Aquifer Characterisation for Planning Artificial Recharge to Groundwater Reservoir

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1. Basic Requirement for Artificial Recharge to Groundwater Reservoir

The basic requirements for implementing artificial recharge to the groundwater reservoir are as follows:

a) Availability of non-committed surplus monsoon run off in space and time.

b) Identification of suitable hydrogeological environment and sites for creating sub-surface reservoir through cost effective artificial recharge techniques.

1.1 Source Water Availability

The availability of source water, one of the prime requisites for groundwater recharge, is basically assessed in terms of non committed surplus monsoon run off, which as per present water resource development scenario is going away un-utilized. This component can be assessed by analyzing the monsoon rainfall pattern, its frequency, number of rainy days, maximum rainfall in a day and its variation in space and time. The variations in rainfall pattern in space and time, and its relevance in relation to the scope for artificial recharge to sub-surface reservoirs can be considered for assessing the surplus surface water availability.

1.2 Hydrogeological Aspects

Detailed knowledge of geological and hydrological features of the area is necessary for adequately selecting the site and the type of recharge structure. In particular, the features, parameters and data to be considered are: geological boundaries; hydraulic boundaries; inflow and outflow of waters; storage capacity; porosity; hydraulic conductivity; transmissivity; natural discharge of springs; water resources available for recharge; natural recharge; water balance; lithology ; depth of the aquifer; and tectonic boundaries.

The aquifers best suited for artificial recharge are those aquifers which absorb large quantities of water and do not release them too quickly. Theoretically this will imply that the vertical hydraulic conductivity is high, while the horizontal hydraulic conductivity is moderate. These two conditions are not often encountered in nature.

The evaluation of the storage potential of aquifers is invariably based on the knowledge of dimensional data of reservoir rock, which includes their thickness and lateral extent. The availability of sub-surface storage space and its replenishment capacity further govern the extent of recharge. The hydrogeological situation in each area needs to be

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appraised with a view to assess the recharge capabilities of the underlying hydrogeological formations. The unsaturated thickness of rock formations, occurring beyond five meters below ground level should be considered to assess the requirement of water to build up the sub-surface storage by saturating the entire thickness of the vadose up to 5 m below ground level. The upper 5 m of the unsaturated zone is not considered for recharging, since it may cause adverse environmental impact e.g. water logging, soil salinity, etc. The post-monsoon depth to water level represents a situation of minimum thickness of vadose zone available for recharge which can be considered vis-à-vis surplus monsoon run off in the area.

The artificial recharge techniques inter relate land integrate the source water to groundwater reservoir. Two effects are generated by artificial recharge in groundwater reservoir namely - (a) Rise in water level and (b) increment in the total volume of the groundwater in the aquifer.

2.0 Planning of Artificial Recharge Projects

The artificial recharge projects are site specific and even the replication of the techniques from similar areas are to be based on the local hydrogeological and hydrological environments. The first step in planning the project is to demarcate the area of recharge. The Project can be implemented systematically in case a hydrologic unit like watershed is taken for implementation. However, localized schemes are also taken to augment groundwater reservoir. The artificial recharge of groundwater is normally taken in following areas:

1. Areas where groundwater levels are declining on regular basis.
2. Areas where substantial amount of aquifer has already been desaturated.
3. Areas where availability of groundwater is inadequate in lean months.
4. Areas where salinity ingress is taking place.

Necessary scientific inputs for planning artificial recharge are obtained through the studies described hereunder.

2.1 Hydrometeorological Studies

These are undertaken to decipher the rainfall pattern, evaporation losses and climatological features. These can bring out the extent of evaporation losses in post monsoon period which would be helpful in designing the storages of particular capacity with a view to have minimum evaporation losses. In semi arid regions of India, evaporation losses are significant after January hence the stored water should percolate to groundwater reservoir by this period. The data on rainfall intensity, number of rain-days, etc. help in deciding the capacity and design of the artificial recharge structures.

2.2 Hydrological Studies

Before undertaking any artificial recharge project, it is a basic prerequisite to ascertain the availability of source water for the purpose of recharging the groundwater reservoir. For determining the source water availability for artificial recharge, hydrological investigations are required to be carried out in the Watershed/Sub-basin/basin where the artificial recharge schemes are envisaged. Four types of source water may be available for artificial recharge viz.

(i) In-situ precipitation on the watershed.

(ii) Surface (canal) supplies from large reservoirs located within basin

(iii) Surface supplies through trans-basin water transfer.

(iv) Treated municipal and industrial wastewaters.

'In situ' precipitation will be available almost at every location but may or may not be adequate to cause artificial recharge but the runoff going unutilized outside the watershed/ basin can be stored/ transmitted through simple recharge structures at appropriate locations. In addition none, one or both of the other two sources may be available in any of the situations; the following information will be required:

a) The quantity that may be diverted for artificial recharge.

b) The time for which the source water will be available.

c) The quality of source water and the pretreatment required.

d) Conveyance system required to bring the water to the recharge site.

Hydrological studies are undertaken to work out surplus monsoon run off which can be harnessed as source water for artificial recharge.

2.3 Soil Infiltration Studies

In case of artificial recharge through water spreading methods, soil and Land use conditions which control the rate of infiltration and downward percolation of the water applied on the surface of the soil assume special importance. Infiltration in its most narrow and precise sense can be defined as "The process through which water enters into a soil through the soil surface". Although a distinction is made between infiltration and percolation (the movement of water within the soil) the two phenomena are closely related since infiltration cannot continue unimpeded unless percolation removes infiltrated water from the surface soil.

The soil is permeated by non-capillary channel through which gravity water flows downward towards the groundwater, following the path of least resistance. Capillary forces continuously divert gravity water into pore spaces, so that the quantity of gravity water passing successively lower horizons is steadily diminished. This leads to increasing resistance to gravity flow in the surface layer and a decreasing rate of infiltration as a storm progresses. The rate of infiltration in the early phases of a storm is less if the capillary pores are filed from a previous storm. There is maximum rate at which water can enter soil at a particular point under a given set of conditions, this rate is called the infiltration capacity.

Infiltration capacity depends on many factors such as soil type, moisture content, organic matter, vegetative cover, season, air entrapment, formation of surface seals or crusts etc. Of the soil characteristics affecting infiltration, non-capillary porosity is perhaps the most important. Porosity determines storage capacity and also effects resistance to flow. Thus infiltration tends to increase with porosity.

Vegetal cover increases infiltration as compared with barren soil because (i) it retards surface flow giving the water additional time to enter the soil (ii) the root system make the soil more pervious and (iii) the foliage shields the soil from raindrop impact and reduces rain packing of surface soil. As water infiltrates soil under natural conditions the displacement of air is not complete even after many hours. Air spaces in the soil and intermediate zones interfere with infiltration as air is not pushed out by the infiltrating water but is gradually absorbed by water. Due to this phenomenon infiltration rate may start rising towards a new high after a few days of continuous application of water. Surface conditions have a marked effect on the infiltration process and the formation of surface seals or crusts which forms under the influence of external forces such as rain drop impact and mechanical compaction or through staking reduces the rate of infiltration.

Infiltration of water through surface takes place generally over small periods of time and it is the process of redistribution of the soil water that goes on for most of the time and therefore predominates. When rainfall ceases the water wetted during the infiltration process starts to drain with the soil being wetted lower down the profile. The soil water conditions during the distribution periods are therefore those that primarily influence plant growth and agricultural husbandry and that also provide the buffer action in hydrologic cycle that the soil water zones has on the transport of water from the soil surface to the groundwater aquifer. As such, infiltration is critically inter-linked with the phenomena of water evolution in the vadose zone which includes wetting front propagation.

In order to know infiltration rates of soils infiltration tests are carried out. Cylinder or flood infiltro-meters are common type of instruments which measure the infiltration as the rate of water leaving the device. Map showing infiltration rates of soils are prepared. These help to design suitable artificial recharge structures and to assess the extent of recharge from these structures.

2. 4 Hydrogeological Studies

A correct understanding of hydrogeology of an area is of prime importance in successful implementation of any Artificial Recharge scheme. A desirable first step is to synthesize all the available data on hydrogeology from different agencies. The regional geological maps indicate the location of different geological strata, their geological age sequence, boundaries/contacts of individual formations and the structural expressions like Strike, Dip, Faults, Folds, Flexures, Intrusive bodies etc. These maps also bring out correlation of topography and drainage to geological contacts.

The Map providing information on regional hydrogeological rock units, their groundwater potential and general pattern of groundwater flow and chemical quality of water in different aquifers are necessary. Satellite Imagery maps provides useful data on geomorphic units and lineaments which govern the occurrence and movement of ground

A detailed hydrogeological study besides the regional picture of hydrogeological set up available from previous studies is therefore imperative to know precisely the promising hydrogeological units for recharge and correctly decide on the location and type of structures to be constructed in field. The hydrogeological investigations required before implementation of an artificial recharge scheme are given below.

(i) Detailed Hydrogeological Mapping

The purpose of hydrogeological mapping is to present the following maps which facilitate in the analysis of the groundwater regime and its suitability to artificial recharge schemes.

a) Map showing aquifers (hydrogeological units) demarcated on the basis of their water bearing capabilities, both at shallow and deeper levels.

b) Map showing groundwater contours to determine the form of the water table and the hydraulic connection of groundwater with rivers, canals etc.

c) Map showing the average post- monsoon depth to the water table is usually compiled for the period of one decade.

d) Maps that show amplitudes of groundwater level fluctuations and the maximum depth to the water table of considerable importance for artificial recharge studies.

e) Maps showing piezometric head in deeper aquifers and their variations with time.

f) Maps showing groundwater potential of different hydrogeological units and the level of groundwater development.

g) Maps showing chemical quality of groundwater in different aquifers.

The usefulness of all the above interpretative maps is additive, i.e. their conjunctive usage allows greater knowledge and understanding of an area than when a map is used separately.

At this level of hydrogeological mapping of the area few questions should be answered.

1. Whether there is any gap in data on sub-surface geology of the available lithological logs of the boreholes in the area are sufficient to arrive at a correct picture of aquifer geometry of the area.
2. Whether the available data on aquifer parameters i.e. specific yield, transmissivity, permeability, storage coefficient, are sufficient in case the area shows promise for artificial recharge.
3. Can the available groundwater structure serve the purpose of monitoring the effects of artificial recharge Project.

Aquifer Geometry: The data on the sub-surface hydrogeological units, their thickness and depth of occurrence, and to bring out the disposition and hydraulic properties of unconfined, semi-confined and confined aquifers in the area. For surface water spreading techniques the area of interest is generally restricted to shallow depths. The main stress is on knowing whether the surface rock types are sufficiently permeable or not to maintain high rate of infiltration during the artificial recharge.

2.5 Geophysical Studies

Using certain common geophysical methods, it is possible to model the following.

i) Stratification of aquifer system and spatial variability of hydraulic conductivity of the characteristic zone, suitable for artificial recharge.

ii) Negative or non-productive zones of low hydraulic conductivity in unsaturated and saturated zones.

iii) Vertical hydraulic conductivity discontinuities, such as dyke and fault zone.

iv) Moisture movement and infiltration capacity of the unsaturated zone.

v) Direction of groundwater flow under natural/artificial recharge processes.

vi) Salinity ingress, trend and short duration depth salinity changes in the aquifers due to varied abstraction or recharge.

2. 6 Chemical Quality of Source Water

Problem which arise as a result of recharge to groundwater are mainly related to the quality of raw waters that are available for recharge and which are generally require some sort of treatment before being used is recharge installations. They are also related to the changes in the soil structure and the biological phenomena which take place when infiltration begins, to the changes brought to the environmental conditions. The chemical and bacteriological analysis of source water besides that of groundwater is therefore essential.

2.7. Assessment of Sub-Surface Potential for Groundwater Recharge

Based on the hydrogeological and geophysical surveys and study of the chemical constituents of ground water, the thickness of potential unsaturated zone suitable for recharge should be worked out to assess the potential for artificial recharge in terms of volume of water which can be accommodated in this zone vis-à-vis source water availability. The studies should bring out the potential of unsaturated zone in terms of total volume which can be recharged.

3. Master Plan for Artificial Recharge to Groundwater in Gujarat

The Master Plan for Gujarat has been prepared considering the Aquifer characteristics, hydrogeological parameters, groundwater quality and hydrological data base. The steps followed in preparation of the plan are as follows:

- Identification and prioritization of need based areas for artificial recharge to ground water.
- Identification of Areas of poor chemical quality of ground water and scope of improvement by suitable recharge measures

- Estimation of sub surface storage space and volume of water needed to saturate the unsaturated zone (up to 8mbgl)
- Estimation of storage space and volume of water needed to arrest the declining water levels.

Quantification of surface water requirement and surplus annual run off availability as source water for artificial recharge in each basin/region.

3.1 Data preparation

Depth to water table map for post monsoon period based on decadal average of depth to ground water levels was analyzed to identify deep water level areas (>8 mbgl) where aquifer can be recharged. Similarly a long term (decadal) post monsoon water level trend map also prepared and analyzed. This map brings out the ranges of water level rise and fall on long term basis. These two maps were superimposed to bring out depth to water table variations along with the trends of water levels over the last decade .Ground water quality map was superimposed on these two maps to eliminate areas where ground water quality exceeded TDS > 5000ppm. Thus the areas feasible for artificial recharge were demarcated.

3.2 Identification of feasible areas

The area feasible for artificial recharge has been demarcated into following categories:

- Areas showing water levels between 8 and 10 mbgl and declining trend of >10 cm/year.
- Area showing water levels between 10-12 mbgl and declining trend of >10 cm/year.
- Area showing Water levels between 12-15 mbgl and declining trend of >10 cm/year.
- Area showing Water levels between 15-20 mbgl and declining trend of >10 cm/year.
- Area showing Water levels between 20-25 mbgl and declining trend of >10 cm/year.
- Area having Water levels more than 25 mbgl and declining trend of >10 cm/year

The areas of above categories were demarcated and identified as feasible areas for planning and implementation of artificial recharge to ground water. Based on the severity of decline of ground water levels and ground water scarcity situation, priortisation for implementation of plan has been decided.

3.3 Estimation of available storage space

Various water bearing geological formations occurring in the Gujarat state were categorized broadly in four categories namely alluvial deposits, igneous rocks, metamorphic rocks and other soft rocks which includes consolidated/semi-consolidated sedimentary rock formations. The thickness of available unsaturated zone (below 8 mbgl) of the above categories has been estimated by considering the different ranges of water level in respect of four broad categories of aquifers. The declining trends of various magnitudes are also to be considered while computing the potential zone for planning artificial recharge.

Further while calculating the total space for recharge; clay & massive non porous zones were identified and deleted from the total thickness of potential zone for recharge based on the study of litho logs and geological cross sections. The total volume of unsaturated strata was calculated by considering the above categories and unsaturated thickness of different ranges.

3.4 Estimation of volume of water required for artificial recharge

The "Coefficient of Replenishment" and unsaturated thickness of formations, occurring beyond 8 mbgl has been considered to assess the requirement of water to build up the sub surface storage by saturating the entire thickness of the phreatic aquifer up to 8 m. mbgl. The "Coefficient of Replenishment" is the volume of water in cubic meters which can be put into storage in each column of aquifer having base of 1 m. square and height equal to the thickness of the aquifer, when the water table or piezometric surface is raised by 1m.The unsaturated zones comprises a wide variety of formations with different hydraulic characteristics. The coefficient of replenishment of various formations in the vadose zone is to be estimated considering the relation of porosity vis-à-vis specific yield as given in Table 3. This volume of vadose zone when multiplied by coefficient of replenishment on an area specific basis gives the volume of water required to saturate the aquifer to 8 mbgl and also to arrest the declining water levels.

Table 1. Values of Coefficient of Replenishment

Sl. No.	Formation	Specific Yield	Coeff. of Replenishment
1.	Alluvial deposits	0.10	0.12
2.	Metamorphic Formations	0.015	0.018
3.	Igneous Formations	0.015	0.018
4.	Semi-consolidated Formations	0.02	0.024

3.5 Matching water requirement with source water availability

The surplus surface water resources available in various basins and regions are to be considered. The data for source water availability for each basin includes committed run off, provision for future planning and surplus water available. The availability of source water per annum is to be worked out by adding the amount of surface water provided for future planning and surplus available. This availability so worked out is for the entire basin and not exclusively for the requirement of the areas identified for artificial recharge, hence proportional local availability of surplus surface water resources is to be matched with water requirement for artificial recharge.

4. A Case Study of Sabarmati Basin, Gujarat

The basin is having total area of 22,260 sq.km. The water bearing formations in the basin are alluvium, igneous, metamorphic and other soft rocks. In the major part of the basin alluvium consisting of re-worked aeolian sand, silt, kankar and clay forms principle aquifer (Fig. 1). The average post monsoon water level (1998-2007) ranges from less than 8 to 35 mbgl (Fig 2). The depth to water level is within 8mbgl in the south central and the western part of basin. The quality of ground water is good in general except the western part which is saline having TDS more than 2500 mg/l (Fig 3). The entire Sabarmati basin shows rising trend of post monsoon water level (1998-2007) except a small patch in the southern part where decline of more than 70 cm/year is observed. (Fig. 4). Based on the quality, post monsoon water level and the declining trend the feasible areas for artificial recharge are identified in the northern and western parts of the basin. The areas feasible for artificial recharge are shown in Fig.5.

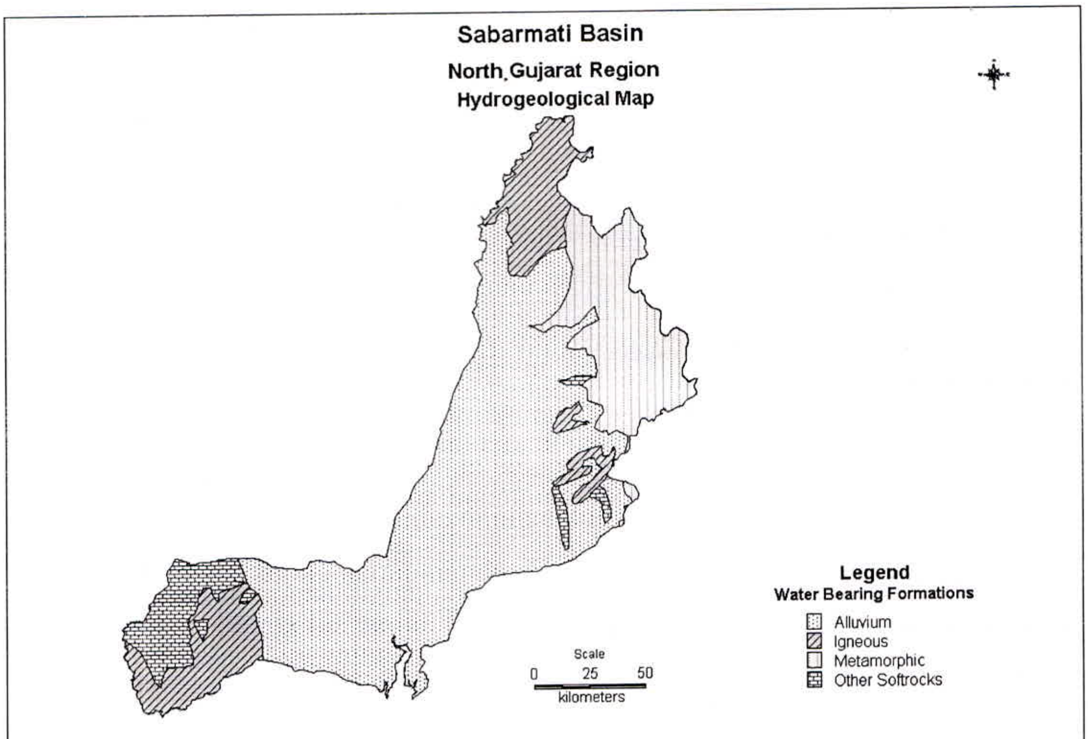

Figure 1: Hydrogeological map of Sabarmati basin

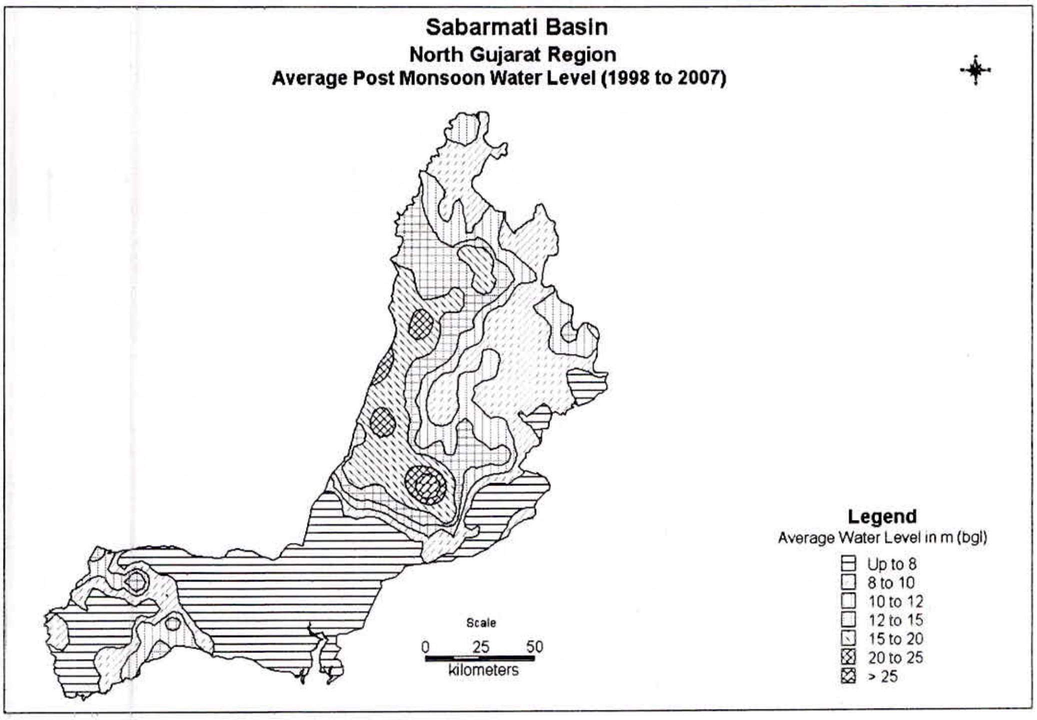

Figure 2: Decadal average depth to water level map of Sabarmati basin

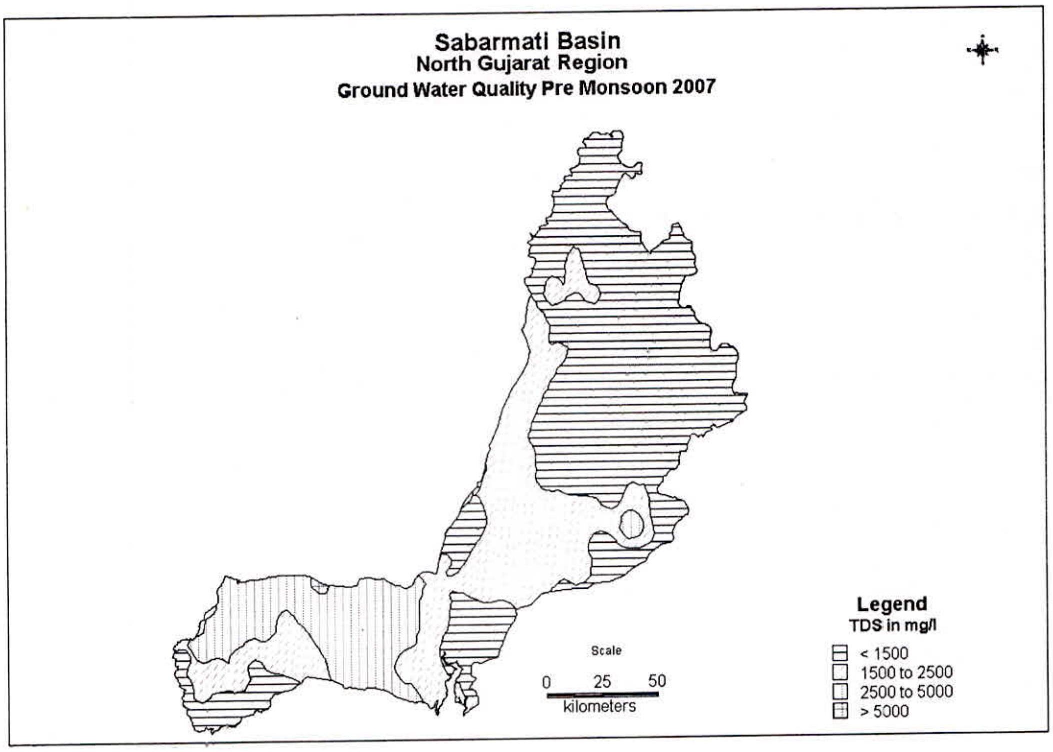

Figure 3: Ground water quality map of Sabarmati basin

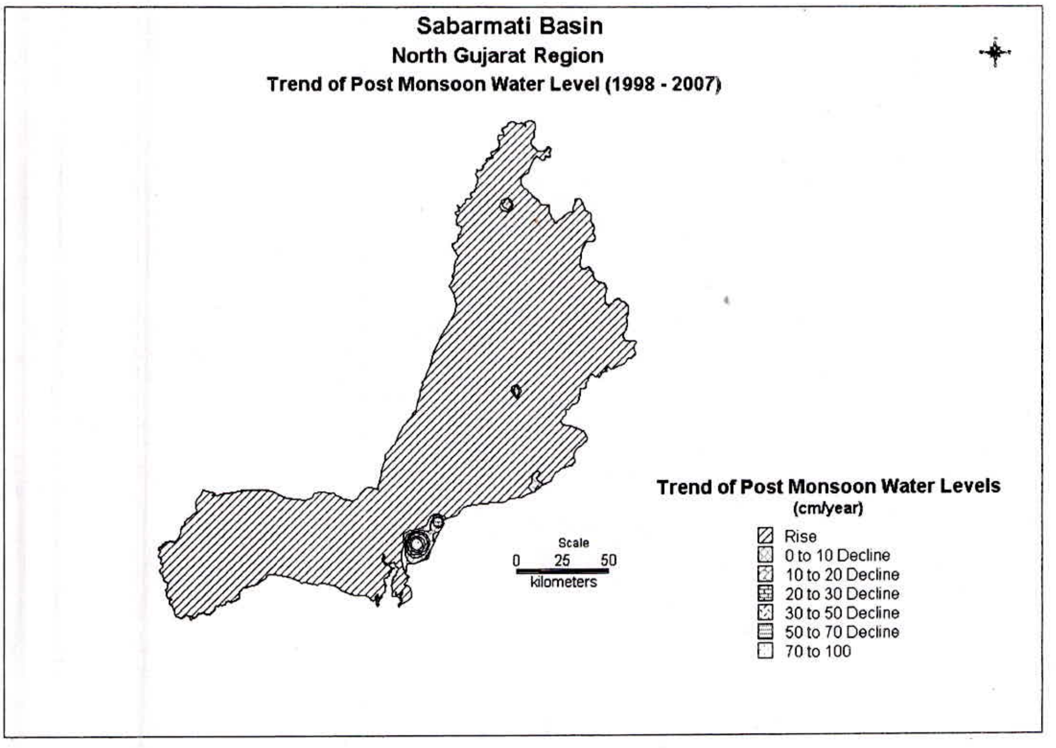

Figure 4: Decadal tend of post-monsoon water levels, Sabarmati Basin

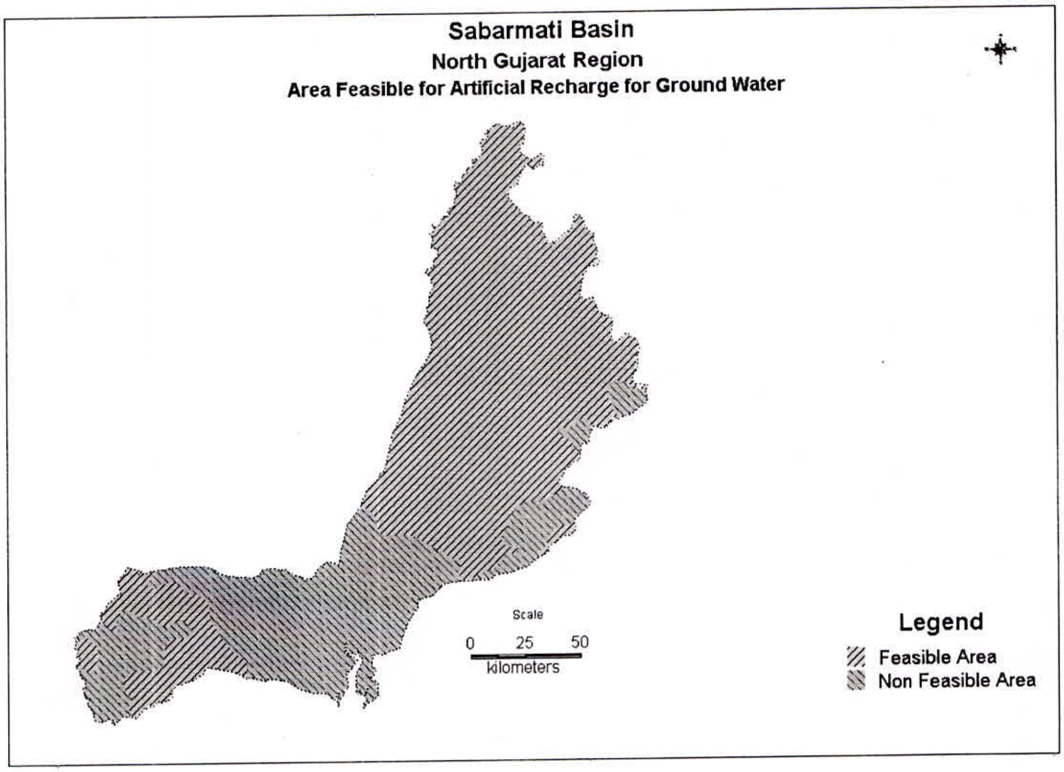

Figure 5: Feasible area for artificial recharge, Sabarmati Basin

It is estimated that an area of 14517 sq.km. having depth to water table more than 8 m bgl, spread over all the geological formations feasible for artificial recharge (Table 1). The total volume of vadose zone of this area is 41348 MCM (Table 2). Further in an area of 464 sq.km. the declining of water level is observed and the volume of vadose zone in this area is 66.93 MCM. Thus the total volume of de-saturated zone feasible for recharge in the basin is 41414 MCM. Considering percentage of clay in alluvium, coefficient replenishment of different formations, it is estimated that about 3534 MCM of water is required for recharge to bring the water level up to 8 m bgl (Table 3).

Table No1 : Computation of Feasible Zones in different formations for Artificial Recharge

Region : North Gujarat — **Basin :** Sabarmati Basin (3)

Sr.No.	Depth to W.L. (mbgl)	Av. Thickness (m)	Area of Different Formations (sq. km)					Volume of Vadose Zone (MCM)				
			Alluvial	Metamorphic	Igneous	Other Softrocks	Total	Alluvial	Metamorphic	Igneous	Other Softrocks	Total
1	< 8	-	Not Considered									
2	8 to 10	1.0	1516.12	2085.37	1457.48	396.12	5455.09	1516.12	2085.37	1457.48	396.12	5455.09
3	10 to 12	2.0	1285.74	765.09	1058.75	215.67	3325.25	2571.48	1530.18	2117.50	431.34	6650.50
4	12 to 15	3.5	1999.07	286.91	496.04	49.81	2831.83	6996.75	1004.19	1736.14	174.34	9911.41
5	15 to 20	6.0	2257.89	77.41	1.95	-	2337.25	13547.34	464.46	11.70	-	14023.50
6	20 to 25	8.5	470.33	-	-	-	470.33	3997.81	-	-	-	3997.81
7	25 to 35	13.5	96.98	-	-	-	96.98	1309.23	-	-	-	1309.23
TOTAL :			7626.13	3214.78	3014.22	661.60	14516.73	29938.72	5084.20	5322.82	1001.80	41347.53

Tableno. 2 : Area with declining Trend - Feasible for Recharge

Region : North Gujarat — **Basin :** Sabarmati (3)

Sr.No.	W.L.Trend cm./yr.	Av.Thickness of desaturation in m	Area of Different Formation (Sq. Km)					Volume of Formations (MCM)				
			Alluvial	Metamorphic	Igneous	Other Softrocks	Total	Alluvial	Metamorphic	Igneous	Other Softrocks	Total
1	Upto 10	0.05	138.99	-	19.44	-	158.43	6.95	-	0.97	-	7.92
2	10 - 20	0.10	124.93	-	18.31	-	143.24	12.49	-	1.83	-	14.32
3	20 - 30	0.15	65.41	-	-	-	65.41	9.81	-	-	-	9.81
4	30 - 50	0.25	40.15	-	-	-	40.15	10.04	-	-	-	10.04
5	50 - 70	0.35	24.63	-	-	-	24.63	8.62	-	-	-	8.62
6	70 - 100	0.50	32.43	-	-	-	32.43	16.22	-	-	-	16.22
Total			426.54	0.00	37.75	0.00	464.29	64.13	0.00	2.80	0.00	66.93

Table 3: **Ground Water Storage Potential**						
Region: North Gujarat			**Basin** : Sabarmati (3)			
Sr.No.	Item	Alluvial	Metamorphic	Igneous	Other Softrocks	Total
1	Volume of Formation to be used for storage upto 8 m bgl (MCM)	29938.72	5084.20	5322.82	1001.80	41347.53
2	Volume of desaturated formation due to declining trend (MCM)	64.13	-	2.80	-	66.93
3	Total volume of formation for Storage (MCM)	30002.85	5084.20	5325.62	1001.80	41414.46
4	Total Clay Content (%)	7.72	-	-	-	-
5	Total Volume Clay (MCM)	2316.22	-	-	-	-
6	Net Volume of formation for storage (3 -5) MCM	27686.63	5084.20	5325.62	1001.80	39098.24
7	Average Sp. Yield of the formations	0.10	0.015	0.015	0.02	-
8	Avarage co efficient & Replenishment of the formations	0.12	0.018	0.018	0.024	-
9	Volume of water required to create sub surface potential upto 8 m bgl (MCM) (6 X 8)	3322.40	91.52	95.86	24.04	3533.82