CHAPTER-VI

GROUNDWATER RECHARGE ZONE MAPPING USING REMOTE SENSING AND GIS

6.1 Introduction:

Geological methods, involving field studies and interpretation of geologic data are undoubtedly, a foremost important step in ground water prospecting. The use of remote sensing data from aircraft or satellite has become an acceptable valuable tool for understanding subsurface water conditions (Todd, 1980).As the satellite picture gives synoptic view of vast stretch of land and enables one to observer see features which cannot be seen easily on the ground. Various surfacial features mapped using remotely sensed data that may be integrated with secondary data related to location specific information on groundwater and surface water resources to develop thematic maps about the potential groundwater zones, areas favourable for groundwater recharge and assessing the water harvesting mechanisms etc. using Geographical Information System(GIS) platform, a software added data based management system.

Development and management of water resources within a river basin requires a host of information on a variety of themes to be collected, compiled and studied individually and also in conjunction with other themes. Remote sensing provides a variety of latest and updated information on natural resources and Geographic Information System (GIS) has the capability for capture, storage, manipulation, analysis, retrieval of multiple layer resource information occurring both in spatial and non spatial forms. Moreover, in GIS it is possible to create and visualize a host of development and management scenarios by varying the key parameters influencing the targeted objectives.

Present chapter deals with the efficiency of RS & GIS techniques to identify groundwater recharge sites. It further envisages to generate a regional model for development and management of water resources with a view to apply at local level.

6.2 Importance of Remote Sensing and GIS:

Developmental planning for any area is a complex process of decision-making based on information about the status of resources and socio-economic conditions. Reliability of the database, both spatial and non-spatial is therefore crucial to the success of the developmental planning. The major advantage of adopting these tools is to provide timely inflow of information to serve planning needs.

Analyzing large number of data attributes require an efficient system of information gathering, compiling, classification, transformation, storage, retrieval and analysis. The GIS has capability of conducting spatial searches and overlays and association of the spatial data with the non-spatial data to eventually generate new information. The Locale specific prescriptions could be arrived through the effective use of space based remote sensing data merged with other collateral data.

6.3 Application of Remote Sensing Technique in Groundwater Studies:

Application of remote sensing for groundwater studies has been practiced for more than three decades. Study of hydrogeological aspects through remote sensing viz. lithology, structural and tectonic attributes of the area depicts the elements of terrain characteristics and land use pattern etc. This in turn greatly facilitates in t deriving temporal qualitative as well as quantitative assessment of the area o probanle potential of water resources.

Blending of tremote ensing and GIS techniques has been proved to be an efficient tool in groundwater studies (Gustafsson, 1993; Saraf and Jain, 1994; Krishnamurthy and Srinivas 1995, Krishnamurthy *et. al.* 1996). Remote sensing data provide accurate spatial information that can be economically utilized over conventional techniques of groundwater investigation.

The interpretation of satellite data in conjunction with sufficient ground truth information makes it possible to identify and outline various ground features such as geological structures, geomorphic features and their hydraulic characters (Das et al, 1997; Srinivasa Rao et al, 2000); and these may serve as direct or indirect indicators of the presence of groundwater (Ravindran and Jeyaram, 1997; Gopinath and Seralathan, 2004). These tools also facilitate to produce conceptual model for delineation and evaluation of groundwater potential zones of an area (Chaterjee and Bhattacharya, 1995; Krishnamurthy and Srinivas, 1995; Srivasthava and Bhattacharya, 2000; Sarkar et al.2001).

GIS technique involves integrated and conjunctive analysis of huge volumes of multi-disciplinary data, both spatial and non-spatial, within the same geo-referencing scheme. Through integration of these two spatial data management technologies it has become possible to organize groundwater development plan through an appropriate identification of sites for water harvesting and artificial recharge. The National Remote Sensing Agency, Govt. of India (1989-1990) under the auspices of the National Technology Mission for

Drinking Water and with the active collaboration of state departments has developed area specific hydrogeomorphological maps at the scale of 1:2,50,000 for the whole of India, utilizing LANDSAT TM and IRS imageries (Reddy, 1999).

6.4 Considerations for Groundwater Recharge:

The type of artificial recharge system that can be developed at any site is controlled to a large extent , by the geologic and hydrologic conditions. Site selection criteria, in addition to economic consideration, should include the following aspects (Das 2002):

i) Source of water to be used for recharge
ii) Chemical, physical and biological characteristics of recharge water
iii) Availability of a geological formation suitable for artificial recharge
iv) Thickness and permeability of the material overlying the geological formation considered suitable for recharge
v) Proximity of the potential recharge site to the cone of depression of an appropriate well
vi) Water level differences between the aquifer and the recharge site.
vii) Infiltration basins/pond shall be excavated in underlying permeable deposits.
viii) Infiltration rate of soil & hydraulic conductivities of water transmission are required to be considered in constructing recharge system.

The presented study envisages integration RS-GIS for analysing various hydrogeological attributes of the study area to classify the area interms of :

- Characterization of the study area with a view to categorized of groundwater potential zones.
- To establish the interrelationships of recharge areas with lithology, structure, geomorphology and soils of the area.
- Qualitative and quantitative assessment of groundwater recharge.
- To identify suitable sites for rainwater harvesting, groundwater recharge and augmentation groundwater regime.

Adopted methodology to attain above cited objectives is discussed in ensuing paragraphs.

6.5 Methodology

Preparation of Thematic Maps

Various theme maps essential for studying various hydrogeological attributes have been prepared using satellite data and or other secondary data into compatible digital formats in GIS environment. Important thematic maps viz., geology, drainage, slope and DEM, soil, geological structures, geomorphology ,land use/ land cover, etc., have been prepared for the study area.

Data Source

The collateral data on geology and soil of the area, maps reports charts relevant to study area, etc. collected from various organizations like Soil Survey, Nagpur, Geological Survey of India, Survey of India, State Census Department etc. have been collected and used. SOI sheets No. 46 B, C, F, G, J & K rainfall data for years 1961 to 2003 from Gujarat Data Centre, Gandhinagar, In addition, hydro-geological maps prepared by Space Application Centre SAC on 1:50,000 and LANDSAT ETM^+ (October, 2001) have been used to analyse Hydrogeological aspects of the study area..

Data Analysis in GIS Environment

To produce basic thematic maps, analysis and interpretation of satellite data was done using ARC GIS (8.3 version) and ERDAS Image softwares. Satellite data registration, correction and other image processing (such as image enhancement, filtering, and classification) and other GIS process, together with field checking of the relevant area was applied at this stage.

Creation of Spatial Database

All the appropriate data was brought together into a GIS database. All the available spatial data was assembled in digital form, and then properly registered for their correct overlapping. Digitization of existing data and conversion between raster to vector, griding, buffer analysis, box calculating, interpolation and other format was conducted. This was followed by the generation of various layers such as annual rainfall, lithology, lineament density, topography elevation, slope steepness, drainage density, and land use and soil.

Spatial Data Analysis.

This stage processes the entire inputs in order to extract spatial features which are relevant to the groundwater zone. Various analyses such as table analysis and classification, polygon classification and weight calculation were done. Polygons in each of the thematic layers were categorized depending on the recharge characteristics by assigning suitable weightages to respective attributes.

6.6 Thematic Layers:

6.6.1. Geology:

The overview of regional geological framework provides a better picture of the geological setting which is diverse in origin and different in their physical and chemical characteristics. The study area in western part is covered with Quaternary alluvium, while the eastern fringe consists of metamorphic and igneous rocks of Pre-Cambrian, sedimentary rocks of Mesozoic and Cretaceous-Eocene volcanic basalt (Fig 2.2). From hydrogeological point of view the area has been divided into two broad categories:

Unconsolidated Formation: This includes Quaternary deposits comprising of recent and older alluvium. The sediments are essentially composed of clays, silts, sands, gravel and kankar. In eastern part of the study area, though area is dominated by hard rock formation but they appear in hilly pediments, along channels and in areas of surfaces depressions. Important hydraulic properties considered such as porosity ranges from a minimum of about 20% in coarse, poorly sorted alluvium to about 90% in soft clays. Specific yield value ranges from almost zero to about 50% values typical of fine silty clays are less than 10%. Gravel and coarse sands have value greater than 20%. Permeability on higher side is 10^9 times while 10^{-7} is the lowest permeability. Moreover, well yield is 50 lpm to 250 lpm from river deposits.

Consolidated Formation: occurrence of groundwater in these hard rock is characterized by the presence of secondary porosity i.e. fissure, fractures, joints, zones of weathering which can be grouped into two different form (Tiwari, 1986).

- Weathered mantle where rainwater percolates and stored in pockets of irregular thickness.

- Joints and fractures within fresh rocks and their interconnection provide conduits for the channelization of groundwater through hard rock, forming linear aquifer zones.

Based on the hydrogeological characteristics of different rock types, weightage was assigned to derive various as groundwater potential categories (Table- 6.1).

Thus, based on the weightage various lithologies in the study area have been reclassified in terms of their groundwater potential suitability as excellent Good, Moderate, Poor, and Very Poor. A map depicting spatial distribution of these hydrogeological (lithology) categories is given in Fig.6.1

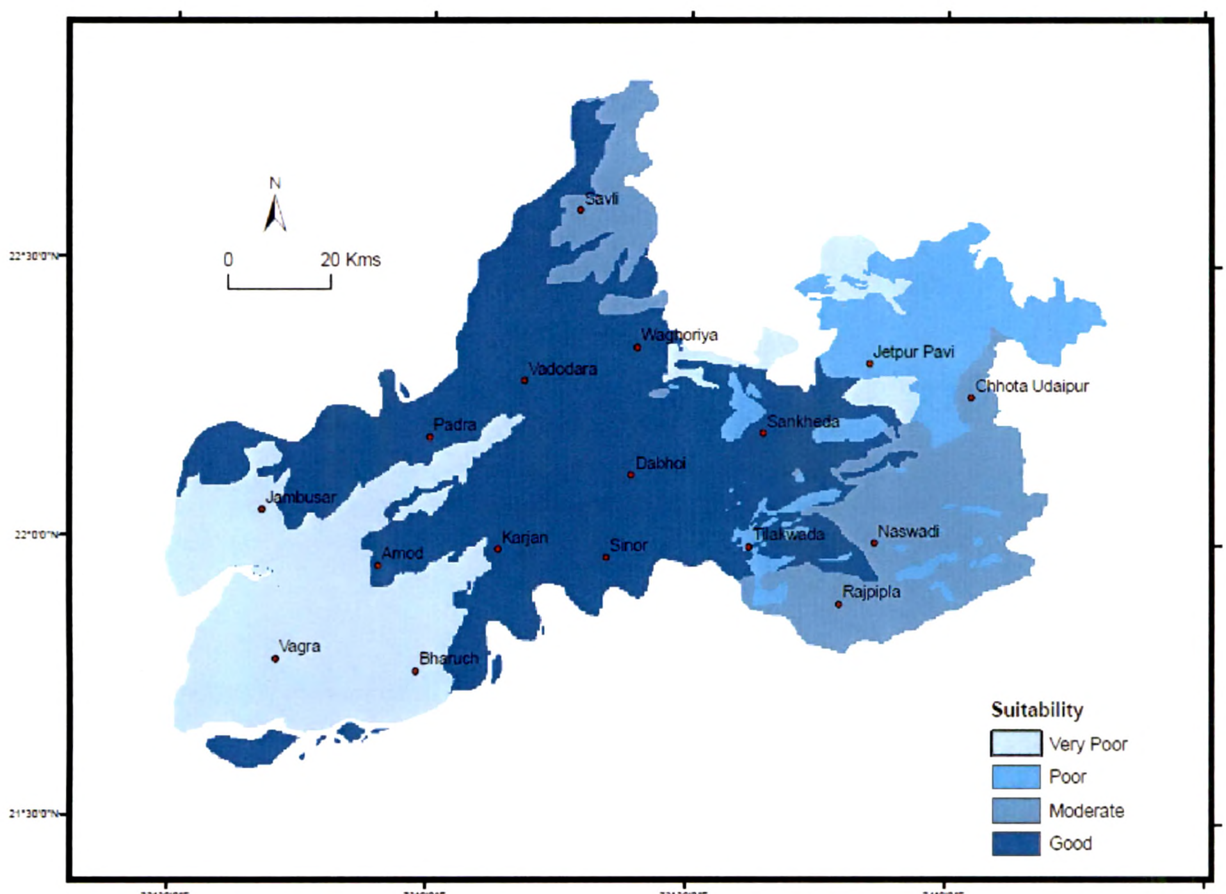

Fig-6.1 Reclassified Geological Map of the Study Area as their Suitability for Groundwater prospects

Table 6.1 Assigned Weightage to Various Lithologies and Structures in Study Area.

Lithology		Hydrostructure	Hydraulic characteristic	Weighted Rating	Remarks
Alluvium	Coastal Plain	--	High porosity but low permeability	1	Mainly present in coastal area consisting of fine clay. Groundwater is saline at shallow and deeper level
	Central Plains	--	Average Q-1000, k-15.58-277.47, T-189-4716,	4	Because of presence of primary porosity and permeability these are the best sites for groundwater development
Sandstone		Fractures and weathered zone	Q-100, C-0.06, T-39.61, k-0.37, S-0.88	2	Sandstone lacks primary porosity due to high cementing and compaction, groundwater is mainly available through joints and fractures.
Dolomite and Limestone		Jointed & Fractured	Q-600, k 5-10, T-25-50	2	Due to lack of primary porosity and permeability they do not form good aquifers.
Deccan Trap		Intersected by joints and fractures and highly weathered	Q-600, k-4.89-12.60, T-42-78, S-0.13-0.28	3	Hard rock lacks primary porosity but water is present through joints, fractures and veins, vesicles etc.
Green Marble		Jointed & Fractured	Q-100, k 5-10, T 25-50	2	The areal extent is not much do not form good aquifers
Quartzite		Sheared, shattered jointed	Q-259, C-0.06, T-16.09, k-0.06, s-0.0179	3	Secondary porosity, moderate yield
Phyllite, Slate, Schist		Jointed, Fractured, Folded & faulted	Q-90, C 0.033, T-91.33, k-0.624, S-0.019	1	Lack of permeability poor yield. However, localized aquifer may be of moderate potential
Gneiss and Granite		Jointed, fractured & sheared	Q-442, C-0.106, T-26.13, k-3.71, S-0.0179	2	Secondary porosity, localized aquifers with moderate potential

6.6.2. Hydrogeomorphology:

The study area is cropped with varieties of landforms shaped by the various processes of fluvial, aeolian and marine environments. The western part is characterized by pedeplains of sedimentaries and metasedimentaries, deccan plateau, eroded land, dissected plateau, hills, residual hills etc. while central part is monotonous formed by a vast stretch of alluvial plains. Rivers flowing through the study area has furher modified the landforms by forming various featrures which in turn gave rise to conditions for groundwater occurrence and movement. The geomorphic features like alluvial fans, buried pediment, old stream channels and the deep-seated interconnected fractures are the indicators of subsurface water accumulation. These features are the natural recharge sites due to their high permeability and water holding capacity. The coastal tract is marked by various features like estuarine river mouth, mudbanks, river bar, backshore alluvial cliffs, alluvial islands etc.

Based on the hydrological characteristic of these geomorphic features weightages are assigned. Details on this account are given in Table-6.2. Accordingly, author has reclassified the varoius goemorphic attributes as goundwater prospects categories (Fig.6.2)

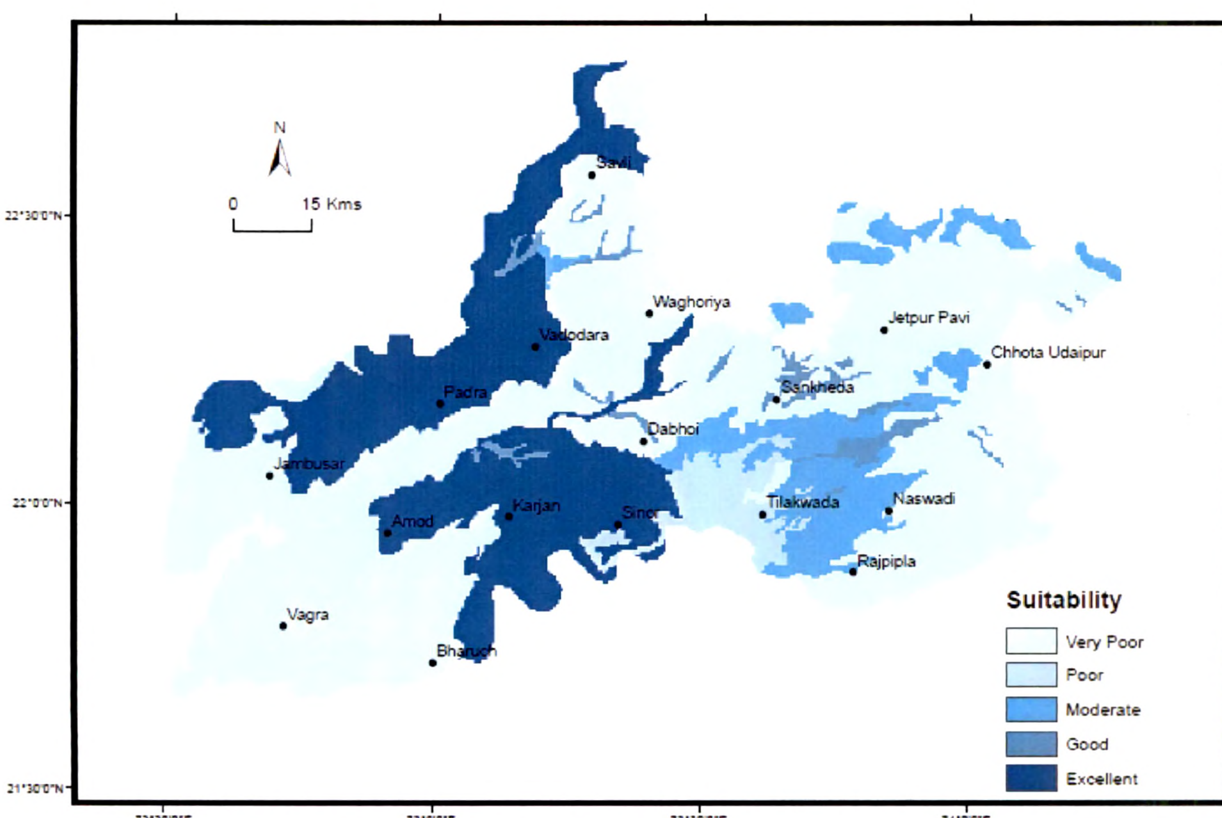

Fig 6.2 Reclassified Geomorphological Map of the Study Area.

Table 6.2 Assigned Weightage to Various Hydrogeomorphic Attributes in Study Area.

Landform	Important Hydro Affinity Features	Associated Lithology	Weighted Rating	Remarks
Alluvial Plain, Palaeo channels, Flood Plains, Old Meanders	--	Consist of gravel, sand, silt, pebble, boulders and clay	5	Level or gentle sloping, normally cultivated & presence of primary porosity and permeability these are the best sites for groundwater development
Valley fills, Vegetation Anomalies Sedimentary Pediplains	Valley fills are either lithological or structural control Sed. Pediplains are dissected with fractures	Comprises of boulders, cobbles pebbles, gravels, sand, silt & clay Sandstone and shale	4	Because of unsorted sediments, limited extent both laterally & vertically these are ranked lower Low relief with thin veneer of detritus, water is present along joints and fractures
Deccan Plateau, River Dissected hills (Meta),	Intercepted by joints and fractures Major Lineament Fault and fractures	Lava flows Varying Quartzite, phyllite & Schist	3	Low relief, undulating topography, normally cultivated. Groundwater is confined along joints & fractures & weathered zone High relief with steep slopes, water is mainly confined along lineaments
Eroded land,	--	Composed of sand, gravel, kankar etc.	2	Dissected with steep slopes usually barren
Plains, Pediplains (Meta), Dissected Plateau (mod/highly) Old Mud Flats, Sand Dunes	-- Fault, fractures Fractured & jointed -- --	Fine clay Quartzite, phyllite & Schist Lava flows Fine clay & silt Sand & silt	1	Broad erosional surface with low relief
Dissected hills (Sedimentary), Residual hills Mud flats	Highly fractured, jointed Jointed, fractured --	Sandstone, Limestone, shale Precambrian crystallines Fine silty mud	0	High relief, steep slopes, barren, dissected with fractures & no soil cover High relief, steep slopes, isolated hills, jointed & weathered Almost flat, uncultivated land covered with inter tidal water, groundwater occurs in saline condition

6.6.3 Slope:

Slope has a direct control on the surface runoff and infiltration processes. Infiltration is inversely related to slope. Gentle slopes coupled with vegetative cover will have higher infiltration and less runoff. Slope map has been generated using SOI maps. The topographic maps were scanned and geo-referenced to the specific coordinates. The slope analysis was carried out to further classify the area into five classes according to groundwater holding capacity (Table-6.3). Coastal area shows very gently or nearly horizontal slope similarly alluvium area also shows very gentle slope. Only eastern part of the study shows steep slopes (Fig-6.3). Accordingly, weight values have been assigned to the corresponding slope.

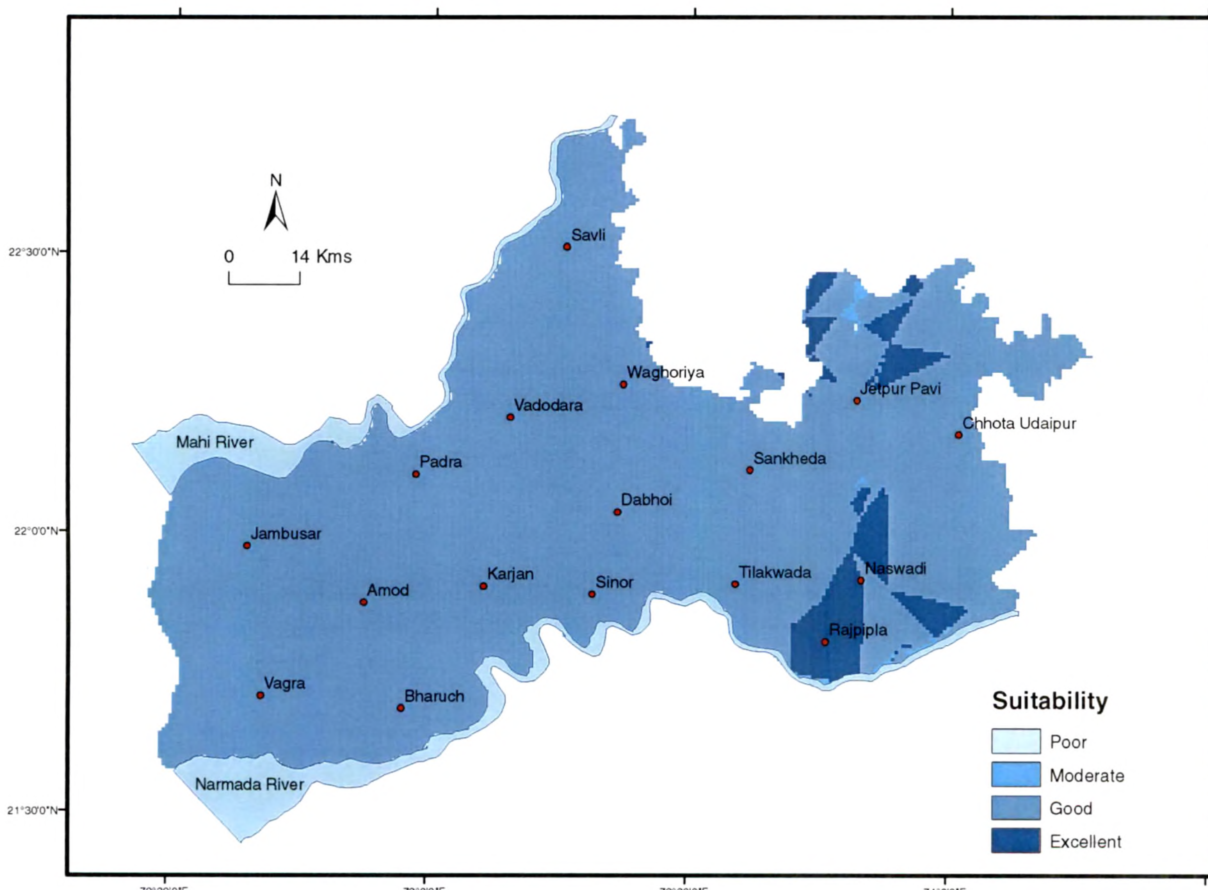

Fig-6.3 Reclassified Slope Map of the Study Area as their Suitability for Groundwater prospects

Table 6.3 Assigned Weightage for Slope in Study Area

Slope in Degree	Weighted Rating	Remarks
0-3°	5	In low slope the drainage density is less, soil development is more, weathering depth is also more which all together leads for better groundwater prospects.
3-9°	4	Dominating Supporting Recharge
9-12°	3	Dominating Supporting Runoff
12-24°	2	This is prominent in the piedmont area which contributes more towards surface runoff
Above 24°	1	High slope promotes higher runoff, no soil development and no weathered profile.

A Digital Elevation Model (DEM) was generated (Fig-6.4) using SRTM data. DEM is a digital representation of continuous variation of topographic surface with the elevation or heights above any geodetic datum. DEM helps for appreciating, the terrain and supporting factors for the slope determination.

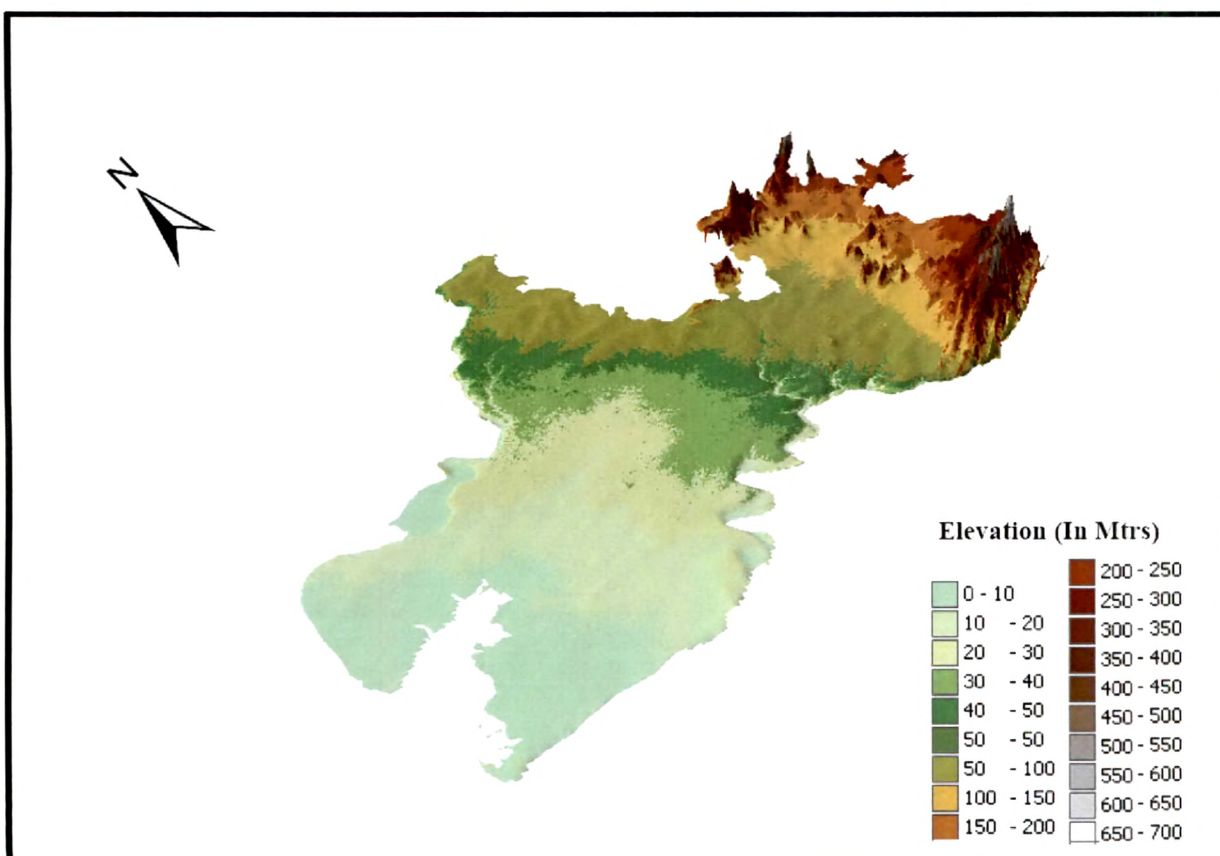

Fig-6.4 Digital Elevation Model of the Study Area.

6.6.4. Drainage Density:

It is the ratio of total channel-segment lengths cumulated for all orders within a basin area to the watershed area (Chow, 1964). Drainage density depends upon both climate and physical characteristic of the drainage basin. It defines how well or poorly a watershed is drained by stream channel. Soil permeability, bed rock type characteristics affect the runoff/recharge of watershed. Impermeable ground or exposed bed rock will lead to an increase in surface runoff and therefore more number of streams. Rugged terrain or those with high relief will also have a higher drainage density than the other basins, if the other characteristics of basin are same. Shape of river's hydrograph also depends to a large extent on drainage density. Rivers that have a high drainage density will often have flashy hydrograph with a steep falling limb. High drainage densities normally indicative of high flood peak hydrographs.

The major portion in the study area is occupied by alluvial deposits which is porous, permeable and under low relief. The area dose not show development of drainages especially in the western and central part. The eastern part of the study area is characterized by terrain with steep topography and good development of drainage network.

In general, high drainage density reflects high runoff and low infiltration while low drainage density denotes low runoff and high infiltration (Chow, 1964). However, the vast area under study is covered by alluvium and top soil horizon is characterized by black cotton soil as well as saline soil (coastal area) therefore, stratum lack requisite permeability to infiltrate the water and causing inundation during monsoon. This very aspect has been taken into account during overlaying of various thematic maps for producing one single map of identified recharge area/point (Fig-6.5).

All streams in each grid were calculated in order to determine the drainage density values Study area was divided into square grids of 10 x10 km and the total lengths of in km/km^2. These values were regrouped to produce a drainage density map that was classified into five categories (Table-6.4).

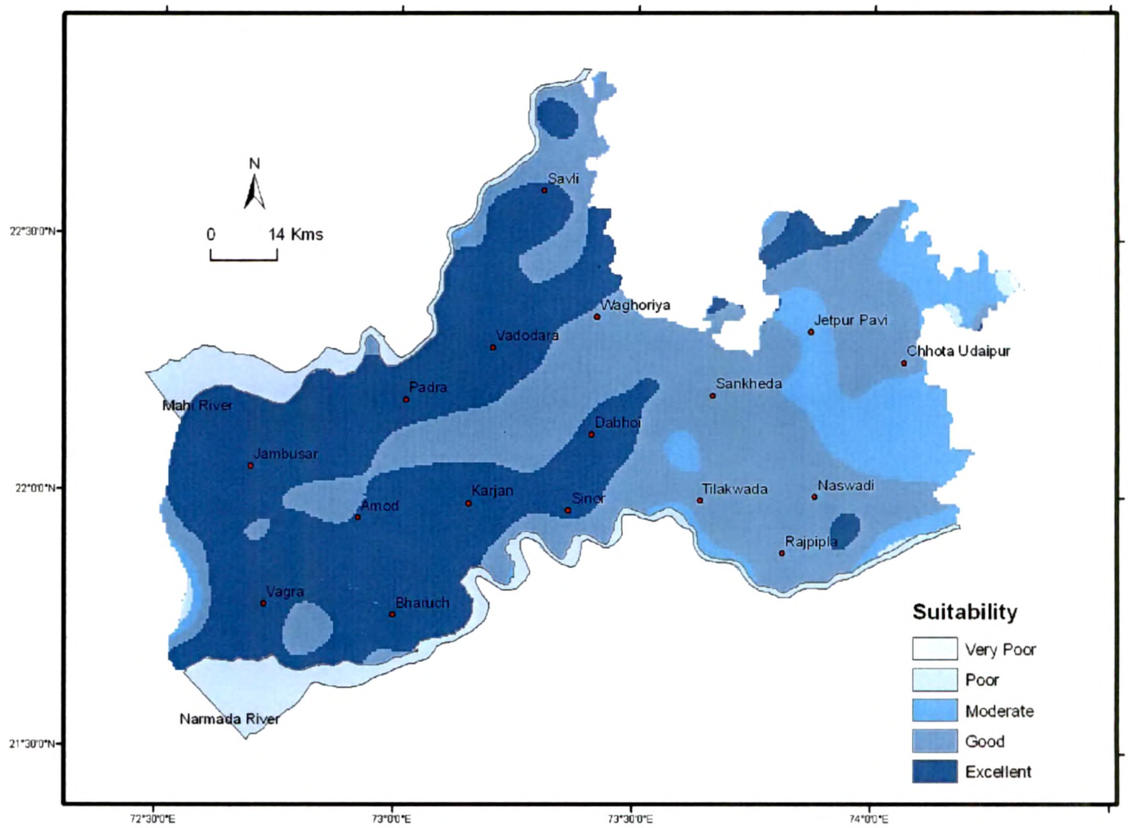

Fig-6.5 Reclassified Drainage Density Map of the Study Area as their Suitability for Groundwater Prospects.

Table 6.4 Assigned Weightage Values for Drainage Density

Sr No	Range	Weighted Rating	Remarks
1	0 – 0.38	5	Highly permeable subsoil material, dense vegetation and low relief
2	0.38 – 0.77	4	In-between values varies between the two extreme conditions
3	0.77 – 1.16	3	
4	1.16 – 1.55	2	
5	1.55 – 1.94	1	Exposed hard rock terrain, low permeable formation, sparse vegetation and mountainous relief

6.6.5. Land Use:

The term land use refers to man's activities on land which are directly related to land. Satellite image of Landsat ETM^{+}, 2001 for the post monsoon was used for visual classification. The study area was classified into eight major land use attributes classes (Table-6.5) as per USGS classification level I. It is observed that the eastern part of the study area comprises of dense and open forests and waste land while the central and western part is predominantly agriculture based. The extreme west closer to coast area is saline hence zero weight value has been assigned. Accordingly re-classified land use map (Fig. 6.6) was prepared assigning 05 different suitability categories

Table 6.5 Assigned Weightage Value for Land Use

Land use	Weighted Rating	Remarks
Dense Forest, Agriculture & Water Body	5	These are the best sites as it regulates, retards surface runoff and enhances recharge to groundwater.
Open Forest	4	Such sites primarily checks surface runoff by decreasing the velocity of rainfall and reducing the surface runoff thereby accelerating recharge.
Fallow Land	3	Such sites do contribute by providing favourable conditions for ground recharging.
Settlement	2	Such area are paved which impedes recharging of water to ground.
Waste Land	1	Due to high rate of erosion development of soil and weathered profile do not take place hence such area do not contributes for groundwater recharge.
Saline land	1	Saline lands are mainly clay dominating wherein recharge is almost nil, moreover, soil is rich in salt content and shallow and deeper aquifers are saline.

6.6.6. Soils:

Black cotton soil is predominantly present in Amod, Vagra, part of Bharuch taluka between river Narmada and Dhadhar. Also, in Jambusar area which is North of Dhadhar and in Nandod taluka. The soils in the alluvium plains are dominantly very deep, well drained, and fine loamy to fine in texture. They are slightly alkaline and calcareous. Along flood banks of rivers like Mahi, Dhadhar and Narmada they are severely eroded. The soils have varying degree of average water capacity from low to high depending upon textural variation. While the soil occurring on the coastal plains are dominantly very deep, imperfectly to poorly drained and fine textured soils are slightly to moderately alkaline and calcareous and salt affected. The alluvium plains area between Dhadhar and Mahi Rivers is occupied by the soils which are very deep, well drained, fine loamy soils which are affected by erosion. Where as the area between Dhadhar and Narmada Rivers in alluvium consist of soil which is very deep, moderately well drained, calcareous, fine to very fine with slight to moderate erosion and at places with moderate salinity. The eastern part of the study area characterized by highland and piedmont zone display wide variation in soil types attributed to varied rock types. The soils in rocky outcrops are shallow. In other areas it is shallow to deep and at places very deep, well drained, and calcareous to clayey fine soils associated with slight to moderate erosion.

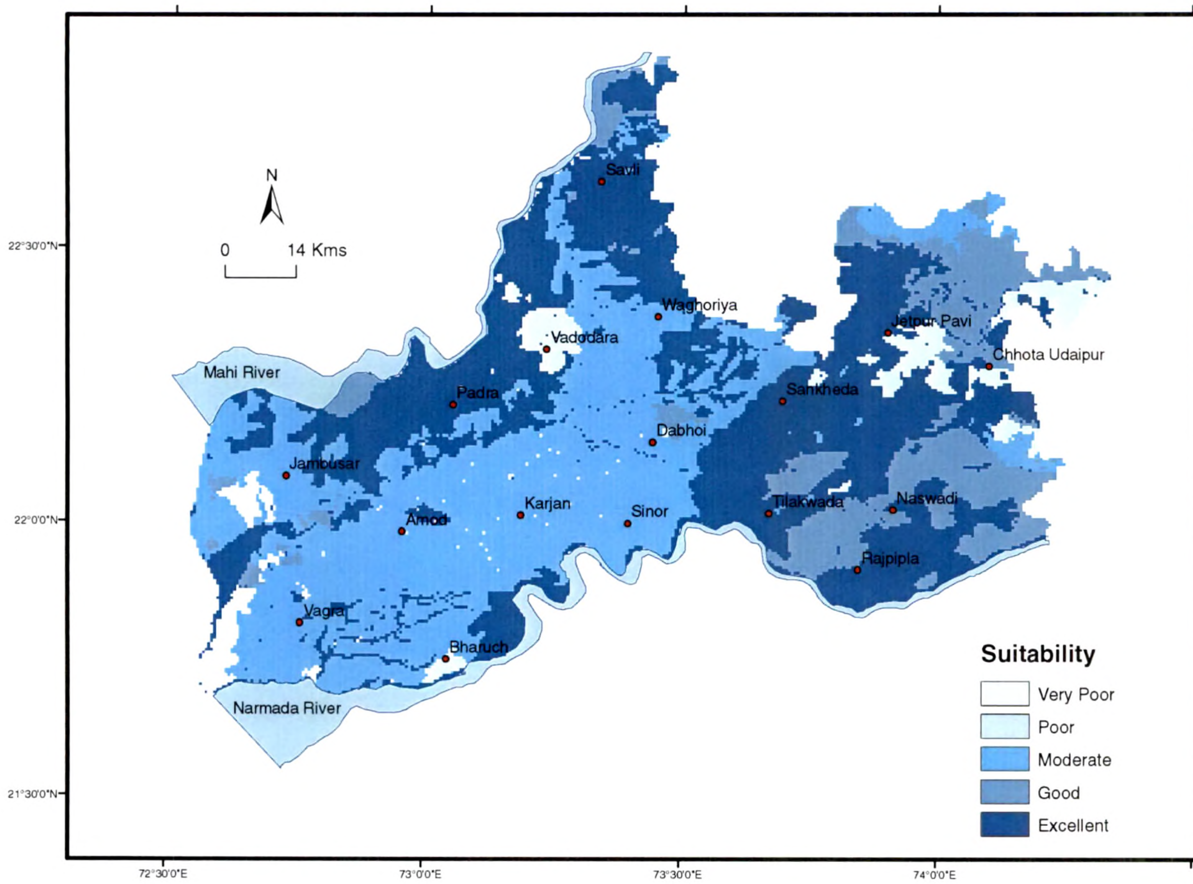

Fig-6.6 Reclassified Landuse Map of the Study Area. As their suitability for groundwater prospects

Based on the properties of soils available in study area corresponding weightage are assigned from 5 to 1 wherein the soil with 5 weightage are considered to be the best from groundwater recharge point of view. Details on the assigned weightage are given in Table-6.6. The reclassified soil map has been prepared based on the five weightage which clearly indicates areas suitability for groundwater recharge (Fig-6.7).

Table 6.6 Assigned Weightage Value for Soil

Soil Classification	Weighted Rating	Remarks
Coarse Loamy, very deep, excessively drained, nearly level, slight erosion	5	Intergranular porosity is high as a result good for recharging
Calcareous coarse Loamy, moderately deep, excessively to moderately drained, slight to moderate erosion, very gentle slope	4	Due to gentle slope the development of soil takes place which contributes to groundwater recharge.
Fine Loamy, deep, moderately to excessive drained, on gentle sloping ground, moderate erosion	3	The infiltration and percolation of groundwater is restricted to some extent due to fine loamy nature of soil.
Fine soil, moderately shallow, moderately to well drained, gentle sloping, severs erosion	2	As soil becomes fine the permeability decreases which impedes groundwater movement.
Clayey, shallow, well drained, moderately steep with very severe erosion	1	Because of clay, permeability is low, further steep slopes contributes to runoff rather than recharge.

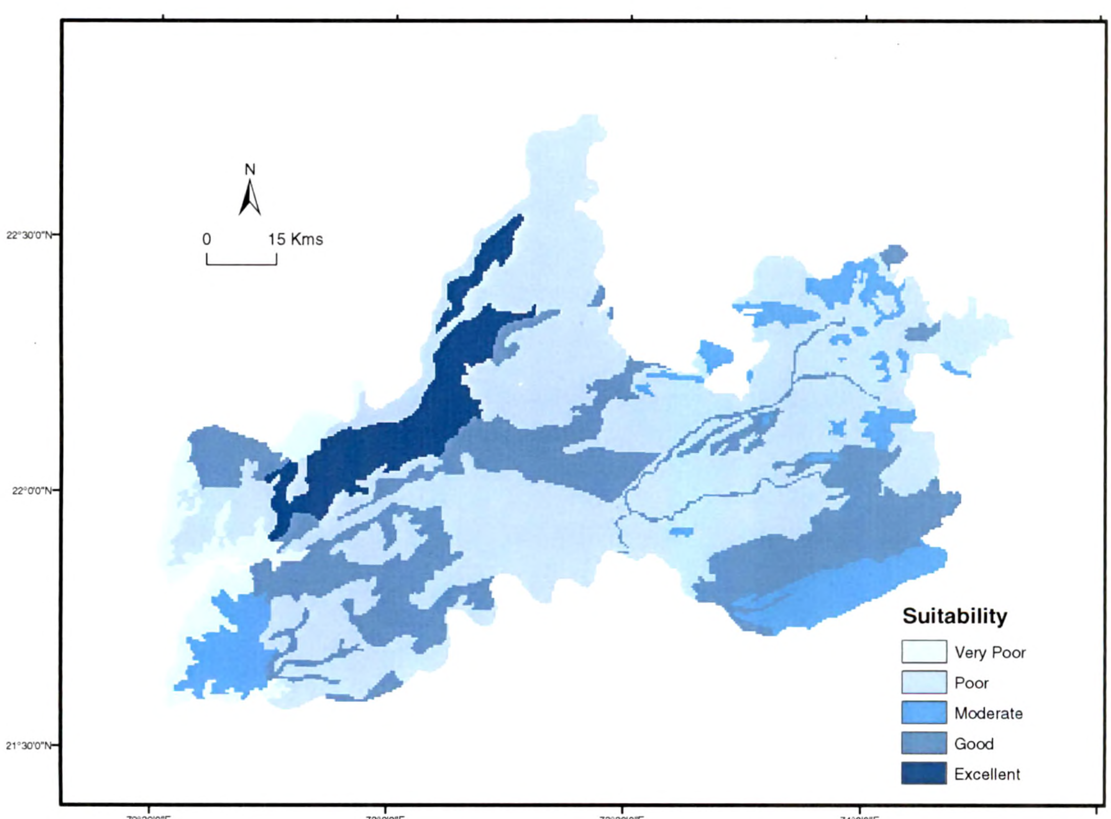

Fig-6.7 Reclassified Soil Map of the Study Area. As their suitability for Infiltration and groundwater prospects

6.7. Groundwater Resource Evaluation: Interpretation and Modelling

In groundwater development estimation of groundwater recharge is an important issue. This requires proper understanding of the recharge and discharge process and their interrelationship with geological, geomorphological, soil, land use and climatic factors. There are various methods in vogue for the quantitative evaluation of groundwater recharge viz. (a) groundwater level fluctuation and specific yield method, (b) rainfall-infiltration method and c) Soil moisture balance method (Thornthwaite and Mather, 1957) and (d) water balance approach.

The conventional approach for groundwater recharge assessment has some limitations in spite of its simplicity and wide applicability in varied hydrogeological setup. Methods like rainfall infiltration or water level fluctuation uses average values of rainfall or water level fluctuation for a watershed which is the most appropriate unit for groundwater recharge estimation. But the spatial variability in the components of recharge is not considered whereas in case of remote sensing and GIS application, spatial distribution of the variables are taken into account, thus preparing an information layer for the whole of the study area.

6.7 Weighted Sum Analysis

The Weighted Sum Tool provides the ability to weight and combine multiple inputs to create an integrated analysis. It is similar to the Weighted Overlay Tool in that multiple raster inputs, representing multiple factors, can be easily combined incorporating weights or relative importance. One major difference between the Weighted Overlay Tool and the Weighted Sum Tool is that the Weighted Sum Tool allows for floating point values whereas the Weighted Overlay Tool only accepts integer rasters as inputs.

Generally, the values of continuous raster are grouped into ranges and each range is assigned a single value to represent a class such as low, medium or high importance. The re-classify tool allows for such raster being re-classified. The Weighted Sum Tool is useful when floating-point output or decimal weights are required. Weighted Sum works by multiplying the designated field values for each input raster by the specified weight. It then sums (adds) all input rasters together to create an output raster. Thereafter, each raster layer was added to weighted sum table. Each input raster can be weighted or assigned a percentage of influence, based on its importance. The cell value of each input rasters are multiplied by raster's weight. The resulting cell values are added to final out put raster (Fig-6.8).

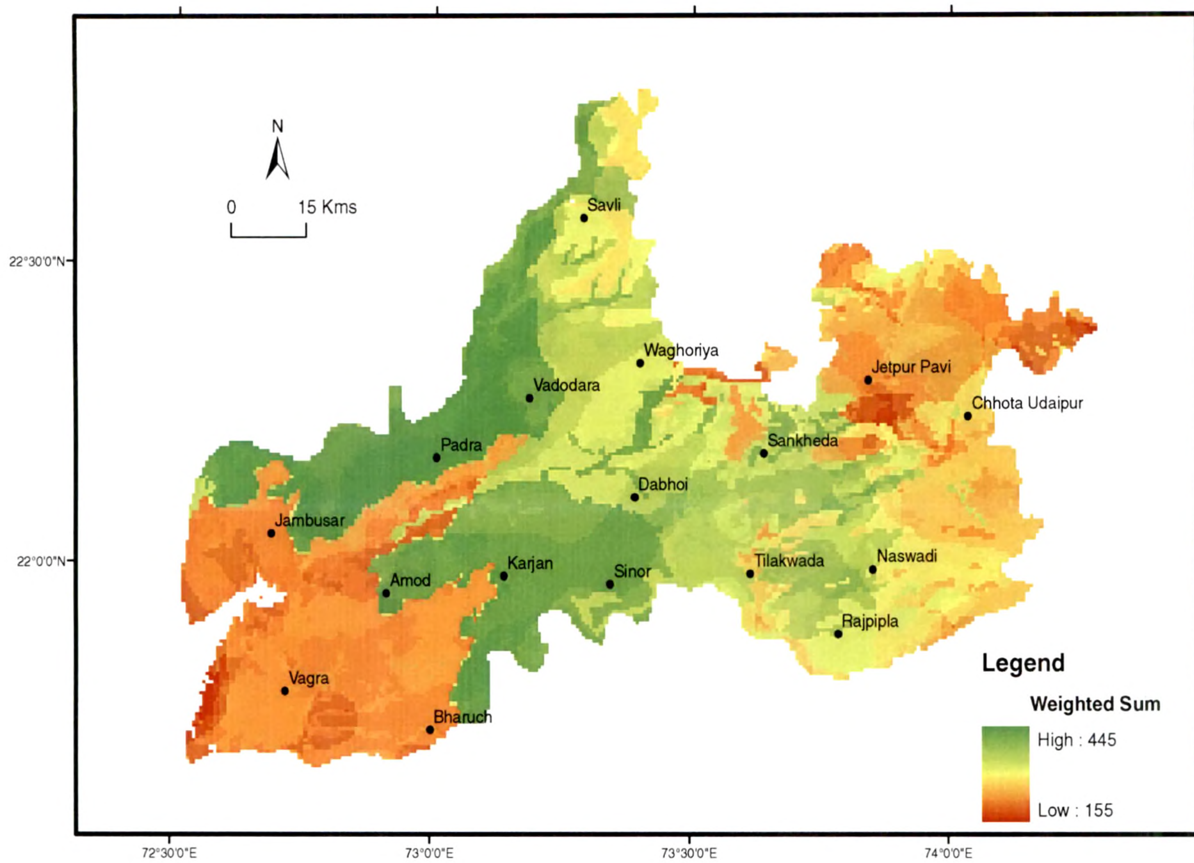

Fig-6.8 Weighted Sum Map of the Study Area

6.9. Weighted Index Overlay Method for Groundwater Prospects

Weighted Index Overlay Analysis (WIOA) is a simple technique for applying a common measurement scale of values to diverse and dissimilar inputs to create an integrated analysis. The effectiveness of this method is that the individual thematic layers and their classes are assigned weightages on the basis of their relative contribution towards the output. There is no standard scale for a simple weighted overlay method. For this purpose, criteria for the analysis are defined and each parameter is assigned weightage based on its importance (Saraf and Choudhury, 1997 and Saraf and Choudhury, 1998). Determination of weightage of each class is the most crucial in integrated analysis, as the output is largely dependent on the assignment of appropriate weightage. Consideration of relative importance leads to a better representation of the actual ground situation (Choudhury, 1999).

In the present study, weighted indexing method has been used to identify and demarcate the suitability zones for groundwater recharge which can also be used as sites for artificial recharge. Thus, multiple thematic layers of influencing parameters like Geology, Soil, Slope, Drainage density and Land use were prepared and assigned weights as per the importance in the selection of recharge sites. These layers in turn formed the vector base which was converted into raster according to the weights. Each raster was assigned percentage influence based on its importance (Table-6.7). Each input raster can be weighted and the total influence for all raster equals 100 percent. Moreover, individual thematic layers and their classes are assigned weightage on the basis of their relative contribution towards the output. Using this suitability modeling, suitable areas were identified wherein the classes with higher values indicate the most favorable zones for natural recharge and also for artificial recharge structures (Fig-6.9).

Table-6.7 Showing the Percentage Influence on Layer Attributes

Sr No	Major Unit	Raster layer	% influence
1	Hydrogeology	Geology	35
2	Hydrogeomorphology	Drainage Density	20
3		Landform	20
4		Slope	15
5		Soil	5
6		Land use	5

6.10 Results and Discussions:

- Groundwater recharge estimation

Quantitative estimation of groundwater recharge is done by adopting rainfall infiltration approach. The area of recharge following in various categories as identified in weighted overlay map is calculated. Thereafter, isohyets map is superimposed over the weighted overlay map. Average rainfall falling in different zones/category is taken. For Zone-2 (Poor recharge potential) average of minimum (640mm) and maximum (1070mm) contour is taken. In Zone-3 (moderate recharge potential) average value 794 of minimum 640mm and maximum 1010mm is taken. For Zone-4 (Good potential site) average 916mm of minimum 690mm and maximum 1070mm is taken.

The study area consists of both consolidated and unconsolidated lithounits with varying infiltration capacity. Therefore, lower values have been taken for computation of recharge by rainfall. The validity of groundwater recharge can also be computed by superimposing the water table map of the study area and thus comparing the results. This shall also require other factors affecting the groundwater recharge like groundwater draft, recharge from canal seepage, recharge from recycled groundwater, recharge from recycled surface water and unaccounted natural discharge from the subsurface water regime and others. By computing all above variables a realistic picture can be obtained for better groundwater management practice. In the present work author has only used rainfall infiltration approach so as to compare the results with other approaches adopted in 'water budgeting' chapter.

Table 6.8 Potential Groundwater Recharge Area

Sr. No.	Value Class	Classification	Area (km2)	Average Rainfall (mm)	Percentage Recharge %	Total Recharge MCM
1	2	Poor	2930.22	880	3	77.35
2	3	Moderate	4114.41	794	8	261.34
3	4	Good	4056.853	916	15	557.41
4	**Total**		**11101.49**			**896.11**

The total average recharge of the study area based on the above factors comes out to be ±896MCM annually.

- Groundwater Quality Estimation:

Groundwater quality is the main factor for its use in drinking, domestic, irrigation and industrial purpose. In order to compare and test the result obtained from GIS work, TDS-isoline map is superimposed over the weighted overlay map. The high TDS values coincide with the areas of poor recharge (Fig-6.10).

An Iso-TDS map of post monsoon 2002 is used to compare with the results obtained from weighted overlay method. The Iso-TDS map depicts that the contours are ranging between 500-15000 ppm with an average concentration of ±1300 ppm for the entire area. Further, the contour pattern indicates an increasing trend towards western side with four well developed maximas at various locations that coincides with the poor zone of weighted overlay map. The Iso-TDS map of the study area shows higher concentration of isolines in coastal plains than the alluvial plains which is much higher than the eastern highlands.

In weighted overlay map the eastern highlands shows poor to moderate zone of recharge, whereas TDS value in this area is low and within the permissible limit of drinking and

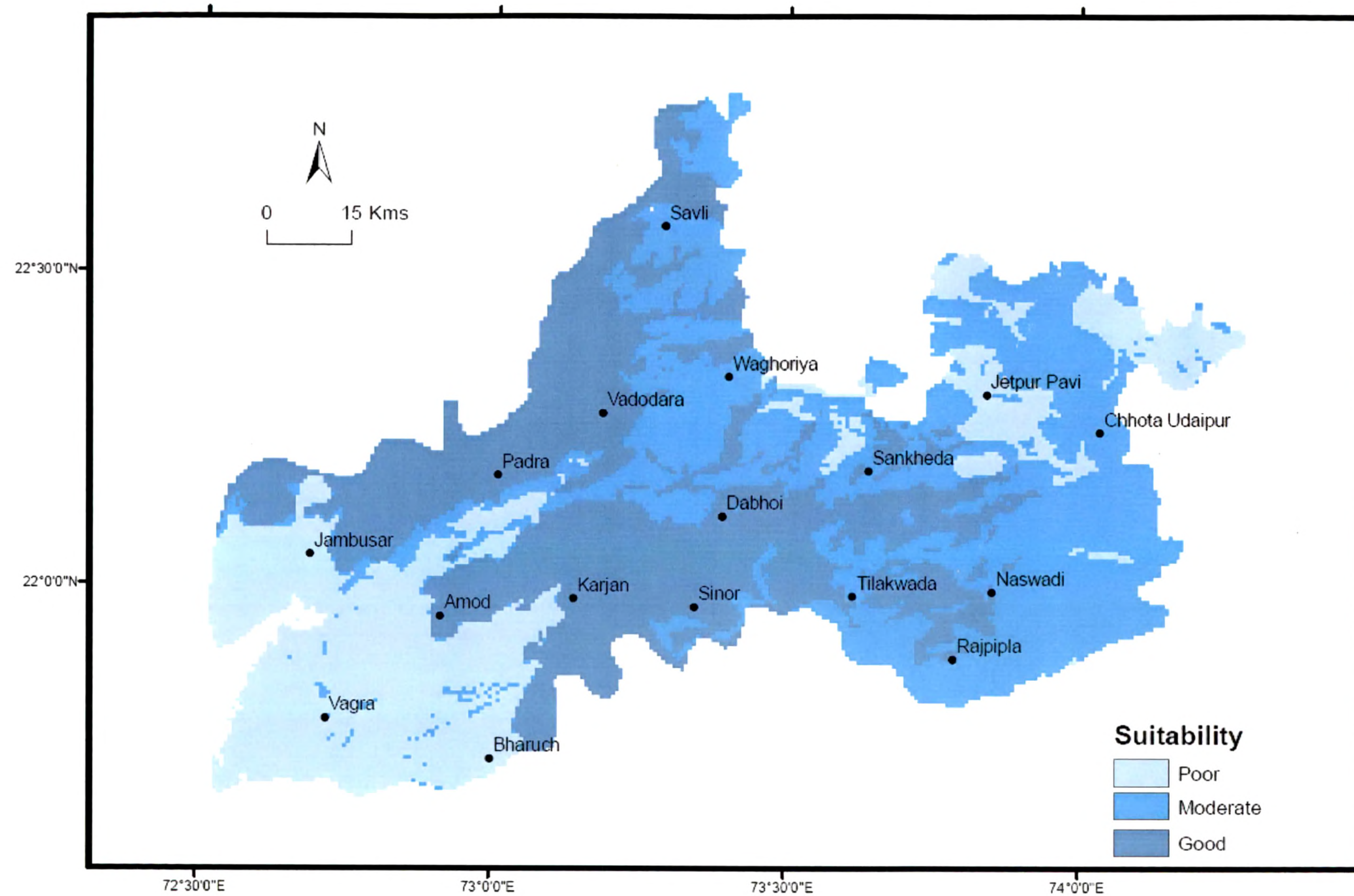

Fig-6.9 Final Weighted Overlay Index Map of the Study Area Showing Suitable Areas for Groundwater Recharge.

agricultural norms. This is mainly due to the fact that in hard rock although primary porosity and permeability is low, but fractures and joints facilitate flushing of salts. Further, high drainage density and slope, poor soil development and other hydrogeomorphic features favourable for groundwater development are less which contributes for lower assigned values. In alluvial and coastal plains although the groundwater prospects are better however, its poor quality is contrary to eastern highlands.

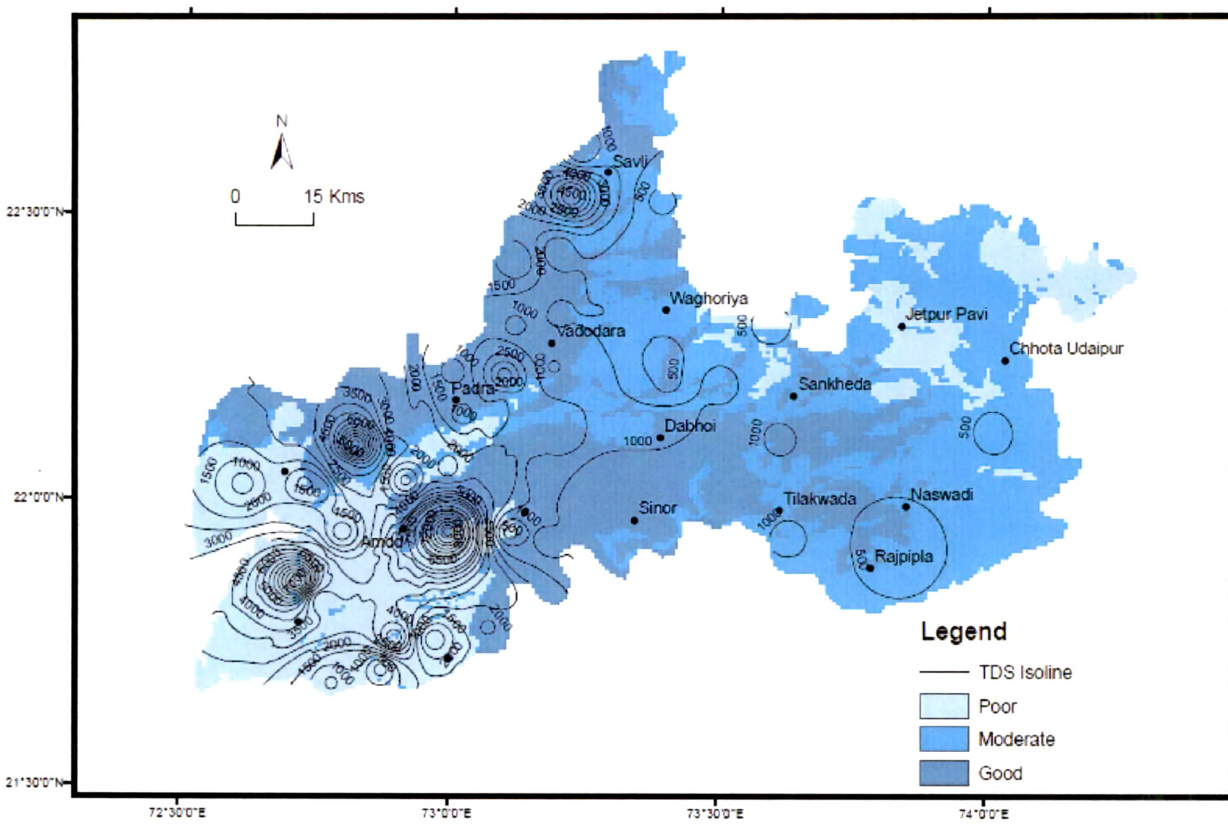

Fig- 6.10 Overlay of TDS Isoline and Weighted Overlay Index Map.

These highlands act as a zone of recharge for aquifers at downstream. Groundwater after monsoonal recharge flows downstream towards west under the effect of gravity/slope. This is also evident from well hydrographs (Fig-5.5 to 5.8) wherein effect of rainfall is quite conspicuous and pre and post water level fluctuation is high. In alluvial plain the water fluctuation is not high and the effect of rainfall is not seen immediately. Coming to the coastal track groundwater flow appear minimum to non-existent as a result of no effective flushing mechanism exists therefore, groundwater is saline in most part.

➢ Integration of Weighted Overlay Map And Oxygen Isotope As An Indicator To Identify The Zones Of Recharge

The pre and post monsoon groundwater fluctuation data for 10 years (1993-2003) is utilized for quantitative assessment of recharge in the study area. The average value for pre and post monsoon water table is calculated. The fluctuation in water table ranges from -3.1m to 11.1m with an average fluctuation stand at 2.3m. Therefore, area exhibiting water table fluctuation greater than 2.3m has been considered, as zones of recharge sites. On integrating these information with weighted overlay map, the zones of recharge identified through GIS approach coincides with the area displaying an overall rise in water table fluctuation data. Similarly $\delta\ ^{18}O‰$ isoline has also been superimposed over the weighted overlay map to validate the area of recharge (Fig-6.11.). The negative values $\delta\ ^{18}O‰$ indicates zone of recharge while positive contour values indicate zones of no recharge. One high maxima in the coastal plain with positive isotope values coincides with the poor recharge zone, whereas the negative maximas overlies the zones of good recharge. Both these integrated maps of oxygen isotope variation and water table fluctuation contour of the study area with weighted overlay map are in conformation and substantiate the conclusion.

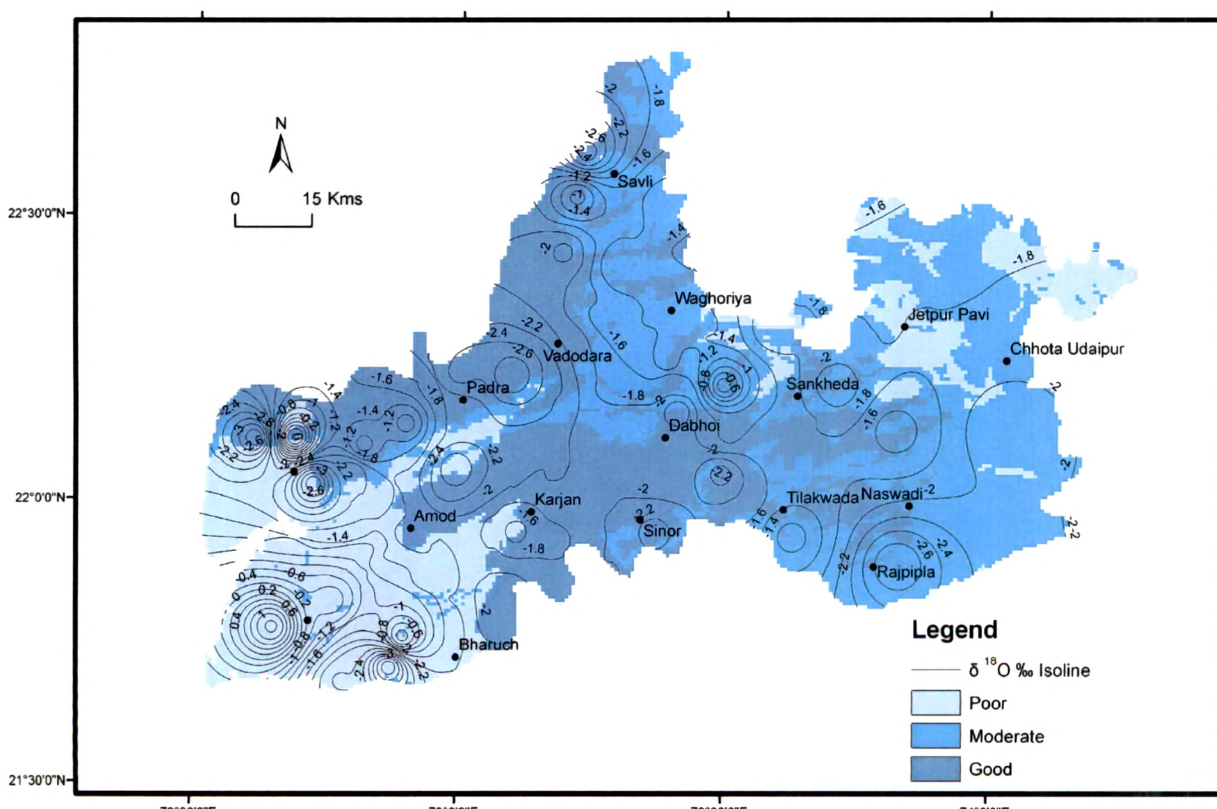

Fig-6.11 Overlay of $\delta\ ^{18}O‰$ and Weighted Overlay Index Map Depicting the Area of Groundwater Recharge.