CHAPTER-V

GROUNDWATER BEHAVIOUR AND RESOURCE POTENTIAL

5.1 Introduction

Groundwater is a dynamic renewable natural resource which gets replenished and depleted periodically depending upon the natural prevailing conditions like changes in climatic, geomorphic, land use pattern, geological conditions (springs, area of discharge, outflow from the groundwater divide etc.) and role of anthropogenic factors mainly concern with groundwater utilization. With the current pace of development in the study area and everlasting demand of the water it is imperative to have assessment of water resources in terms of quality & quantity. Further, there is an acute need for establishing an appropriate mechanism for judicious utilization of water resources by inducting the concept of conjunctive use to impart sustainability to water resources of the area.

5.2 Water Resources of the Study Area

Groundwater together with the surface water constitutes the water resource of an area. Availability of groundwater resources at any point of time is either in dynamic or static form. The dynamic part of the groundwater resource is one which fluctuates with annual recharge through precipitation and other sources and the discharge through withdrawal of groundwater resources to meet the demand of agriculture, domestic and industrial needs besides the losses through evaporation and seepages through springs and subsurface flow. Whereas, the static resource is the one which occurs below the depth of annual fluctuation of the water table due to recharge and discharge (Raju, 1997). The surface water is always in dynamic equilibrium with the surroundings.

5.3 Precipitation

The rainfall as a function of recharge and surface storage plays an important role in overall budget of the water resource of any area. The distribution of rainfall and its variation on annual basis are utilized in an overall water resource assessment of the area in time and space.

Rainfall is prime source of recharge and it varies in space and time. The vagaries of climate put stress on natural resources as at time unprecedented rainfall leads to water logging, flash flood, depletion in recharge and enhanced runoff while dry spell put stresses on groundwater table.

The study area receives rainfall due to SW monsoon and is limited to the period between June to September. The period is further extended upto November month due to retreating monsoon. The rainfall data for 42 years i.e. from 1961 to 2003 from 18 rain gauge stations located within the study area have been used. Summation of average annual rainfall for different stations is given in Annexure-5.1. From rainfall data analyses following constraint were observed.

- There are 18 stations corresponding to 17 different talukas except for Kevadia colony.
- For few stations rainfall data are missing (for e.g. Waghodia (1967), Sankheda (1961, 1969-71 etc.) Therefore, while analyzing rainfall input, these missing years have been omitted.
- For computing rainfall in the study area dependable average annual rainfall has been taken for all the stations.

The average rainfall for the study area stands at 858.99 mm (Fig-5.1). The mean annual rainfall gradually increases from west to the east which can be observed in the isohyetal map of the study area (Fig-5.2). The highest rainfall recorded in the study area is at Savli station in the year 1976 with 2688.7 mm precipitation and lowest was recorded during 1968 with 101 mm at Kawant station.

The graphical representation of rainfall observed at an individual station is not convenient for understanding the rainfall trend as there exists considerable variation in the rainfall values leading to rapid changes in the plot (Subramanya, 2008). Therefore, from rainfall time series the high frequency fluctuations were smoothened out with a view to observe a definite trend, three years moving average has been plotted and mean annual rainfall for the study area has been obtained. (Fig -5.3).

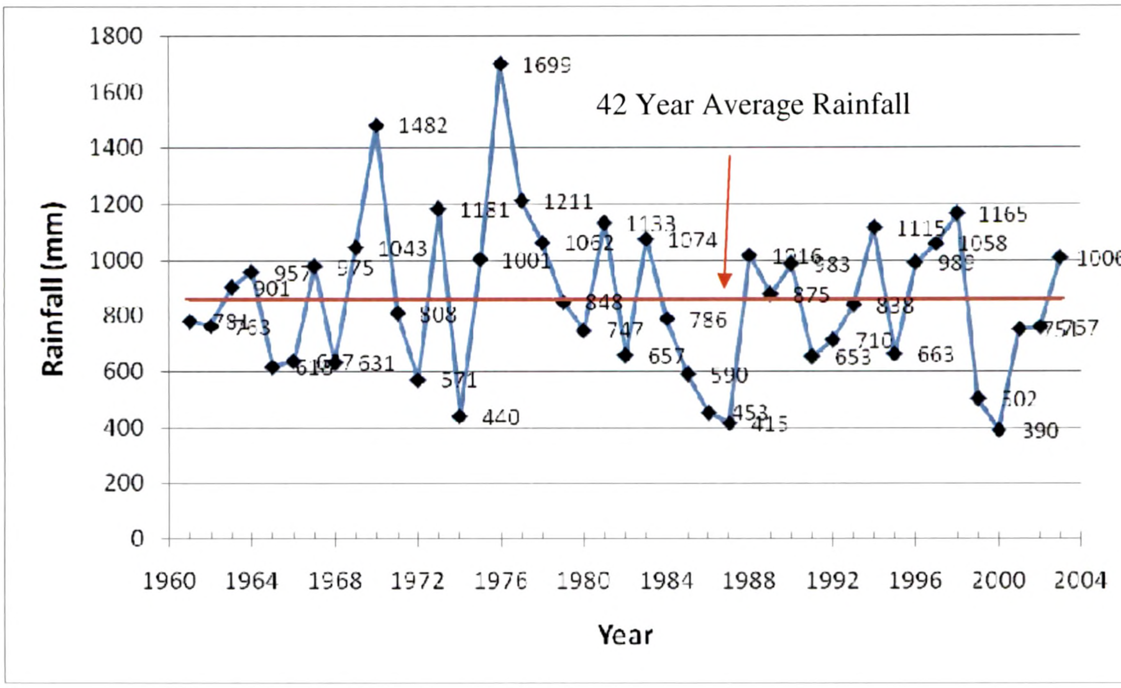


Fig- 5.1 Average Annual Rainfall Distribution Pattern in the Study Area

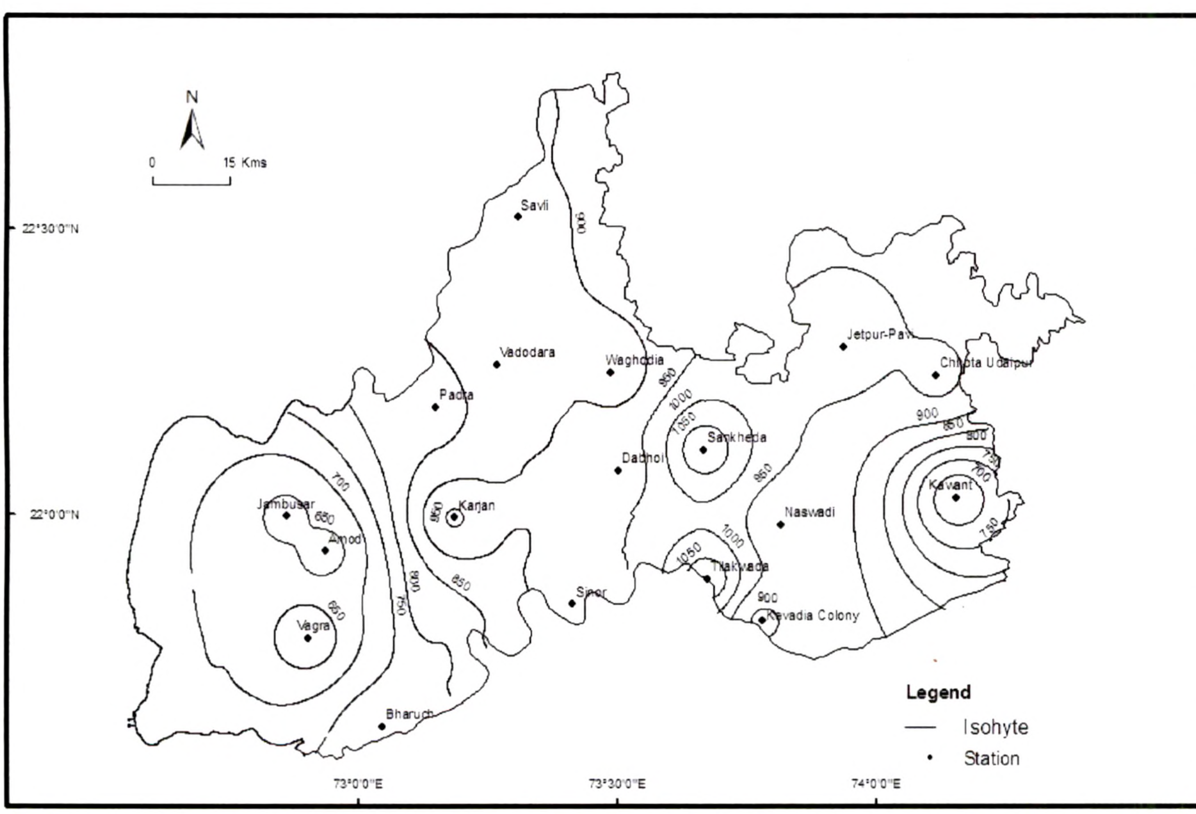


Fig-5.2 Isohytel Map of Mahi-Narmada Interstream Area.

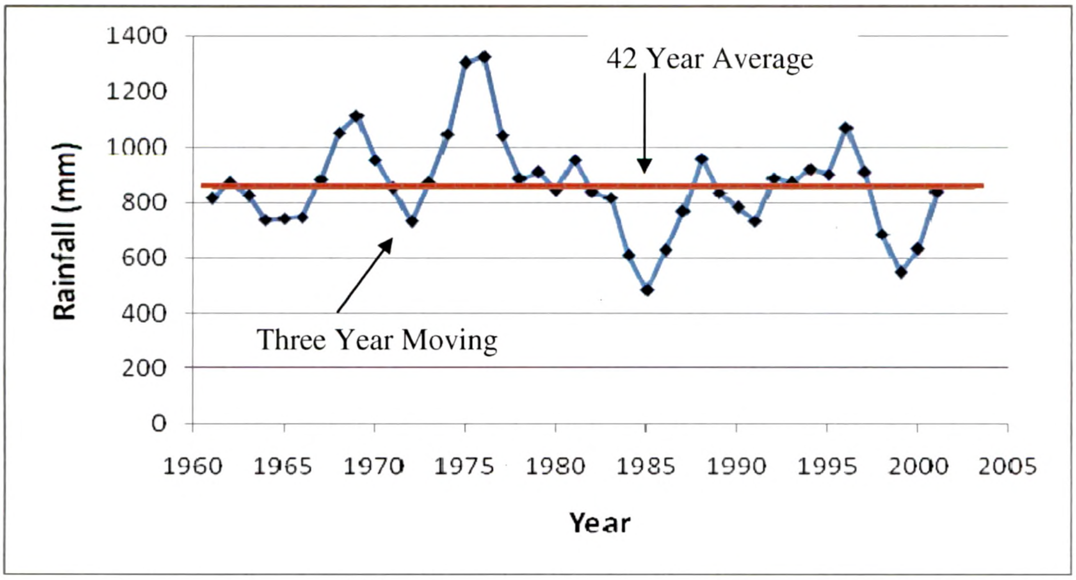


Fig- 5.3 Rainfall Hydrograph of The Study Area Based on Three Year Moving Mean

An average yearly data from the last 42 years i.e. from 1961 to 2003 has been used for computational purpose. The stations selected are uniformly distributed in the study area and provides representative values. The average maximum rainfall for the study area comes out to be 1699.50mm while lowest is 389.79mm. The coefficient of variation (C_V) which is a measure of variability of rainfall comes out to be 32.35% while standard deviation is 27.8. Departure and cumulative departure from the mean annual rainfall for the different rainfall station is given in Annexure-5.2.

Probability of exceedence of rainfall at particular percentage has been computed for all eighteen stations using Weibull formula (Subramanya, 2008), which is widely accepted and practiced. The exceedence probability of the event obtained by this empirical method is called Plotting Position. From probability (P) recurrence interval (T) has been calculated (Table-5.1), then the variation of the rainfall magnitude is plotted against the corresponding T on semi-log scale (Fig-5.4).

Table-5.1 Calculation of Return Period.

Rank (m)	Annual Rainfall (cm)	Probability =m/(N+1)	Return Period T=1/P (Years)
1	170	0.023	44.000
2	148	0.045	22.000
3	121	0.068	14.667
4	118	0.091	11.000
5	117	0.114	8.800
6	113	0.136	7.333
7	111	0.159	6.286
8	107	0.182	5.500
9	106	0.205	4.889
10	106	0.227	4.400
11	104	0.250	4.000
12	102	0.273	3.667
13	101	0.295	3.385
14	100	0.318	3.143
15	99	0.341	2.933
16	98	0.364	2.750
17	98	0.386	2.588
18	96	0.409	2.444
19	90	0.432	2.316
20	88	0.455	2.200
21	85	0.477	2.095
22	84	0.500	2.000
23	81	0.523	1.913
24	79	0.545	1.833
25	78	0.568	1.760
26	76	0.591	1.692
27	76	0.614	1.630
28	75	0.636	1.571
29	75	0.659	1.517
30	71	0.682	1.467
31	66	0.705	1.419
32	66	0.727	1.375
33	65	0.750	1.333
34	64	0.773	1.294
35	63	0.795	1.257
36	62	0.818	1.222
37	59	0.841	1.189
38	57	0.864	1.158
39	50	0.886	1.128
40	45	0.909	1.100
41	44	0.932	1.073
42	41	0.955	1.048
43	39	0.977	1.023

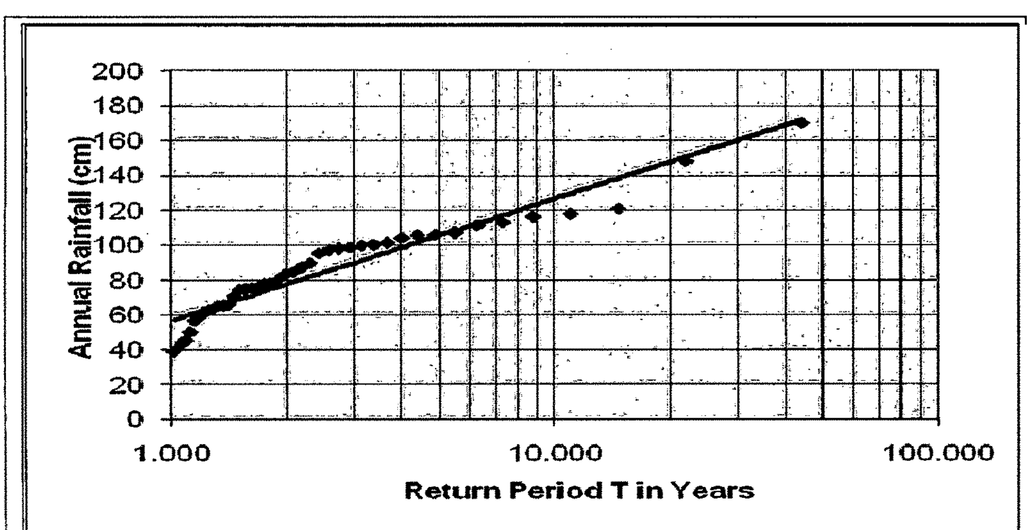


Fig-5.4 Return Periods of Annual Rainfall In The Study Area.

In the study area the observed highest average rainfall in last 42 years is 1720mm and rainfall probability of this magnitude is expected to occur once in 44 years. While in every 3 years the area receives rainfall above 1000mm. The 75% dependable annual rainfall is (the value of annual rainfall at the station that can be expected to be equal or exceed 75% times) i.e. 653mm./1.33 years.

5.4 Surface water Resources

Prima facie the study area constitutes an interstream region of two perennial river systems the Mahi and Narmada Rivers. Therefore, it shows significant prospect of surface water resource. Other tributary streams of these two mega fluvial system although ephemeral in nature, they maintain good base flow up to November-December months that subsists the irrigation needs of the study area to an extent. Noteworthy tributary streams viz. Heran, Orsang and Dhadhar by and large covers almost 60% of the study area.

The major surface water irrigation potential in the study area is created through Sardar Sarovar Project. The construction of Narmada dam at Navagam has created 1,79,2000 ha of irrigation potential out of 4,45,726 ha (i.e. 24.8-% of total potential) is being utilized in the study area (SSNNL, Gandhinagar).

Apart from river water there are some major and minor irrigation schemes in the study area. These irrigation tanks are mainly present in the Vadodara district while the western part of the study area covering four coastal talukas of the Bharuch district are devoid of it. A few minor irrigation tanks of the Vadodara district along with water capacities are listed in Table-5.2

5.5 Groundwater Potential and its Assessment

The availability of groundwater as free water for extraction purpose is in dynamic equilibrium with the natural system within which it is confined. Some important characteristic features influencing groundwater potential assessment of the study area are as under:-

- There are many perennial and non perennial rivers like Mahi, Narmada, Dhadhar and Orsang and Heran along with their tributaries and sub tributaries draining the study area with regional/general slope towards the west. Majority of rivers in its lower reaches display influent character there by feeding its resource to groundwater regime.

Table-5.2 List of Major and Minor Irrigation Tank in the Study Area.

Sr No.	Name	Taluka	Irrigation Potential in 'Ha'	Surface water Volume (MCM)
1	Dhanora	Savli	506	5.06
2	Muval	Savli	541	5.41
3	Subhelav	Savli	116	1.16
4	Javla	Savli	209	2.09
5	Vadadala	Savli	405	4.05
6	Karachia	Savli	486	4.86
7	Haripura	Savli	157	1.57
8	Manopura	Savli	295	2.95
9	Sarsi	Savli	162	1.62
10	Wadhwana (Major)	Waghodia	1400	14
11	Shreeportimbi	Waghodia	735	7.35
12	Vesania	Waghodia	95	0.95
13	Sarvan	Waghodia	109	1.09
14	Kotambi	Waghodia	77	0.77
15	Jambuvai	Waghodia	100	1.00
16	Dudelav	Waghodia	58	0.58
17	Jarod	Waghodia	72	0.72
18	Raval	Waghodia	78	0.78
19	Dharola	Waghodia	178	1.78
20	Amalwant	Kawant	1129	11.29
21	Singla	Chhotaudepur	121	1.21
22	Zer	Chhotaudepur	650	6.50
23	Jamli	Chhotaudepur	485	4.85
24	Harwant	Chhotaudepur	326	3.26
25	Nalej	Chhotaudepur	472	4.72
26	Lindatekra	Chhotaudepur	163	1.63
27	Dhaniawala	Naswadi	345	3.45
28	Kundanpur	Naswadi	124	1.24
29	Kandi	Jetpurpavi	384	3.84
30	Raipur	Jetpurpavi	20	0.20
31	Bhabhar	Jetpurpavi	232	2.32
32	Jogpura	Jetpurpavi	418	4.18
Grand Total			**10600**	**106**

(Source: C.D.O, Govt. of Gujarat, Gandhinagar)

- Eastern parts of the study area are dominated by rocky highlands while central and western parts are under alluvium cover. Aquifers have diverse hydraulic properties and therefore, behave independently in areas covered by the consolidated and unconsolidated formations. Moreover, in alluvial tracks there are multiple aquifers and some of them are in hydraulic connectivity with each other.

- The groundwater recharge factor in the study area varies from place to place due to varying land use pattern, geological and geomorphological setup, and infiltration capacity of top soil.

- Estimation of groundwater draft from various means is a difficult task due to lack of up to date information.

- The study inhibits large no. of surface water bodies. Lack of information on their dimensional parameter or storage capacity (particularly village ponds), incipient recharge estimation is difficult.

- The central and western parts of the study area falls in Narmada Canal Irrigation Phase-1 Scheme and incipient leakage and return inflow from agricultural fields needs to be incorporated to derive realistic value of recharge to the groundwater system.

- The agricultural practice in the study area varies from east to west. In the eastern rocky upland region due to non availability of water during post monsoon period, agriculture practice is uncommon. Whereas in the central part and to some extent western part (except coastal tract) cultivation during Rabi (non-monsoon) period is common. Therefore, lack of crop pattern data makes difficult in allocating return irrigation seepage inputs and transpiration losses.

- The built up area/urban sprawl in the study part decreases the infiltration capacity of the alluvium.

- The presence of Gulf of Cambay has its impact on groundwater dynamics of the study area and invites problems of hydraulic reversals during tidal ingress.

- The eastern part displays wide variation in the depth and lateral extent of zone of weathering i.e. phreatic aquifers extent greatly influence the rate of recharge.

- Wide variation in the composition and extent of phreatophytes within the study area in different terrain conditions and elevations effects the computation of transpiration losses which itself is a complex system (Tiwari, 1986).

5.6 Temporal Behaviour of Groundwater Levels

Study of seasonal behaviour of water table gives insight to examine aquifers response to groundwater recharge and utilization, a key factor of groundwater management. Groundwater storage is affected by rainfall recharge, incipient recharge from irrigation field and seepage from canal losses. Whereas groundwater draft, evaporation and subsurface flow are the key players in overall decline in the storage.

In case of study area water levels from the year 1993-2003 for nearly 76 wells have been studied for it's pre and post monsoon fluctuations (Annexure-5.3). The fluctuation values were compared with the corresponding rainfall to deduce the sensitivity of the aquifer to rainfall. As the recharge to the aquifers is rainfall dependent, overall water levels are lowest in the month of May (Pre-monsoon) whereas higher in November (Post-monsoon). Further, the rainfall begins in the month of June and maximum water level is acquired in October, thereby infiltration is by and large poor especially in alluvium area. In order to develop clear understanding of seasonal behavior of water levels for litho-specific aquifers, the author has constructed observation well hydrographs by considering 1993-2003 pre and post monsoon water levels (Fig-5.5). Almost all well hydrographs show strong correlation with the rainfall input.

5.7 Water Table Fluctuation in Relation to Geo-environment

5.7.1 (a)Coastal Plains:

The coastal plains are consists of thick pile of alluvium material comprising high percentage of clay sediments. Due to inherent salinity the groundwater at all depths is saline therefore; the stress on groundwater extraction is more on few shallow aquifers which are potable. Analysis of nine tube wells for last one decade in coastal area indicates that the ground water levels in the coastal plains is at shallow depth which may be attributed to its geological conditions, land use pattern and salinity problem. The average decadal pre-monsoon level is 10.8m while post-monsoon level comes out to be 8.6m with a positive average rise of 2.2m in storage having standard deviation of 1.2. Well hydrographs of Tankaria (Fig-5.5a) and Bhadkhodra (Fig5.5b) villages indicates that during year 1999 & 2000 because of poor monsoon sudden decline in groundwater levels has been observed. During the year 1998 rise in groundwater level has been observed in almost all villages which is mainly due to good rainfall in that year. The average coastal rainfall for the year 1998 stand at 985mm with Bharuch receiving the highest rainfall of 1760mm in the last 42 years. The overall trends of hydrographs in most of the coastal villages indicate a declining groundwater levels (Fig-5.5 c & d). Further, in pre-monsoon deepest water level at 18.3m from Amod village (Taluka Amod) while shallow level in post-monsoon from Tankaria, village (Taluka Jambusar) is noticed.

This overall decline may be attributed to growing demand due to increase in population as well as rapid industrialization of the area.

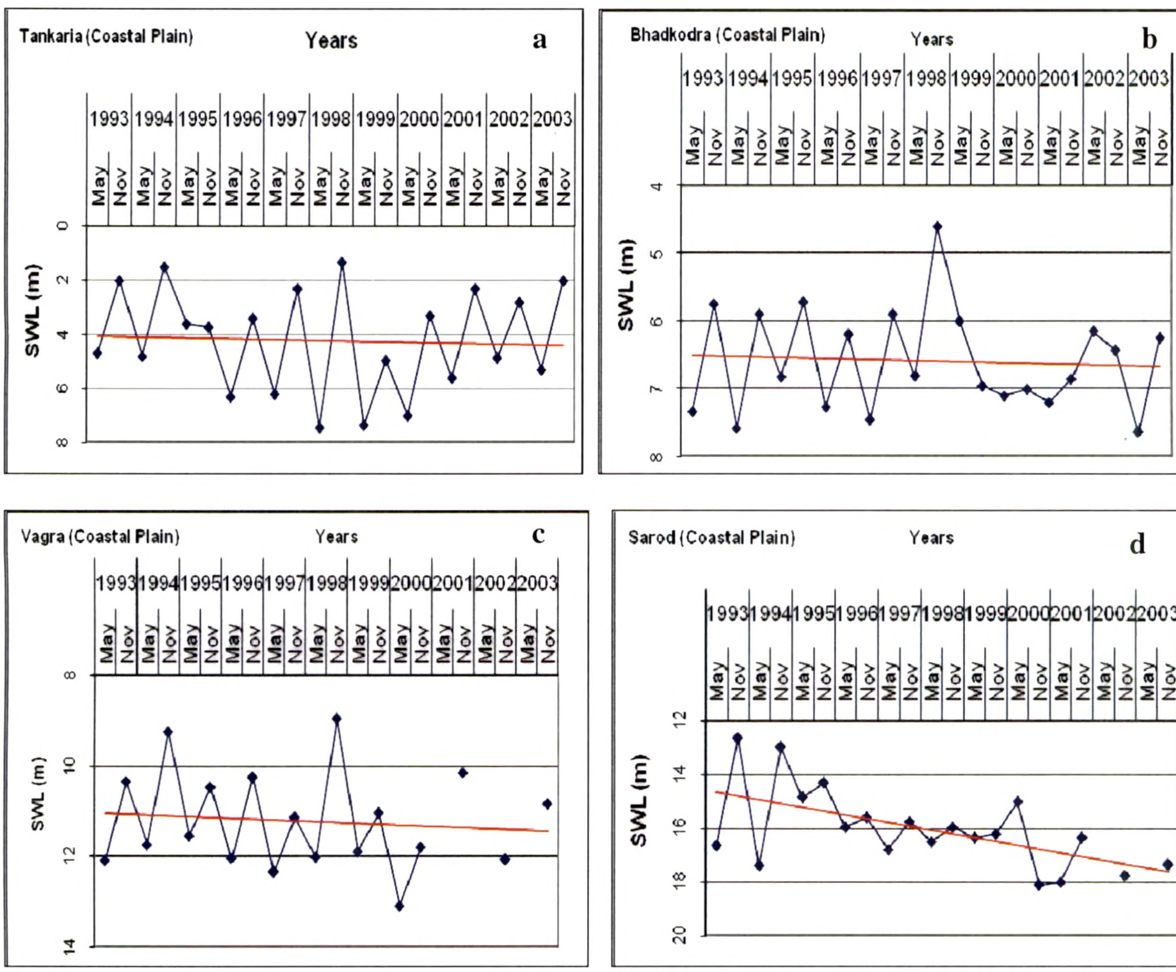


Fig 5.5 Well Hydrographs Showing Temporal Behaviour in Coastal Plains

5.7.2 (b)Alluvial Plains:

The alluvial plains consists of thick pile of flood plain deposits that are extensively been utilized for agricultural purpose. The alluvial plains share large part of the study area. Well hydrographs constructed for 21 tube wells have been studied to evaluate the behavior of groundwater. The selected hydrographs of this area indicates positive trend especially from Atladra (Fig-5.6a), Dharampura(Fig-5.6b), Chansad (5.6 c) and Varnama (Fig 5.6d) villages while negative trend from Sinor of Sinor Taluka (Fig-5.5e) and Chhatral village (Fig-5.6f) has been observed. The year 1998 indicates an overall increase in water levels because of good rainfall. The effect is more conspicuous in both Sinor and Chhatral village. Further, because of lean rainfall in year 1999 & 2000 decline in groundwater levels has been recorded throughout. The average of last one decade indicates that the minimum and maximum pre-monsoon level is 8.05m & 30.11m while that of post-monsoon is 4.48m and 28.22m respectively. Therefore, average decadal fluctuation indicates a minimum of -0.4m while maximum average fluctuation is 11.16m with a standard deviation of 2.28.

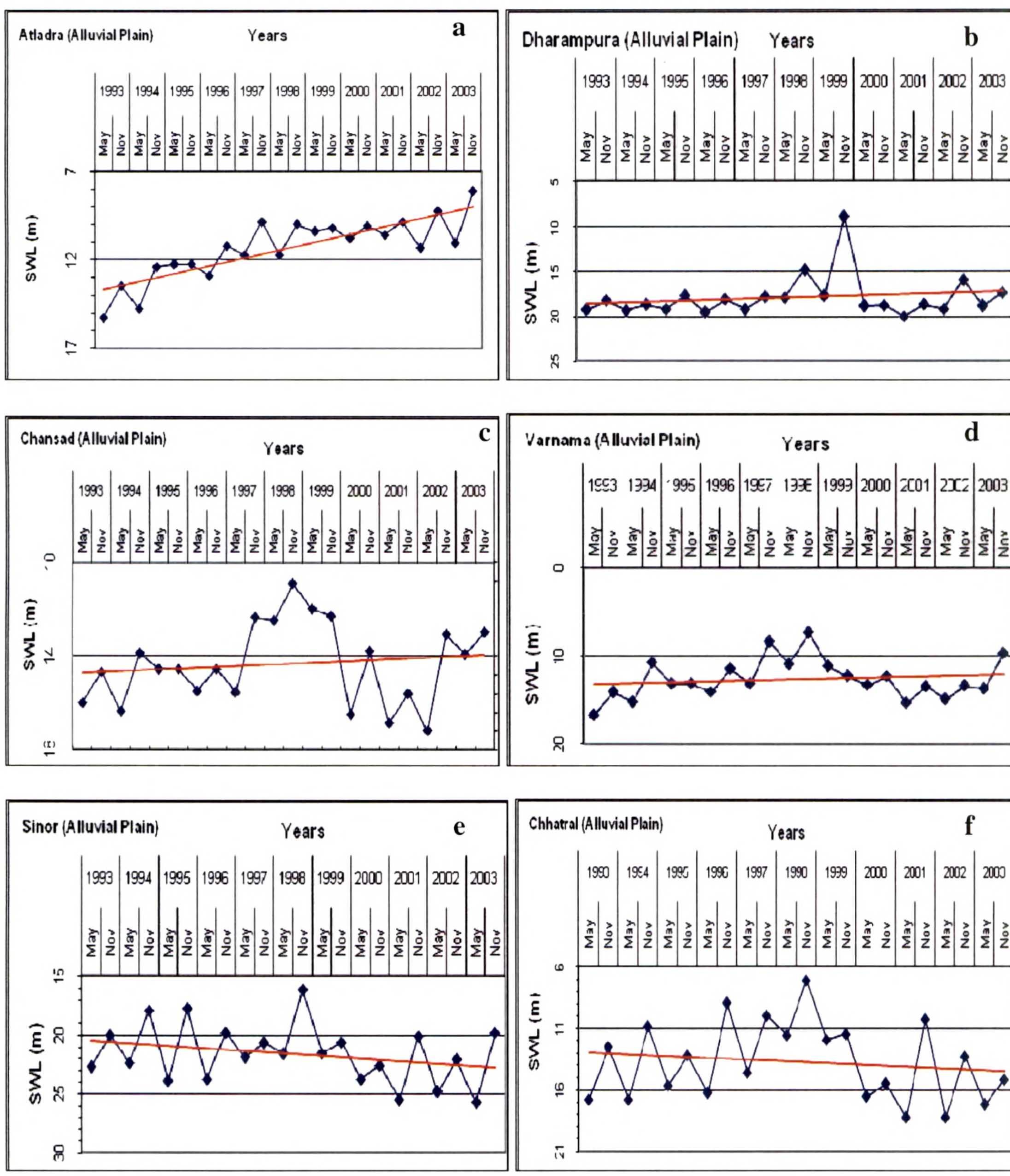


Fig 5.6 Well Hydrographs Showing Temporal Behavior in the Alluvial Plains.

5.7.3(c)Piedmont Zone:

The narrow piedmont zone demarcates transitional strip between highlands on the eastern side to alluvial plains on the western side. The area is dominated by thin veneer of colluvial sediments over the surface and hard rock at shallow depth. From piedmont zone, well hydrographs of 22 bore/tube wells have been studied. Most of them indicate a declining trend over the years but the pattern also indicates that the draft during pre-monsoon period and subsequent recharge in monsoon period is more or less the same. Govindpura (5.7a) and Chindiapura village (5.7b) are the good example that shows consistency in recharge and draft. In the year 2000 and 2001because of poor monsoon the groundwater level has gone down. It is observed that in last ten years average pre-monsoon groundwater level is minimum at 2m and maximum at 19m while during post-monsoon minimum is at 1m and maximum at 18m. The average mean change in water level is 1.94m with a standard deviation of 1.5. Well hydrographs representing Vadadiya, Alladpur (5.7c&d) villages belong to this geomorphic unit.

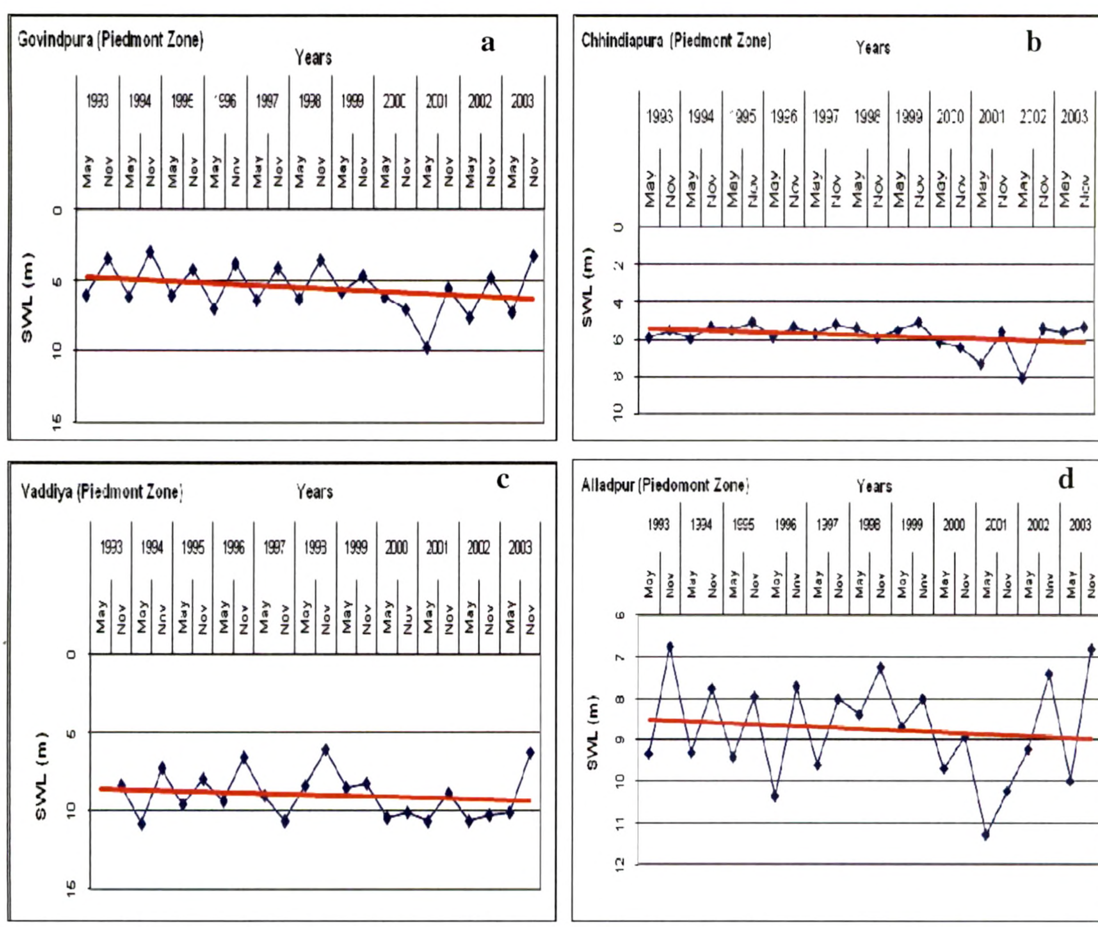


Fig 5.7 Well Hydrographs Showing Temporal Behavior in the Piedmont Zone.

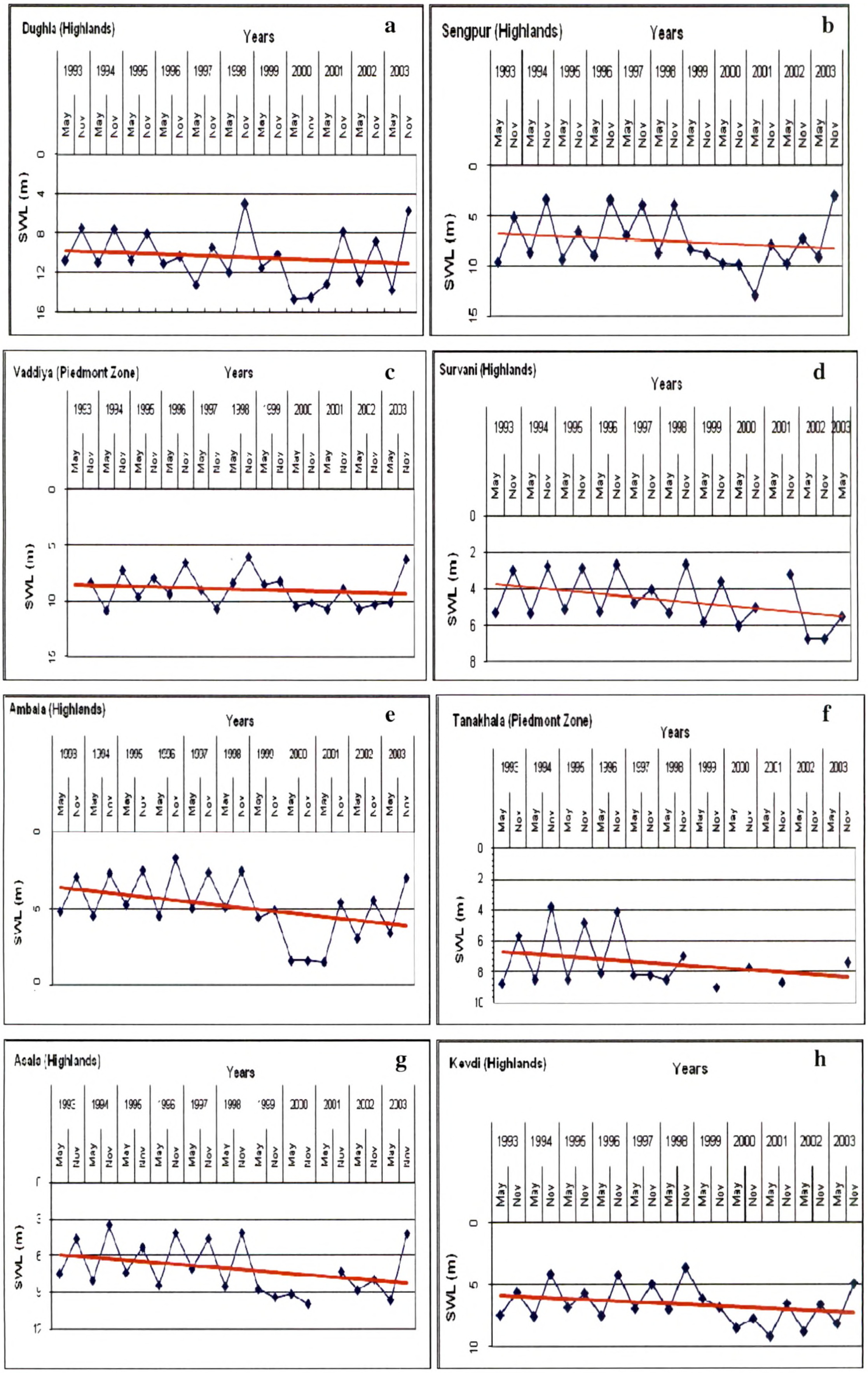
5.7.4 (d)The Highland Zone:

The eastern highland zone is characterized by hard rock terrain signifying less population, sporadic settlements and patchy agricultural land compared to alluvial plains of the study area. In all 23 well hydrographs have been studied. The hydrographs evaluation on decadal average pre-monsoon minimum and maximum stand at 4.7m and 12.55m respectively while that of post-monsoon is 3.5 and 10.8m respectively. The net average change in storage is 2.5m with a standard deviation of 1.1m. The various hydrographs of this zone suggests an overall declining trend in most of the areas (Fig 5.8 a & b).

The two hydrographs for the basaltic aquifers viz. Vadala (Savli Taluka) and Survani (Nandod Taluka) indicates declining trend in water levels (Fig-5.8c& d). At Vadala during the year 1995 because of lean rainfall (541mm) decline in water table (11.42m) has been observed resulting with +0.44m of net change in storage. Moreover, in Survani village during lean rainfall in the year 1999 (625mm) & 2000 (405mm) decline in water table of 3.5m has been observed.

In dolomite and limestone aquifer at Ambala village the well hydrographs suggests an overall declining trend (Fig 5.8e). The continuous lean rainfall observed during the year 1999 and 2000 produced a sharp decline in ground water levels that has been bounced back after receiving good rainfall during subsequent years. Similarly the sandstone aquifers in Tanakhala village (Fig 5.8f) shows average pre-monsoon decline of 8.42m and post-monsoon rise of 6.63m thereby suggesting average rise of 1.8m.

Well hydrographs of the aquifers developed within the gneissic rocks viz. Asala and Kevdi (Chottaudepur Taluka) villages (Fig 5.8g & h) indicates shallow groundwater levels. However, they are characterized by high level seasonal fluctuation. They show sharp decline in water levels at times even below the level of pre-monsoon season. Similar seasonal fluctuation trends have been observed in the aquifers composed of phyllite, slate and schist etc. at the localities viz. Bar and Gorej villages (Fig 5.i& j). The average pre and post monsoon water level is 10.33 and 6.36m.


Dughla (Highlands)
Years
a
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SWL (m)
Survani (Highlands)
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d
SWL (m)
Ambala (Highlands)
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e
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Tanakhala (Piedmont Zone)
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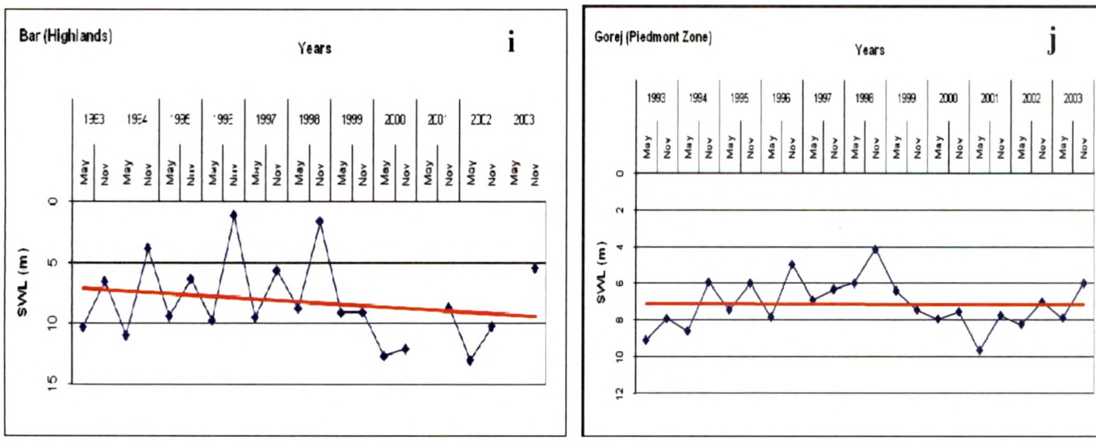

Fig-5.8 (a-j) Well Hydrographs Showing Temporal Behavior in Highland Zone and also in different formations.

5.8 Spatial Behavior of Ground Water Table

The spatial distribution and behavior of groundwater table is governed by a variety of attributes viz. nature and composition of aquifer; lateral continuity of the aquifers; ground slope; rainfall input as a function of recharge and groundwater utilization.

The reduced water Level (RWL) are duly corrected values with reference to datum plane i.e. Mean Sea Level (MSL). Therefore, it facilitates in analyzing the spatial behaviour of groundwater with the changing patterns of landscape. The RWL gradient and movement direction contour patterns are also helpful in deriving the various sub-surface controls through which the groundwater flows.

The reduced water level contours map of the study area shows a strong control exercised by the topography and litho-structural parameters. Physiographically the hilly zone is characterized by steep slopes and hard rock terrain comprised of Precambrian crystalline and Deccan Traps. Therefore, the RWL contours around Vagudan and Chhinddapura villages show circular patterns and radial flow (Fig 5.9). The narrow pediment zone followed by alluvium plain and coastal plain westward are characterized by unconsolidated sediments and the contour show progressive flattening indicative of reduction in gradient. Overall characterization on groundwater behaviour is given in Table-5.5.

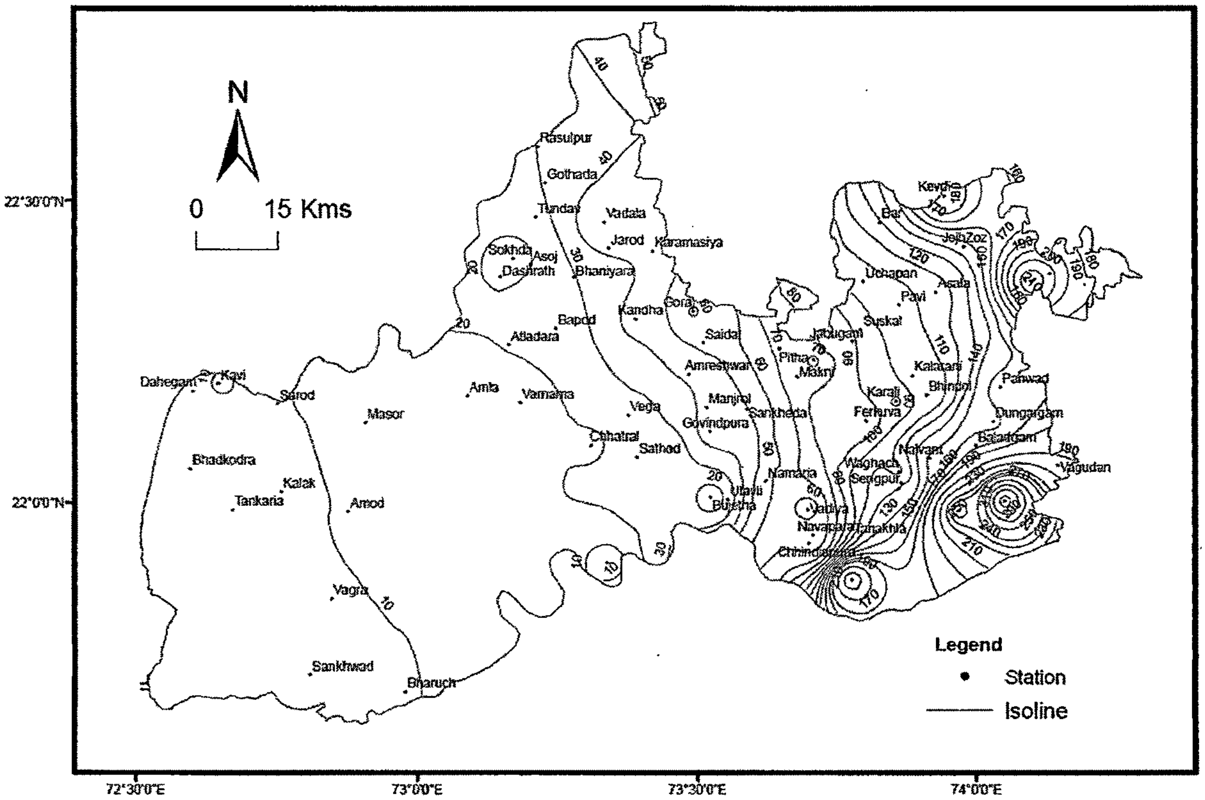

Fig-5.9 Reduced Water Level (Pre-monsoon, 2003) Map of the Study Area.

Table-5.3 . Groundwater Behaviour in Study Area

Sr. No.	Physiographic Zones	Sediment Characteristics	Groundwater Gradient	Groundwater Movement Direction
1	Eastern Hilly Zone	Precambrian Crystalline sedimentary and Deccan Traps	1 : 93 (SE) 1:154 (NE)	NW and WNW
2	Piedmont Zone	Colluviums followed by rock	1:352	WNW, WSW and West
3	Central Alluvium Plain Zone	Unconsolidated flood plain deposits	1 : 653	NW and SW overall Westerly
4	Western Coastal Zone	Unconsolidated mud dominated sediments	1 : 2542	Westerly

The SWL contour map for the year 1993 (Both Pre and Post) indicates that the water level is deepest in central portion while shallower in eastern and western part (Fig 5.10). For three consecutive years i.e. from 1991 to 1993 the rainfall was below normal (Fig 5.1). As a result water table has gone down due to insufficient recharge.

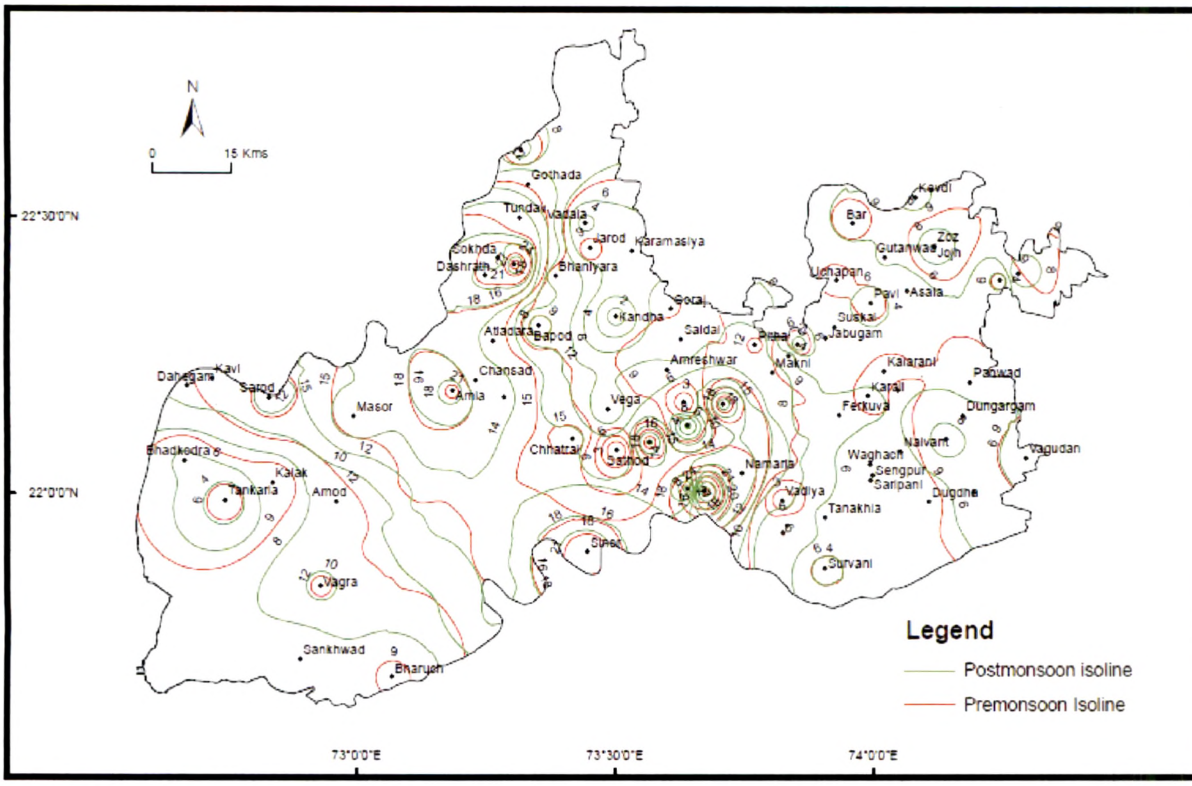

Fig-5.10 Static Water Level Contour Map of the Study Area (Pre & Post monsoon 1993)

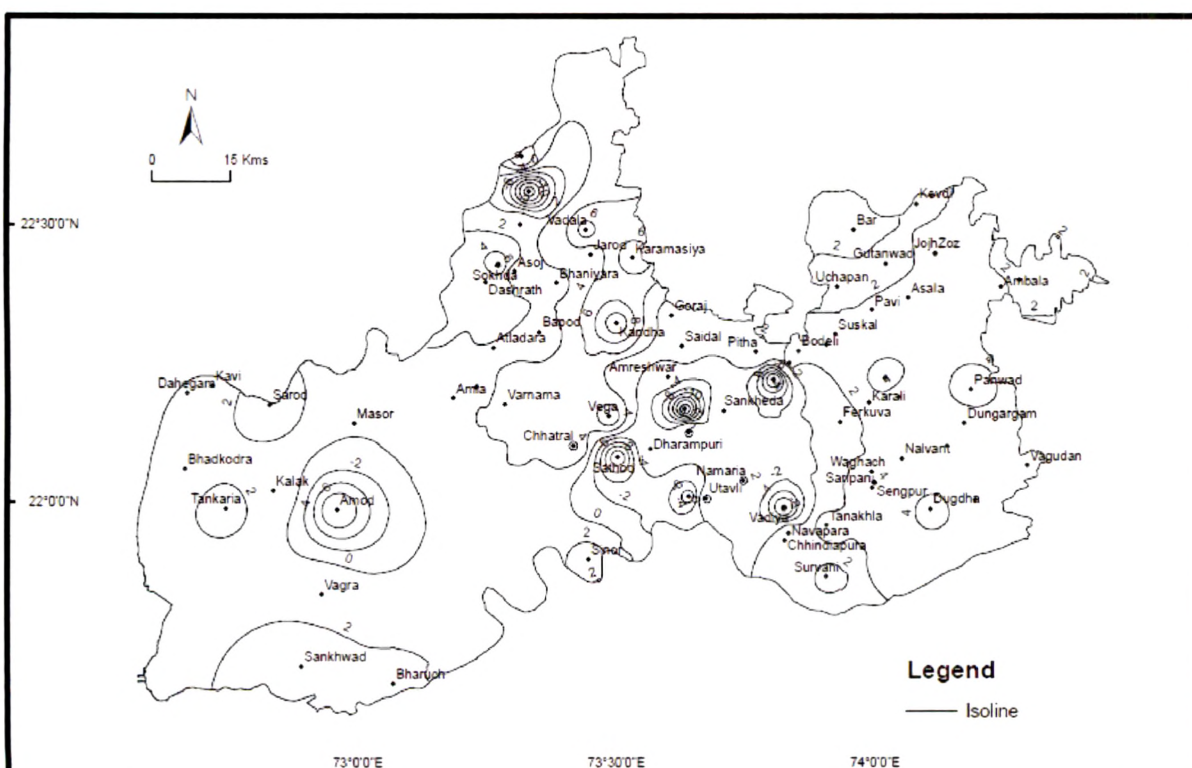

Fig-5.11 Net Annual Change in Groundwater Levels (Year: 1993)

Similarly the SWL contour map for the year 2003 depicts more or less similar trends (Fig 5.12).

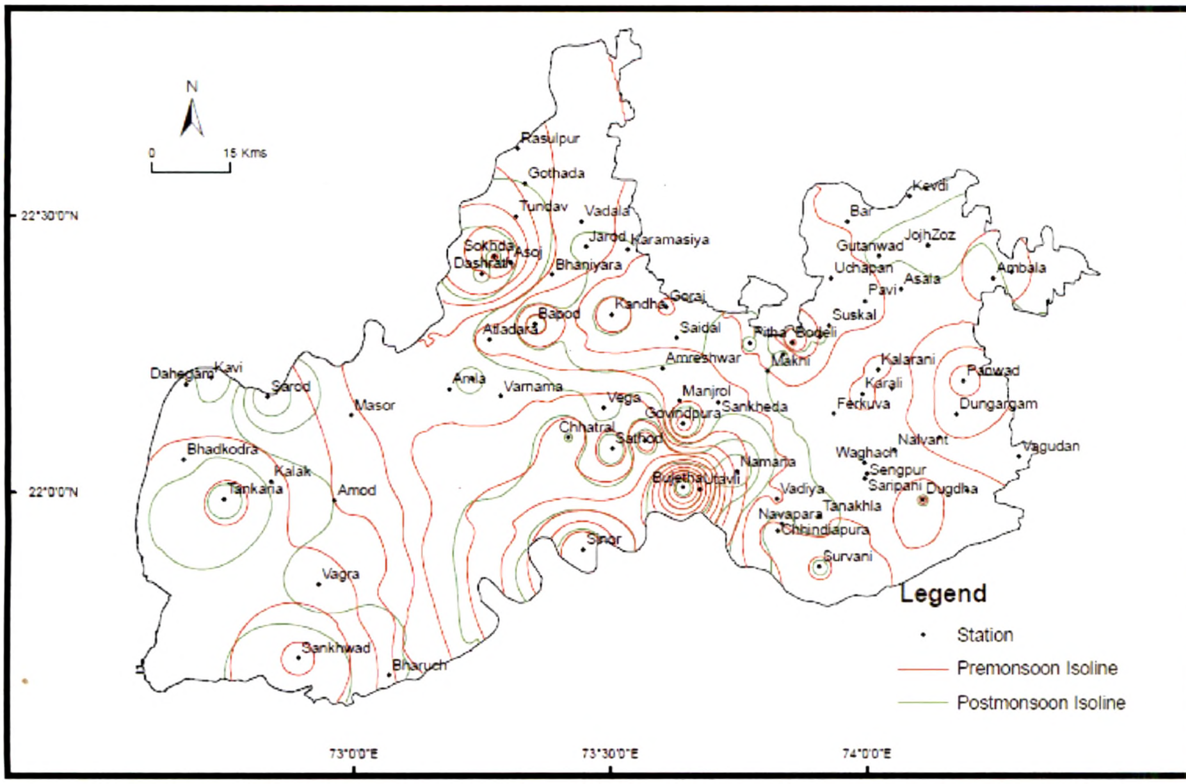

Fig-5.12 Static Water Level Contour Map of the Study Area (Pre & Post monsoon 2003)

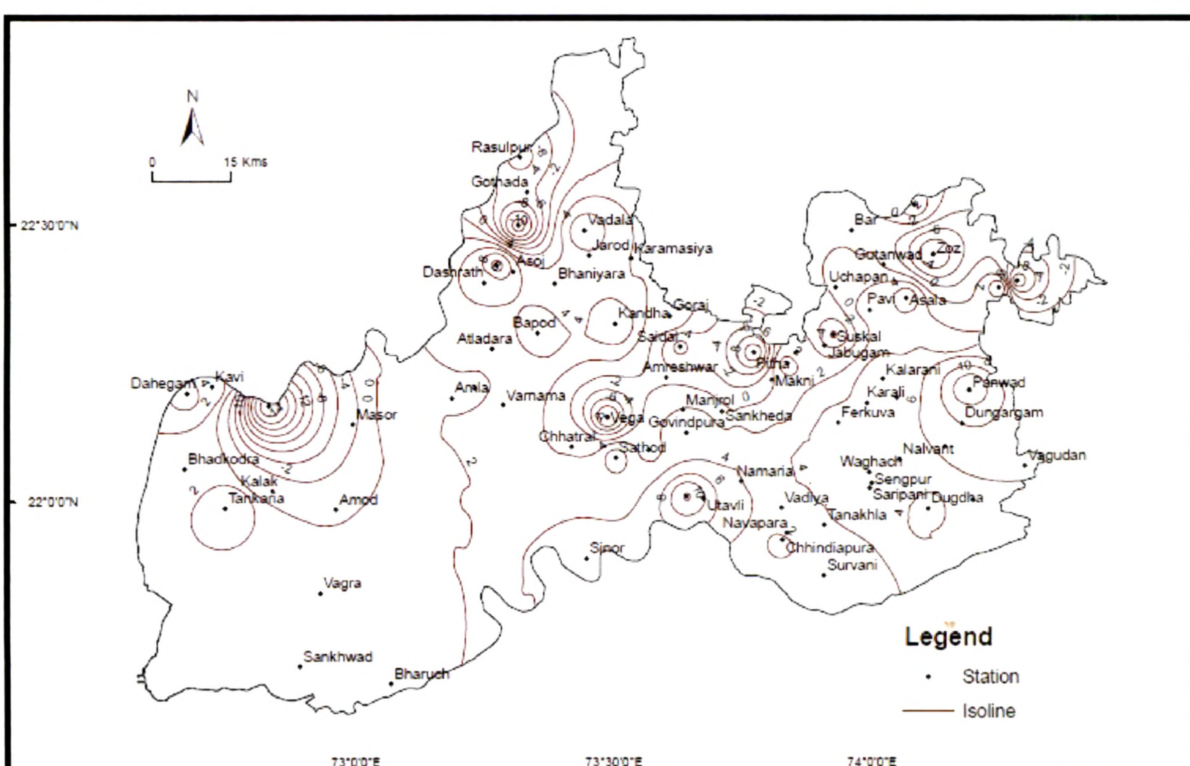

Fig-5.13 Net Annual Change in Groundwater levels (Year: 2003)

The corresponding spatial annual change in groundwater storage maps (Fig.5.11 to 5.13) for the year 1993 and 2003 indicates that the maximum observable change is in the central alluvium plains. The obtained change is in conformation with the decadal change. In this case also rainfall data for the years 1999, 2000, 2001 and 2003 show below normal rainfall wherein minimum rainfall of 390mm was received in 2000 which is lowest rainfall in the last 42 yrs. It is clearly perceived that water table fluctuation is rainfall dependent and water table fluctuation can be co-relatable with the rainfall input (Fig 5. 10). The equation so obtained can broadly be used to calculate net fluctuation at known rainfall.

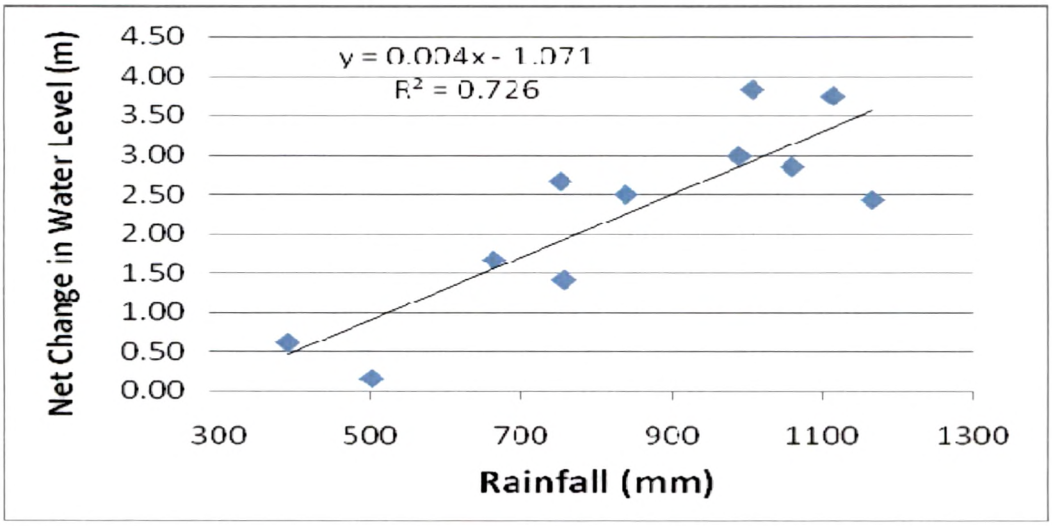

Fig 5.14 Correlation Between Rainfall And Change In Water Level.

The decadal change in water levels of pre and post-monsoon depicts average water level fluctuation is ranging between 0.5 – 3.0m in low lying area whereas 0.5 - 4.5m in high topographic regions. The central part (west of Gorej village) shows maximum positive fluctuation upto 6m. Maximum decline of -3.1m has been observed in Tilakwada Taluka with minor decline in Sankheda and Padra Taluka (Fig 5.15). The observed negative change in Tilakwada and Padra Taluka may be attributed to excessive withdrawal (i.e. Demand > Recharge) attributed to population growth and industrialization of the area. Other areas show normal behavior on groundwater storage and at places show surplus resources.

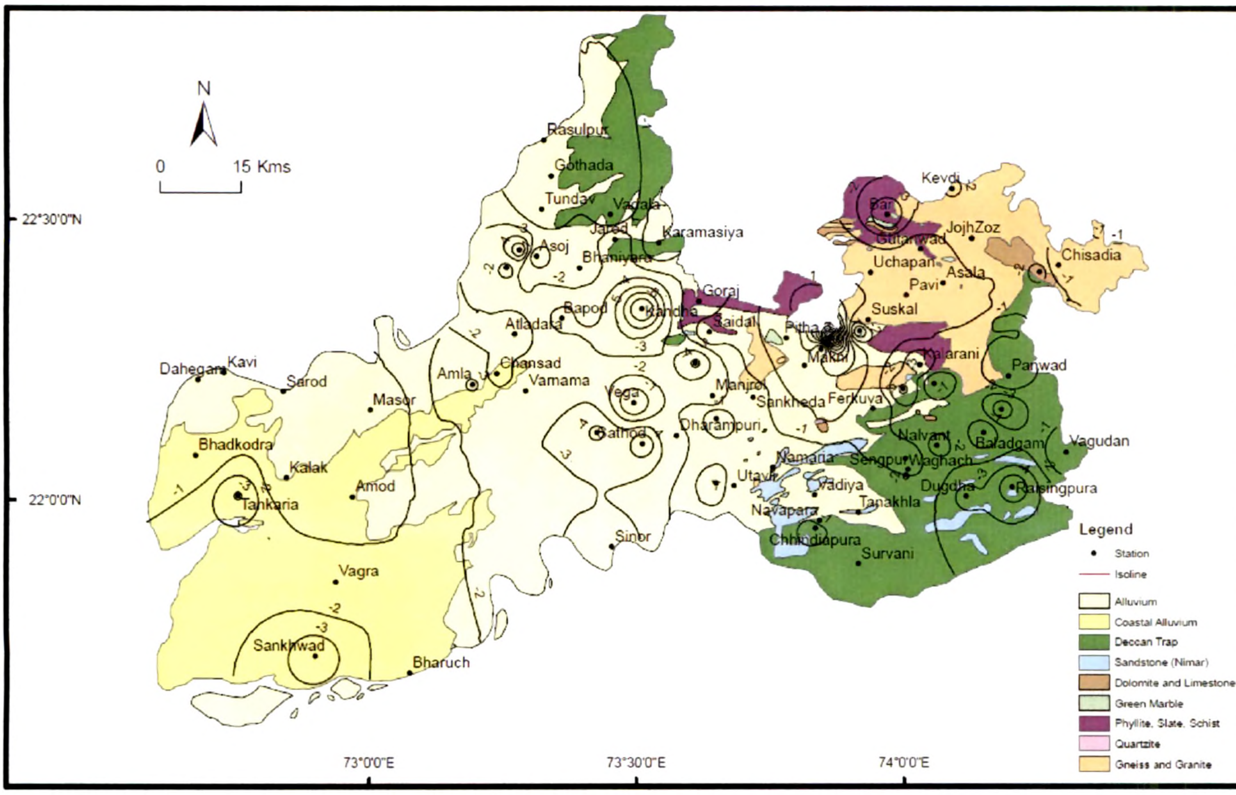

Fig-5.15 Decadal Change in Water Level of the Study Area.

Groundwater reserve scenario has been assessed on 5 yearly basis in the study area and a comparison is made for 1994-1998 and 1999 to 2003, (Fig 5.16 &17.) Broadly SWL contour map shows more or less similar trend with concentric maxima and minima. In coastal plains one concentric minima is visible near Kalak village with an average fluctuation between 3-6m. Similarly in alluvial plains concentric rings of deeper water levels is visible near Tundav village (Savli Taluka) and in Dabhoi and Tilakwada Taluka. The eastern part falling in highland zone shows concentric minima of water level near Baladgam and Zoz village of Chottaudepur Taluka with an average fluctuation of 2m.

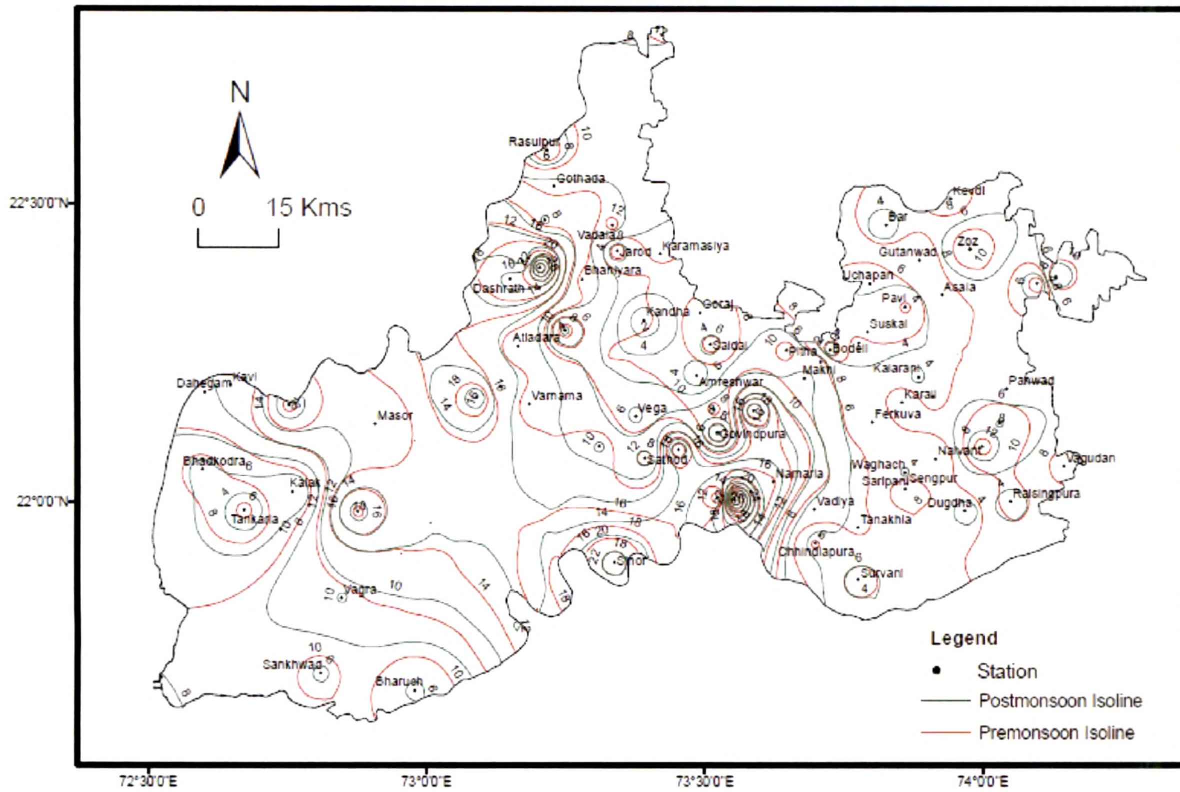

Fig-5.16(a) Average Five Year Water Level Change in Water Level (1994-1998)

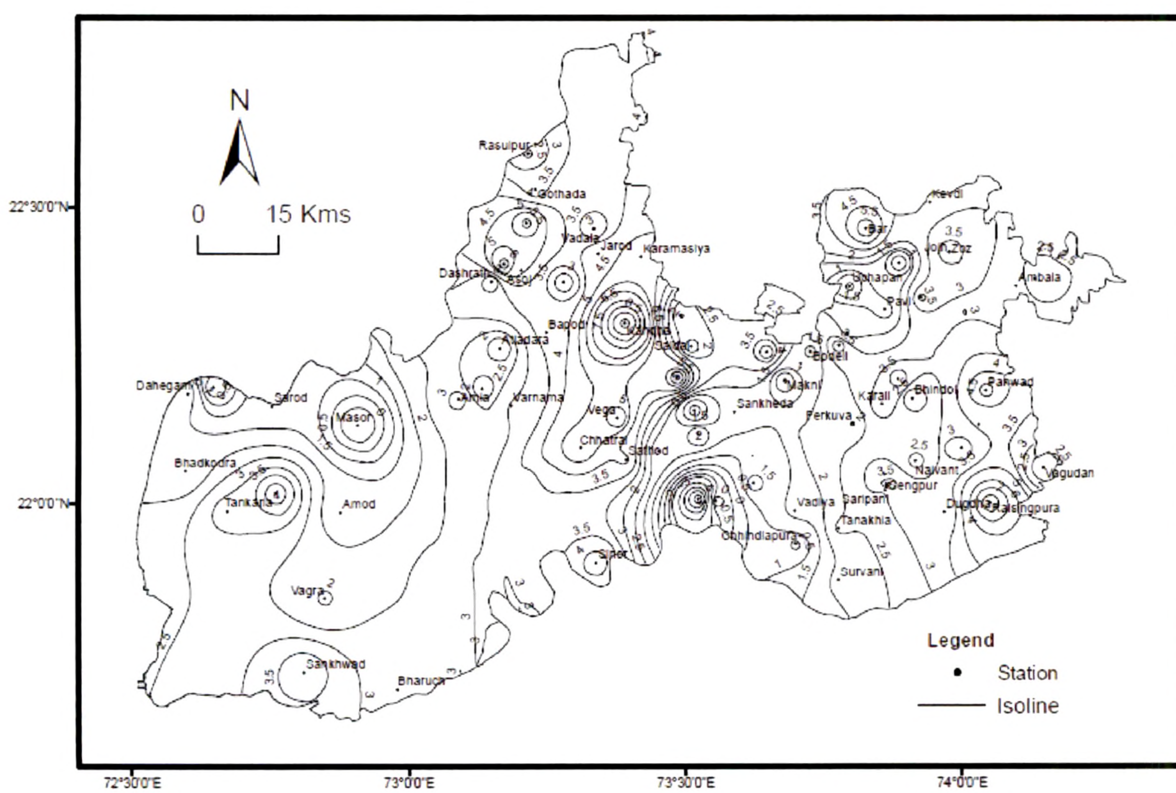

Fig5.16 (b) Spatial Observed Net Change in Groundwater Storage (1994-1998)

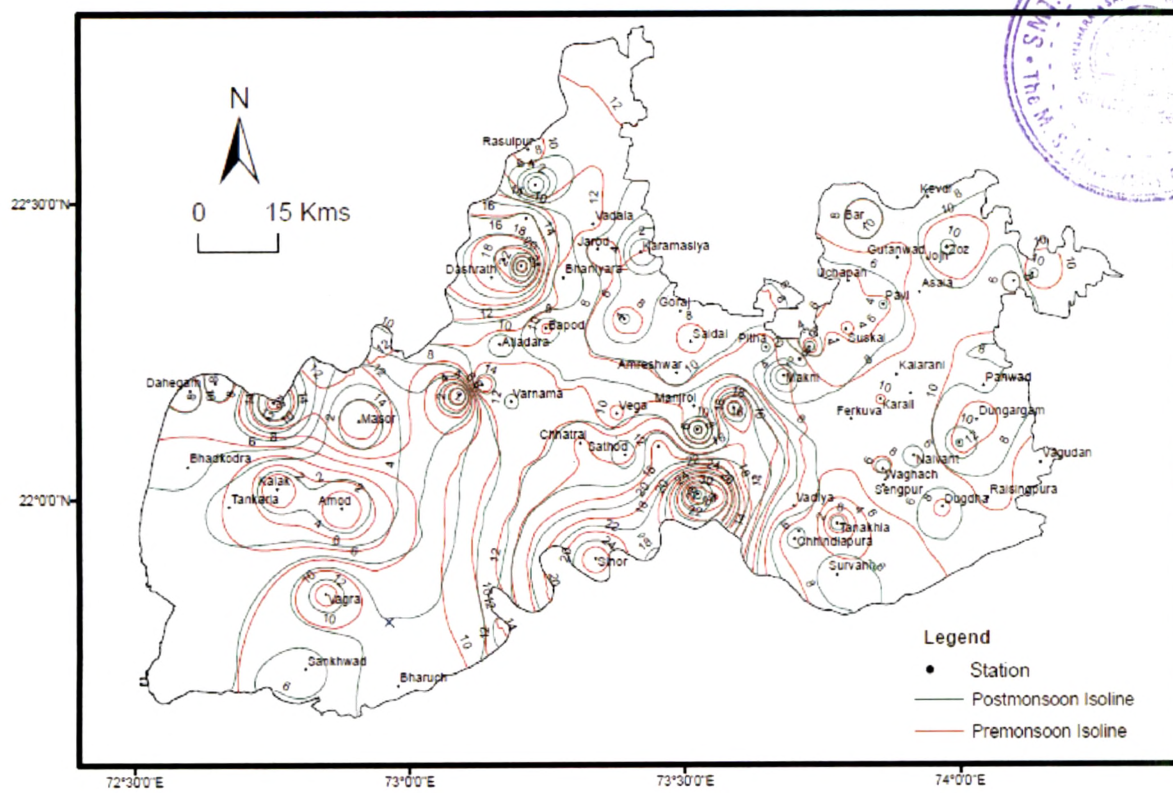

Fig-5.17 (a) Average Five Year Water Level Change in Water Level (1999-2003)

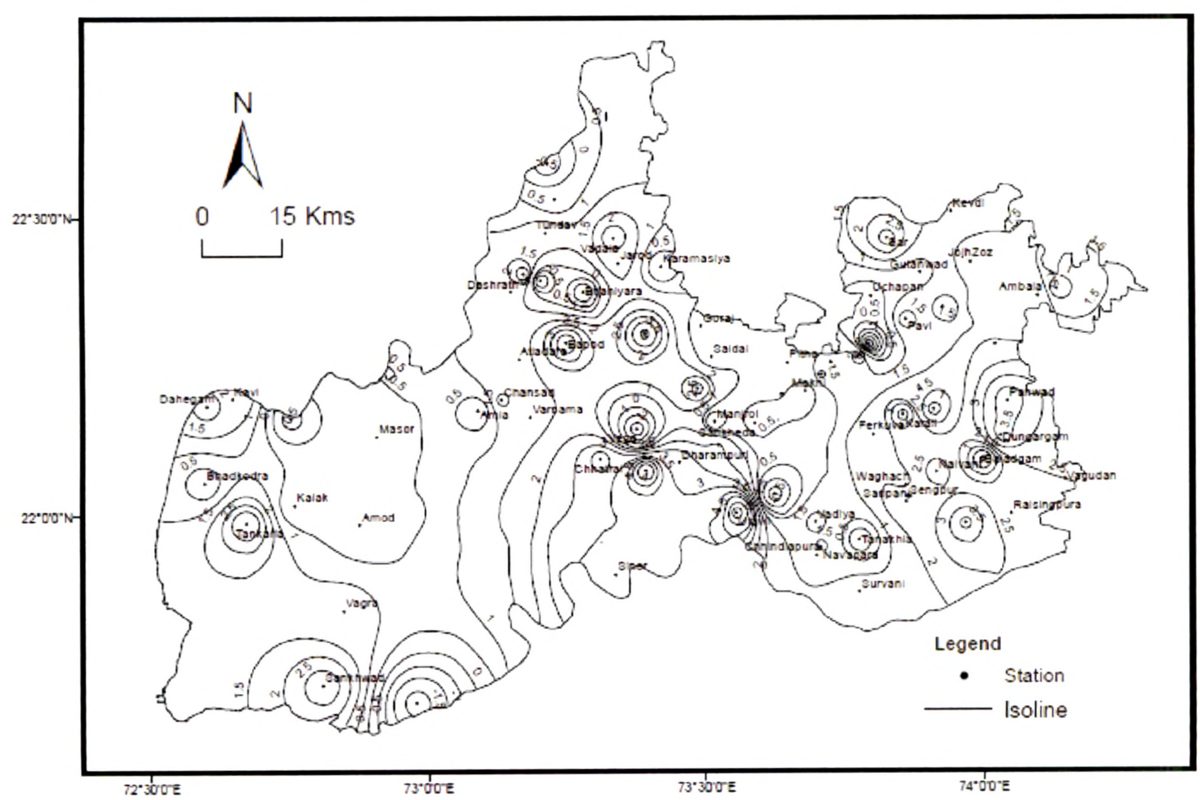

Fig5.17 (b) Spatial Observed Net Change in Groundwater Storage (1999-2003)

5.9 Spatial Groundwater Trend in the Study Area

In order to infer the trend and behavior of water levels across the study area spatial groundwater level profiles have been plotted from coast to highland (E-W). The profile of pre and post monsoon levels (1993 & 2003) together have been plotted to study the level of water table fluctuation. The profile line for both seasons i.e. 1993 and 2003 has kept same as shown in Fig-5.18. This line starts from coastal plains where the demand is more but aquifers both at shallow and deeper depths are saline. The western most part is the rocky highlands where groundwater quality is good but its occurrence is restricted to vadose zone (weathered zone). The net seasonal change in recharge and draft varies along the profile line

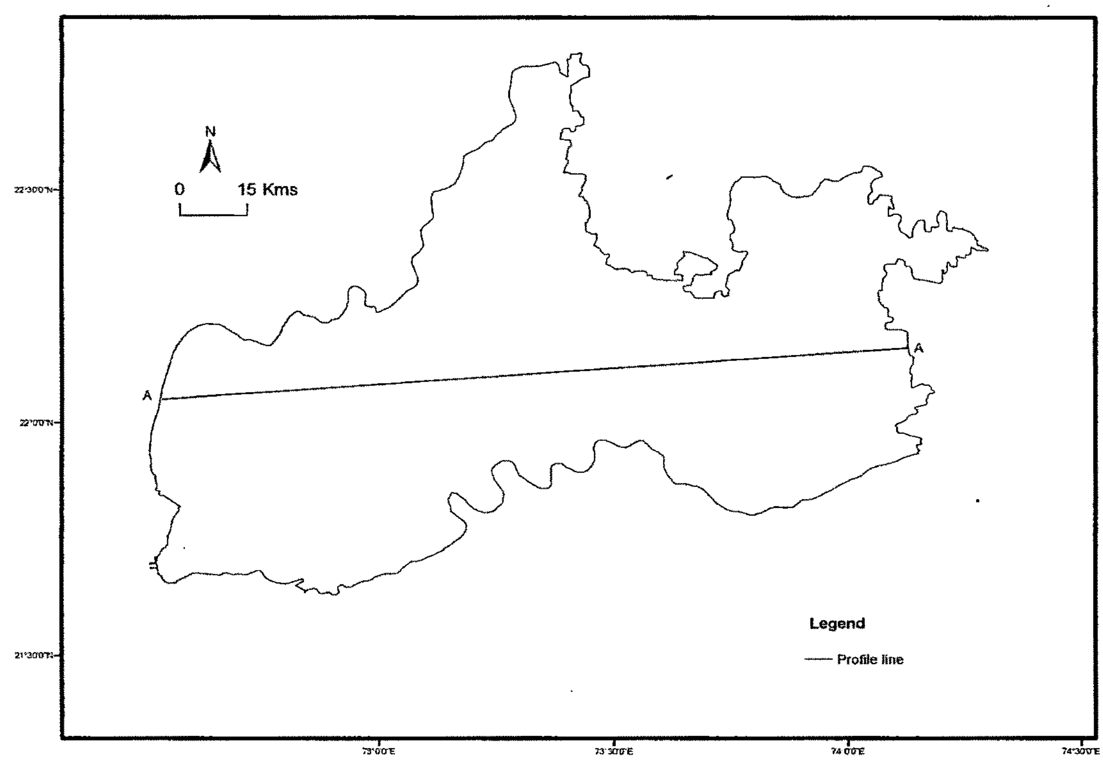

Fig-5.18 Index Map for the Hydrographic Profile from West to East.

The hydrographic profile of 1993 (Fig 5.19) depicts seasonal fluctuation which is maximum (4m) in the central and eastern parts whereas piedmont zone and coastal plain shows minimum change in annual groundwater storage. The hydrographic profile for water level fluctuations of 2003 (Fig 5.20) in the eastern high land zone is very conspicuous and shows almost 10m difference where as other parts of the study area while piedmont zone shows minimum fluctuation. This exceptionally high (10m) observed seasonal change in eastern highland zone may be attributed to below normal rainfall received by the area during 2003, impending less recharge to the groundwater system. Both profiles shows more or less similar trend with shallow level in coastal plains deepest in alluvial plains with a general rise in piedmont zone and again marked fluctuation in eastern highlands.

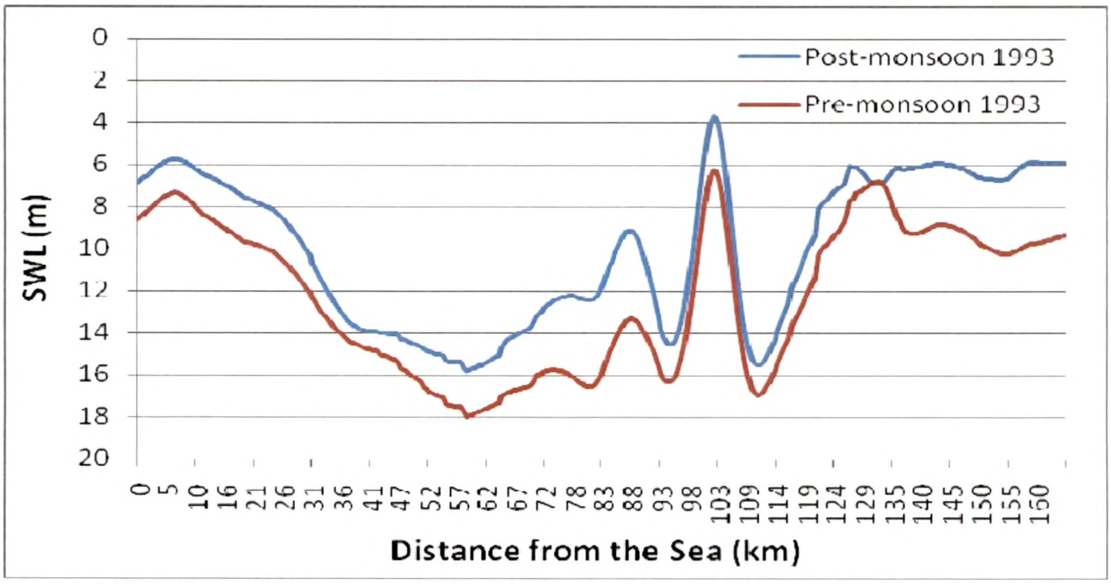

Fig- 5.19 Spatial Hydrographic Profile along A-A' (Year 1993).

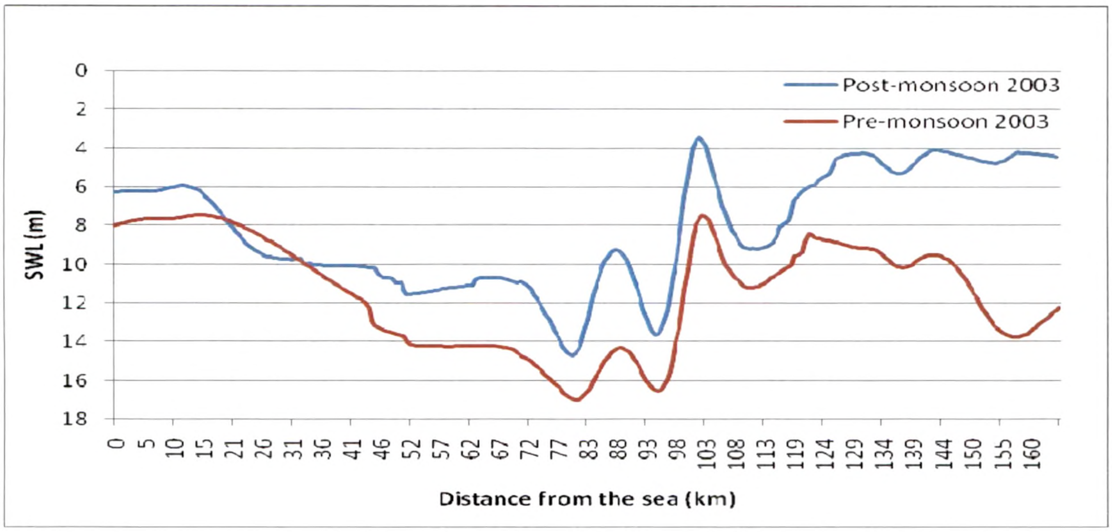

Fig 5.20 Spatial Hydrographic Profile along A-A' (Year 2003).

The net change in water level for one decade (1993-2003) is shown in Fig 5.21. Profile show gradual decline in water levels especially in villagers like Masor (Padra) of -0.4m, Makni (Sankheda) of -1.5m and Bujetha (Tilakwada) i.e. -3.5m while in rest of the area water table is more or less constant.

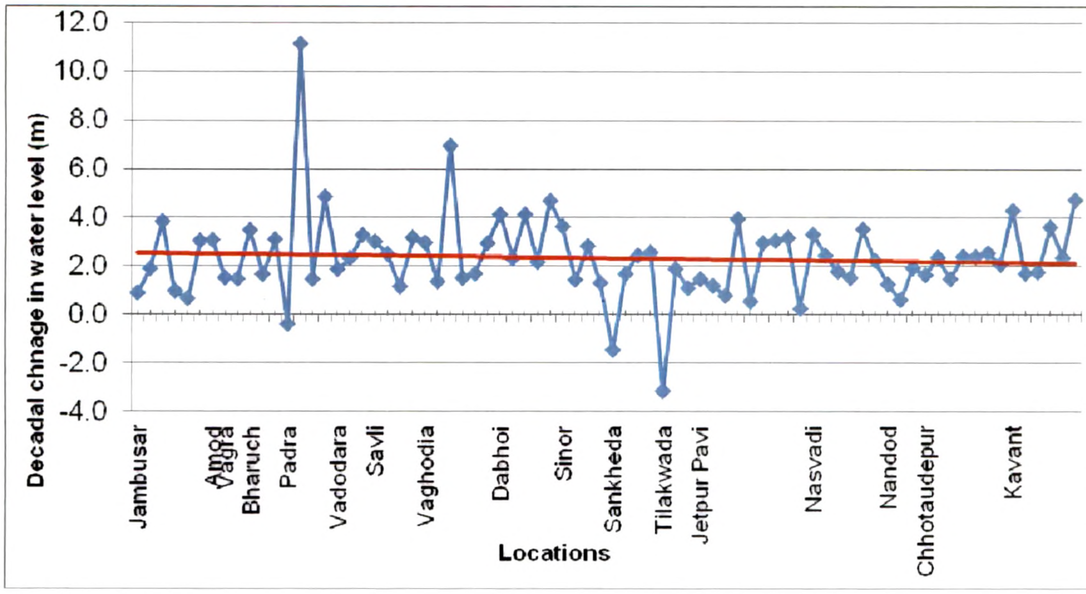

Fig-5.21 Net Decadal Change in Groundwater Storage from Coast to Eastern Highlands within the Study Area (straight line indicates general trend)

5.10 Approaches for Calculating Groundwater Potential of the Study Area

The groundwater resource potential assessment for any area is carried out using standard approaches that utilizes mainly replenishable component of recharge on annual basis. The source of recharge to groundwater for any area can be accounted mainly through rainfall which is a main source and also due to infiltration through surface water bodies like rivers, ponds and canals and return flow from irrigation. The quantitative estimation of recharge in natural condition is difficult and condition becomes further more complicated because of presence of multiple variables influencing the recharge process.

There exits several approaches for evaluation of groundwater recharge which in turn depends upon the factors influencing infiltration variables and their attributes. CGWB (93-94) has used Professor Chaturvedi's Empirical Formula for calculation of the rainfall infiltration factor for various taluka's of Vadodara. The formula $Rp = 2\ (R-15)^{2/15}$ representing geological conditions of those of Ganga Plains of western Uttar Pradesh has been used wherein 'Rp' is the amount of rainfall that would infiltrate from rainfall 'R'. The author, for estimation of groundwater recharge has adopted Water Level Fluctuation and Specific Yield Approach and Rainfall –Recharge empirical methods as suggested by different workers:

5.10.1 (A) Water Table Fluctuation/Specific Yield Approach

This approach is widely accepted one and considered to be the most realistic as this encompasses all factors of the terrain and reflect actual contribution from recharge to the groundwater system. The equation to compute groundwater recharge is -

$$R = A \times Sy \times (h_1 - h_2)$$

Where,

R= Groundwater Recharge
A=Area under evaluation
Sy=Specific yield of aquifer
h_1=Post Monsoon groundwater level
h_2=Pre-monsoon groundwater level

Area Under Evaluation (A):

The study area comprises both consolidated and unconsolidated formations. Out-crops of the consolidated formations is mainly confined to the eastern parts of the study area. Whereas, central and western parts are dominated by unconsolidated sediments. Further, at places within the consolidated formations there exits pockets of unconsolidated sediments viz. colluvium and of flood plain deposits. The study area sprawls for about 11101.49 km^2.

Specific Yield (S_y):

The specific yield is the ratio of the volume of water that, after saturation, can be drained by gravity to its own volume in water table type of aquifer (Santos, 1969). It has been observed that the values of S_y in the study area depend mainly on grain size, shape, interstitial ratio, compaction of the stratum and time of drainage. In hard rock area the basic hydraulic properties i.e. porosity and hydraulic conductivity have been modified due to the effect of metamorphism caused by intensive magmatic activities and the rock mass has become more compacted. Similarly, in the unconsolidated sediments the observed heterogeneity in sediment's characteristics, level of compaction and abundance of clay fractions has considerably reduced the specific yield. Specific yield values for different formations adopted for the Heran river basin (Tiwari, 1986) are; Metamorphic (3%), Sandstone (2.5%), Basalt (2.5%) and alluvium (10-12%). However, for present study specific yield data have been adopted from GWRDC which is based on pump test results obtained for different formations. Details about the formation specific Sy within the study area are given in Table 5.4.

Table 5.4 Average Annual Recharge to Groundwater Based on Water Table Fluctuation/Specific Yield Approach

Sr No	Rock Type		Area m^2	Change in Water Table 'm'	Specific Yield	Recharge MCM
1	Alluvium	Flood Plain	4477	2.77	0.14	1736
2		Coastal	3011.86	2.1	0.05	316
3	Deccan Trap		1958920000	2.56	0.02	100.4
4	Dolomite and Limestone		70743000	1.79	0.008	1.01
5	Gneiss and Granite		1079130000	2.24	0.026	62.84
6	Green Marble		13194000	1.68	0.008	0.17
7	Phyllite, Slate, Schist, etc.		308588000	2.49	0.05	38.41
8	Quartzite		2108000	1.8	0.02	0.07
	Sandstone (Nimar)		180614000	1.79	0.02	6.46
	Total		**11101491000**	--	--	**2261.3**

Change in water table is taken average of pre and post monsoon period of last 10 years. The total recharge based on this approach comes out to be ±2261 MCM.

5.10 ((B) Recharge Calculation based on Groundwater Over Exploitation Committee (1979). The above committee has suggested following norms.

1) Alluvial area
   - In sandy areas: 20 to 25% of Normal rainfall
   - In area having large clay content: 15-20% of Normal Rainfall

2) Hard rock area
   - 10-15 % of Normal rainfall

Since the area consists of both hard rock and soft rock and the infiltration capacity of the study area found to be less therefore, lower range values have been adopted for computation of recharge. The total recharge based on this approach stand at 1596.854 MCM.

5.10. (C) Sukhija's Approach (1979): based on injection of radio isotope viz. tritium.

- Recharge from consolidated formation: 3% of Normal rainfall
- Recharge from unconsolidated formation: 8% of Normal rainfall

The groundwater recharge estimated by various approaches is given in Table 5.6.

Table 5.6 Comparison of Groundwater recharge in the Study Area by Various Approaches.

Sr No.	Approach	Rock Type	Area (km^2)	Percentage Normal Rainfall (859mm)	Recharge (MCM)	Total Recharge (MCM)
1	G'water over Exploitation Committee	Alluvial	7488.194	20	1286.472	1597
		Hard Rock	3613.297	10	310.382	
2	Sukhija	Alluvial	7488.194	8	514.58	608
		Hard Rock	3613.297	3	93.11	
3	Specific Yield Approach	Alluvial	7488.194	*2.1-2.7	2052	2261
		Hard Rock	3613.297	*1.68-2.56	209	

*Water Table Fluctuation/Specific Yield Approach

As any change in groundwater regime is a function of recharge due to rainfall, returned irrigation seepage, ponds and reservoir etc. Similarly, out put is a function of consumptive use, soil evaporation, draft and sub-surface out flow. Therefore, considering groundwater regime a closed system any change in its storage would always reflect the influence of input and output parameters of the water balance equation.

Looking to this very fact that Water Table Fluctuation and Specific Yield Approach would provide the most dependable estimates on the groundwater storage. Hence, the author has considered 2261 MCM as recharge for the study area.