development of the district is 26.53; however, talukas wise it ranges from 12.97% (Bansada taluka) to 44.09% (Chikhali taluka, *Newly created khergam taluka is included in Chikhli taluka).

Thus, further ground water development could be augmented in a judicious way.

7.3 Management plan

The uneven distribution of groundwater availability and its utilization indicates that a single management strategy cannot be adopted and requires integrated hydrogeological aspects along with socio-economic conditions to develop appropriate management strategy (table 12). The study suggests notable measures for sustainable groundwater management, which involves a combination of various measures given below.

- Ground water development Plan
- Supply side measures
- Demand side measures
- Regulatory measures
- Institutional measures

7.3.1 Ground water Development Plan

To elevate the stage of ground water development in all blocks, 3000 nos. of Dug wells (30 m depth) and 1500 nos. of Tube well (100m depth) are proposed as feasible extraction structures (table 11). The extraction structures will result as expected annual ground water draft of 3750 Ham, which will create 8333.33 Ha additional irrigation potential in the district.

Table 11 Feasible Extraction structures to elevate the Stage of GW development

Extraction / Talukas	Feasible Extraction structures to elevate the Stage of GW development			G.W Draft from Extraction structures (ham)	Additional Irrigation Potential Created (Ha)
	TW	DW	Total		
Bansdsa	357	180	537	448.50	996.67
Chikhli	1231	615	1846	1538.00	3417.78
Gandevi	609	304	913	760.50	1690.00
Jalalpore	453	226	679	565.50	1256.67
Navsari	350	175	525	437.50	972.22
District	3000	1500	4500	3750	8333.33

7.3.2 Supply side interventions

As per Master Plan 2020, surplus surface water of 401.14(40114 Ham) mcm non committed is allocated to suggest artificial recharge and Available subsurface space is 1193 Ham in district of Navsari. To harvest the surface water, the different artificial recharge structures are proposed as check dam, Percolation tank and use existing defunct tube well to recharge the aquifer which is presented in table 12. Expected annual Groundwater recharge is 724.60 Ham through check dams of total 212 nos. of 17000 m^3capacity, 37 nos. of percolation tank of 90000m^3 capacity, are recommended for harvesting the part of available runoff and to recharge the Groundwater as in table 12.

Table 12- Proposed Artificial Recharge and WUE Interventions in Navsari District

Taluka	Check Dam (17000 m3 Capacity) Nos.	Percolation Tank (~ 90000 m3 capacity) Nos.	Recharge through defunct tube wells @3Ham Nos.	On-farm Activities (in ha)	Numbers of Farm Pond of capacity 0.3645ham	Additional Recharge from Recharge interventions (ham)
Bansdsa	50	8	0	885	10	165.69
Chikhli	62	8	0	2668	70	352.15
Gandevi	38	8	0	907	50	159.73
Jalalpore	30	5	0	1528	120	200.19
Navsari	32	8	0	1258	10	190.75
District	212	37	0	7246	260	1069

7.3.4 Demand side intervention

Feasible extraction structures are proposed to elevate the stage of ground water development to 30.99 %, to avoid further exploitation demand side management is also recommended to restrict the stage of ground water development to 30.03 %. An area of 7246 Ha is proposed for on farm activities (Laser leveling/Bench terracing/Contour banding), 260 no. of farm ponds are recommended to recharge the ground water. And expected conservation of ground water through efficiency enhancement measures is 406.6 Ham is expected for the district.

- **Farm pond**

A farm pond is a large hole dug out in the earth, usually square or rectangular in shape (Figure 42), which harvests rainwater and stores it for future use. It has an inlet to regulate inflow and an outlet to discharge excess water. The pond is surrounded by a small bund, which prevents erosion on the banks of the pond. The size and depth depend on the amount of land available, the type of soil, the farmer's water requirements, the cost of excavation, and the possible uses of the excavated earth. Water from the farm pond is conveyed to the fields manually, by pumping, or by both methods.

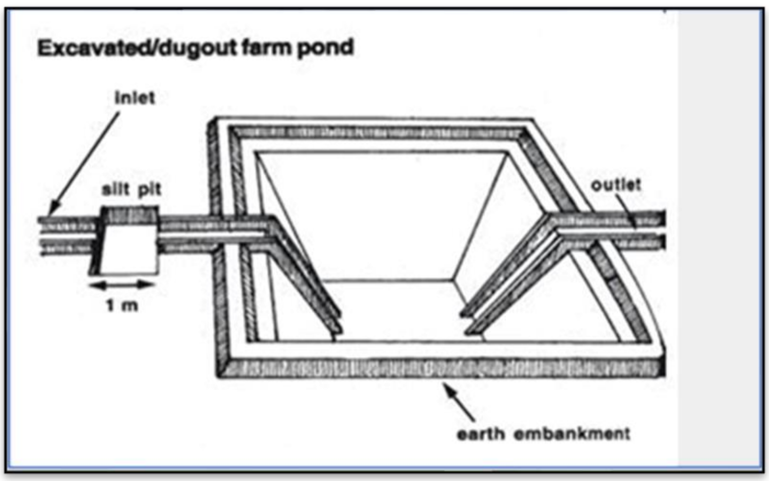

Figure 42: Schematic diagram of Farm Pond.

Advantages of Farm Ponds

- They provide water to start growing crops, without waiting for rain to fall.
- They provide irrigation water during dry spells between rainfalls. This increases the yield, the number of crops in one year, and the diversity of crops that can be grown.
- Bunds can be used to raise vegetables and fruit trees, thus supplying the farm household with an additional source of income and of nutritious food.
- Farmers are able to apply adequate farm inputs and perform farming operations at the appropriate time, thus increasing their productivity and their confidence in farming.
- They check soil erosion and minimize siltation of waterways and reservoirs.
- They supply water for domestic purposes and livestock
- They promote fish rearing.
- They recharge the ground water.
- The excavated earth has a very high value and can be used to enrich soil in the fields, leveling land, and constructing farm ponds.

Table 13 Projected Status of Groundwater Resource after implementation of GW Management Plan, Navsari District (Gujrat)

Projected Status of Groundwater Resource after implementation of GW Management Plan, Navsari District (Gujrat)												
Taluka	Net G.W. Availability (Ham)	Additional Recharge from Recharge interventions (ham)	Additional Recharge from Return flow of GW Irrigation	Total Net G.W. Availability after intervention (Ham)	Existing G.W Draft for all purpose (ham)	Conservation of Ground water through WUE, on farm activity & farm ponds (ham)	G.W Draft from Extraction structures (ham)	Net GW draft after interventions (ham)	Present stage of G.W. Development (%)	Projected stage of G.W. Development after construction of extraction structures (%)	Projected stage of GW development after construction of extraction structures & implementation of conservation & Recharge measures (in %)	Additional Irrigation Potential Created (Ha)
Bansda	15438.66	165.69	116.61	15720.96	2001.83	42.92	448.50	2407.41	12.97	15.75	15.31	996.67
Chikhali	18618.69	352.15	399.88	19370.72	8209.01	141.75	1538.00	9605.26	44.09	51.25	49.59	3417.78
Gandevi	9662.18	159.73	197.73	10019.64	4075.31	56.31	760.50	4779.50	42.18	49.05	47.70	1690.00
Jalalpore	22535.92	200.19	147.03	22883.14	3864.78	105.94	565.50	4324.34	17.15	19.53	18.90	1256.67
Navsari	11099.28	190.75	113.75	11403.78	2403.48	59.71	437.50	2781.27	21.65	25.34	24.39	972.22
Sum	**77354.73**	**1068.524**	**975**	**79398.25**	**20554.41**	**406.6245**	**3750**	**23897.79**	**26.53**	**30.99**	**30.03**	**8333.33**

Chapter 8: CONCLUSION AND RECOMMENDATIONS

- Artificial recharge structures like recharge Check dam and through percolation tank are proposed in the district to encounter needed surface runoff.
- To elevate the stage of ground water development 30.99 to in district, 3000 nos of Dug wells (20 m depth) in Hard rock and 1500 no. of Tube wells (100m depth) are proposed as feasible extraction structures.
- The extraction structures will result as expected annual ground water draft of 3750.00 ham which will create 8333.33 Ha additional irrigation potential in the district.
- To prevent Over Exploitation, water conservation activities like on farm activities, farm ponds and check dams are recommended.
- 7246 Ha area is proposed for on farm activities (Laser leveling/Bench terracing/Contour banding) and 260 nos. of farm ponds are recommended which will serve dual purpose of irrigation and recharge to ground water.
- Ground water return flow of 975 ham is expected from irrigation of fields in the district.
- 406.6 ham conservation of ground water through WUE measures, on farm activities & farm ponds is expected for the district.
- As a conservation measure, farmers should be encouraged and educated to adopt modern irrigation techniques like drip, sprinkler irrigation etc. to effect minimum withdrawal and maximum utilization of groundwater.
- We have collected 55 pre-monsoon ground water samples from shallow aquifer for this study. Chemical analysis of these samples is showing that GW of Eastern talukas are potable and fit for domestic, drinking, irrigation and other industrial purposes and and coastal Taluka are not fit for drinking purpose (Mochhiya Vasan, Abrama, Mirjapur, Mandariya, Mirjapur, Amalsar, and Delwada village in Coastal taluka Jalalpur and Gandevi having TDS value more than 2000 mg/l) but may be used for irrigation and other industrial purposes. Fluoride is in permisble limit in the district. Nitrate (3 Locations) beyond acceptable limit (As per the BIS standards [IS 10500: 2012] for drinking water) in Shallow and deep aquifers identified in localized isolated villages.
- Present supply side interventions are suggested based on availability 401.14 MCM non committed source of water and 11.93 MCM available space for recharge in the district is referred by State Government (Reference Master Plan of Artificial recharge 2020). Proposed enhancements of present Groundwater development stage are subjected to implementation of recharge interventions, availability of cultivable land and yield of Groundwater structures.
- These interventions also need to be supported by regulation, so that the ground water resources are protected for future generation and also serve as ground water sanctuary in times of distress/drought. IEC activities and capacity building activities needs to be aggressively propagated to establish the institutional framework for participatory ground water management.