An Integrated Geochemical and Geospatial Approach for Assessing the Potential Ground Water Recharge Zones in Mahi -Narmada Inter Stream Doab Area, Gujarat, India

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Abstract

Mahi-Narmada inter-stream region (Doab) in Gujarat is a unique landscape bounded by rivers Mahi and Narmada in the north and south respectively followed by the physiographic truncation by the eastern highlands comprising mainly the Deccan flood basalts and abruptly ending along the western margin due to the Cambay gulf. These distinct hydro-geological boundaries have controlled the ground water regime in the region. The region being part of the Golden Quadrilateral has witnessed highest industrial growth in India. Use of groundwater for irrigation, industrial development and urban expansion have stressed the aquifers and even the surface water bodies are also over utilized; thus adversely affecting the quality and quantum of the water resource of the region.

A study was carried out to understand the gravity of the problem stated and also to propose a strategy of monitoring and management of the water resource of the region. The pre- and post-monsoon groundwater sampling of 2002 was carried out and corresponding physical and chemical data generated has established that the groundwater in the study area has unusually high concentration of major, minor and trace elements.

A multi-parametric dataset comprising satellite data and other conventional maps including Survey of India (SoI) topographic maps (1:50,000 scale), drainage density, landforms, slope, soil and land use maps, etc. were integrated into Geographic Information System (GIS) environment to generate various thematic maps such as; recharge and discharge zone maps, groundwater quality maps finally culminating into water resource management scheme for the region. The maps so generated have been very close to the field conditions, the study has thus helped in the development of ground water monitoring and managing strategy.

The study indicates that periodic monitoring of the groundwater resource with the help of GIS will help in proper management of groundwater resource by identifying the zones/areas of recharge that shall be required to be protected from being converted into built up areas. Moreover, such area also needs to be protected for being used for extensive cultivation as this can leads to contamination of groundwater resource by use of insecticide, pesticides and other chemicals. The study puts emphasis on conjunctive use of surface and groundwater by applying proper management practices so that there is effective use of water.

Keywords: Hydro geochemistry, GIS, groundwater, Total Dissolved Solids (TDS)

1. Introduction

Development of any area to a large extent depends upon the utilizable water resources present and its development potential. Rapid pace of industrial and agricultural development coupled with population growth has necessitated looking in the intricacies of hydro-geological regime with a view to reexamine the role of natural processes that affect the natural water resources in terms of quality and quantity. Further, to explore the possibilities of tapping deeper water resources and aspects of conjunctive use.

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

2. The Study Area

The Central Gujarat region i.e. Mahi-Narmada Inter stream Area (Doab) represents an ideal terrain characterized by a diverse geological environment infected from assorted hydrological problems. The study area has a distinct physiographic boundary and is bordered by Gulf of Cambay in the West, the rocky uplands in the East, Mahi River in the North and Narmada river in the South. The area lies between 72º 30' E and 73º 43' E Longitudes and 21º 40' N and 22º 53' N Latitudes, falling in 46/ B, C, F, G, J & K topographic sheets of the Survey of India. Administratively it covers almost all talukas of Vadodara district, four talukas of Bharuch district and two Talukas of Narmada district (Figure 1).

2.1 Geography, Climate and Landuse

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

The study area inhabitates sizable population. As per 2001 Census, population of the 18 Talukas falling within 03 districts was 25.61 lakh. Population density for this area is 243 person/km^2 The study area is characterized by poor land use pattern with almost 50% of the land fall under un-irrigated area and less than 7% area as forest land. Only 19% area is benefited by irrigation facility. The land use classification according to the different uses for the rural areas is given in Table 1.

2.2 Geology and Geomorphology

The study area display considerable heterogeneity in its geological environment. Area is characterized by rock formations ranging in age from Precambrian to Recent (Figure 2). The basement gneissic complex, phyllite, schist, quartzite and post Delhi granites belonging to Precambrian Formation are exposed in the eastern parts of the study area. The Precambrian rocks are unconformably overlained by the rocks of Bagh sedimentary sequence consisting of sandstone, shale and limestone of Cretaceous age. These are further intruded by extensive Deccan trap volcanics of Cretaceo-Eocene age.

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

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

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

a) The eastern uplands zone,

b) The intermediate pediment zone,

c) The central alluvial zone and

d) The low coastal zone.

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

2.3 Water Resources

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

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

3. Methodology

3.1 Hydro geochemistry

The groundwater samples were collected from four geomorphic divisions of the study area i.e. coastal plains, alluvial plains, piedmont zone and highlands (Figure 3). Samples were collected from shallow aquifer (hand pumps/dug well) and deeper aquifers (tube/bore wells). As the eastern highland region is rocky and predominated by phreatic aquifers samples were collected only for such aquifers. The groundwater movement direction as evident from reduced water level map indicates that highlands act as a recharge zone to the shallow and deeper aquifers. Some of these aquifers through lower aquitard layer are in hydraulic connectivity with the lower aquifers thereby gets recharged (CGWB, 1994).

Geochemical analysis has established that the groundwater in the study area has high concentration of major and minor ions (Table 2). These ionic concentrations tend to decrease from western coastal plain to the eastern highland parts. Some of the inland aquifers do show high concentration of ions but they are localized viz. at Falod (Waghodia Taluka) village shallow aquifer is saline but deeper aquifer contains potable groundwater.

The pH level of the ground water fall in alkaline field and most of them are well within the range. The pre-monsoon 2002 samples show concentration almost within the permissible limits except at Sindhav village (Jambusar Taluka) and Ambada village (Padra Taluka). The average range of constituent ions in groundwater samples of pre and post monsoon periods indicate minute but noticeable change in their ionic content. The average difference indicate an overall decrease in pH, Total Dissolved Solids (TDS), Ca, Mg and Sulphate whereas increase in total hardness, chloride and nitrate concentration from pre to post monsoon season. Therefore, overall groundwater quality tends to deteriorate from eastern hilly zone to western coastal plains which follow the ground water gradient direction.

3.2 Remote Sensing and GIS

In the present study, integrated remote sensing and GIS techniques have been used to generate groundwater potential map and prediction of recharge zones in the study area. Various information like geology, geomorphology, soil, structures, landcover/landuse, and other relevant information have been extracted from satellite data, Survey of India (SOI) topographical sheet and aided by field checks. All the thematic information layers were digitized and analyzed in GIS environment to derive composite maps for identifying suitable zones for construction of artificial recharge structures. Thereafter, 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. Each input raster was 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.

The result of this study is useful for identifying potential zones for recharging shallow aquifers, while for deeper aquifers further details like sub surface information and aquifer characteristics are required along with field inputs. Overall characterization of the study area based on various adopted approach it can be concluded that the poor recharge zone constitutes 26.1%, moderate zone 37.2% and good recharge zone is 36.7% of the total study area.

3.3 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 3). 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 (Figure 4).

3.4 Overlay of TDS Isoline and Weighted Overlay Index Map.

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 (Figure 5). The high TDS values coincide with the areas of poor recharge.

An Iso-TDS map of pre and 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 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. Eastern highlands of the study area act as a zone of recharge for aquifers at downstream. Groundwater after monsoonal recharge flows downstream towards west under the effect of gravity/slope. 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 highland. Moreover, 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.

4. Results and Conclusion:

As per the census of India (2001) the study area shows that out of total area, forest cover is 6.7%, total irrigated area is 19.5%, un-irrigated area is 50.7%, cultivable waste is 6.8% and area not available for irrigation is 16.4%. With this available data, an integrated remote sensing and GIS based methodology has been used to identify the area suitable for recharge. The study has demonstrated that the recharge sites are in conformity with the land use pattern of the area and the identified sites are the best locations for artificial recharge and putting rain water harvesting structures. This has been confirmed by superimposing the final overlay map over TDS contour map to identify the area not suitable for groundwater development from quality point of view.

The identified sites are required to be protected from pollution as they are most potential/vulnerable sites for overall degradation of the area. Such sites should not be given for industrial area development and especially for chemical industries. Moreover, if they are being used for agricultural practices there excess use of fertilizers, pesticides, insecticide etc should be discouraged. Moreover, these identified zones should not be used for urban area development on the contrary construction of artificial lake/pond in recharge zones shall be very useful for recharging the groundwater.

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Table 1. Population Status and Land use Pattern in the Study Area

District	Area (Km^2)	Total Population (Persons)	Forest land (Km^2)	Total Irrigated area (Km^2)	Unirrigated area (Km^2)	Culturable waste (Km^2)	Area unavailable for cultivation (Km^2)
Vadodara	7264.00	19,95,580	701.2007	1754.441	3401.1322	572.873	825.5523
Narmada	244.422	56059	8.1427	16.862	170.7519	20.3625	28.2973
Bharuch	3016.779	509462	0.8132	261.1085	1759.7931	121.502	871.557
Grand Total	**10525.20**	**2561101**	**710.1566**	**2032.4115**	**5331.6772**	**714.7375**	**1725.4066**
(Source: Census of India, 2001)							

Table 2. Comparison of Groundwater Samples from Study Area with Drinking Water Quality Standards.

Sr. No.	Parameters	ICMR (1975)	ISI (1983)	WHO (1993)	Study Area Sample	
					Pre Mon 2002	Post Mon 2002
1	**PHYSICAL PROPERTIES**					
2	Colour (Hazen)	5 (25)	10	5 (50)	NA	NA
3	Odour	Not Desirable	Unobjectionable	Not Desirable	NA	NA
4	Taste (JTU)	"	Agreeable	"	NA	NA
5	Turbidity	5 (25)	10	5 (25)	NA	NA
6	**CHEMICAL PROPERTIES**					
7	pH	7.0-8.5 (6.5-9.2)	6.5-8.5	7-8 (6.5-9.2)	7.61-8.87	7.06-8.6
8	TDS (mg/l)	500 (1500)	2000	500 (1500)	420-9542	200-15094
9	TH (mg/l)	300 (600)	300	300 (600)	92.4-2667	58-3500
10	Calcium (mg/l)	75 (200)	75	75 (200)	18.5-370.6	5-589.5
11	Magnesium(mg/l)	50 (150)	30	50 (150)	0.55-459.6	0.0-492.8
12	Chloride(mg/l)	200 (1000)	250	200 (600)	49.9-3798.8	20-6240
13	Sulfate (mg/l)	200 (400)	150	200 (400)	50-7800	30-10770
14	Fluoride (mg/l)	1.0 (1.5)	0.6 (1.2)	--(1.5)	NA	NA
15	Nitrate (mg/l)	20 (50)	45	--(50)	NA	NA
16	Copper (mg/l)	0.05 (1.5)	0.05	1.0 (1.5)	NA	NA
17	Iron (mg/l)	0.3 (1.0)	0.3	0.3 (1.0)	NA	NA
18	Manganese(mg/l)	0.1 (0.5)	0.1	0.1 (0.5)	NA	NA
19	Zinc (mg/l)	5.0	5.0	5.0	NA	NA

NA- Not Analyzed

Table 3. 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

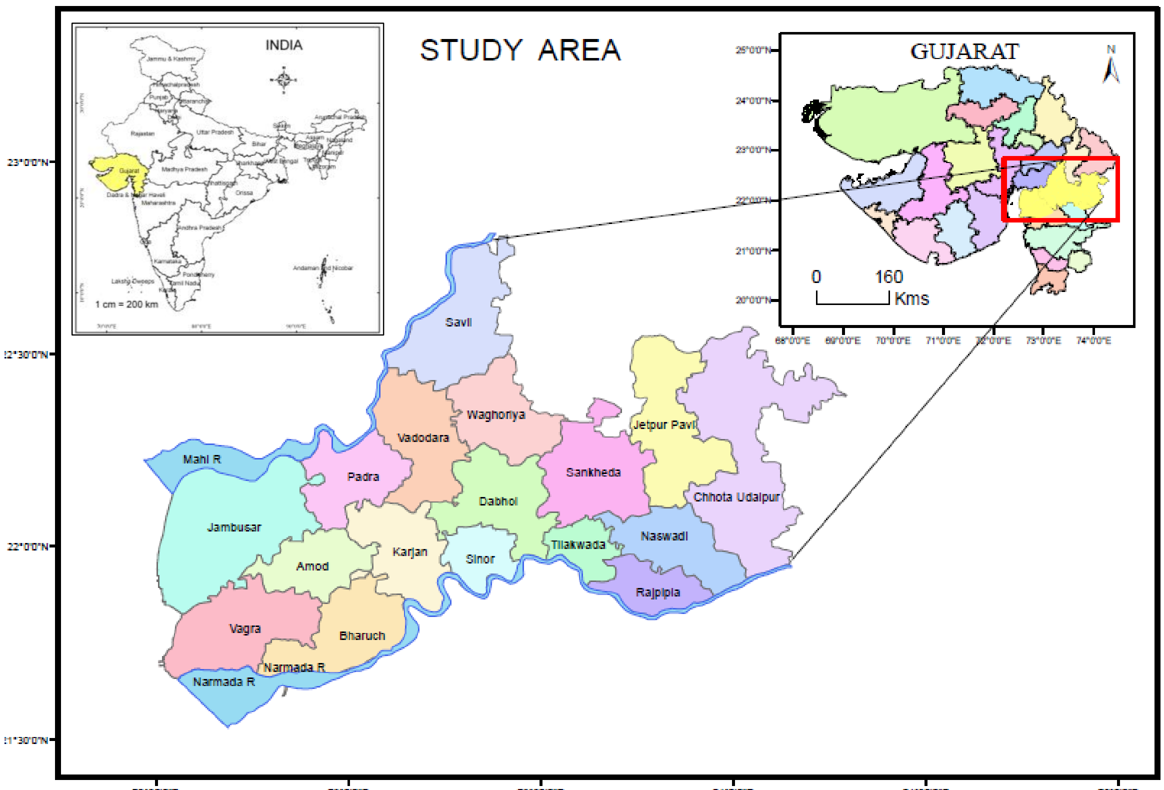

Figure 1. Location Map of the Study Area.

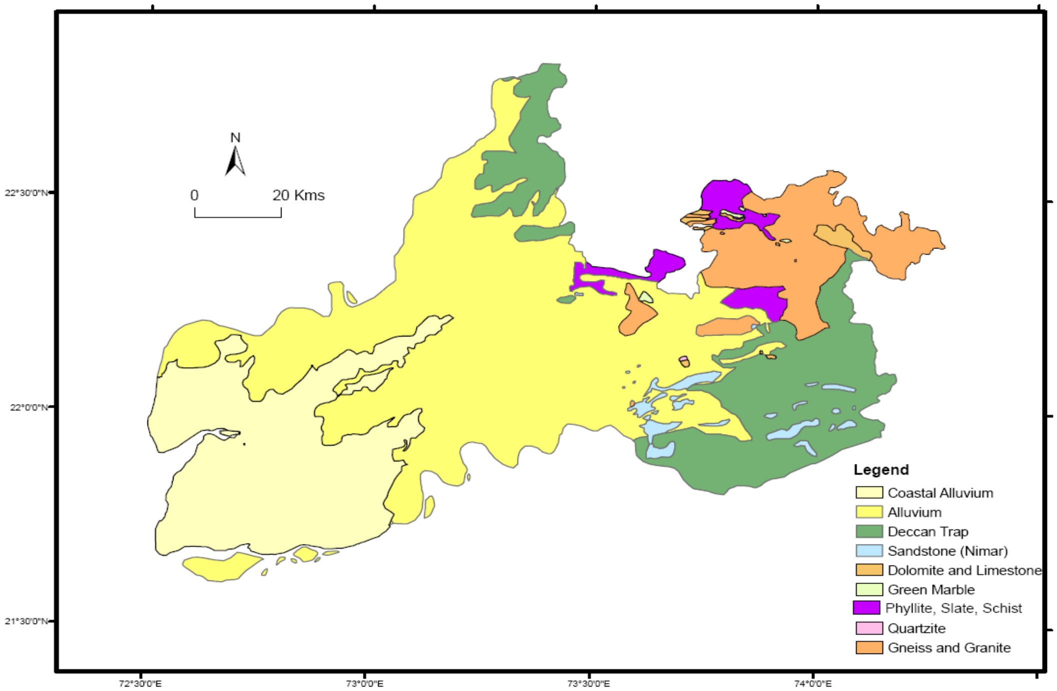

Figure 2. Geological Map of the Study Area. (Complied After GSI)

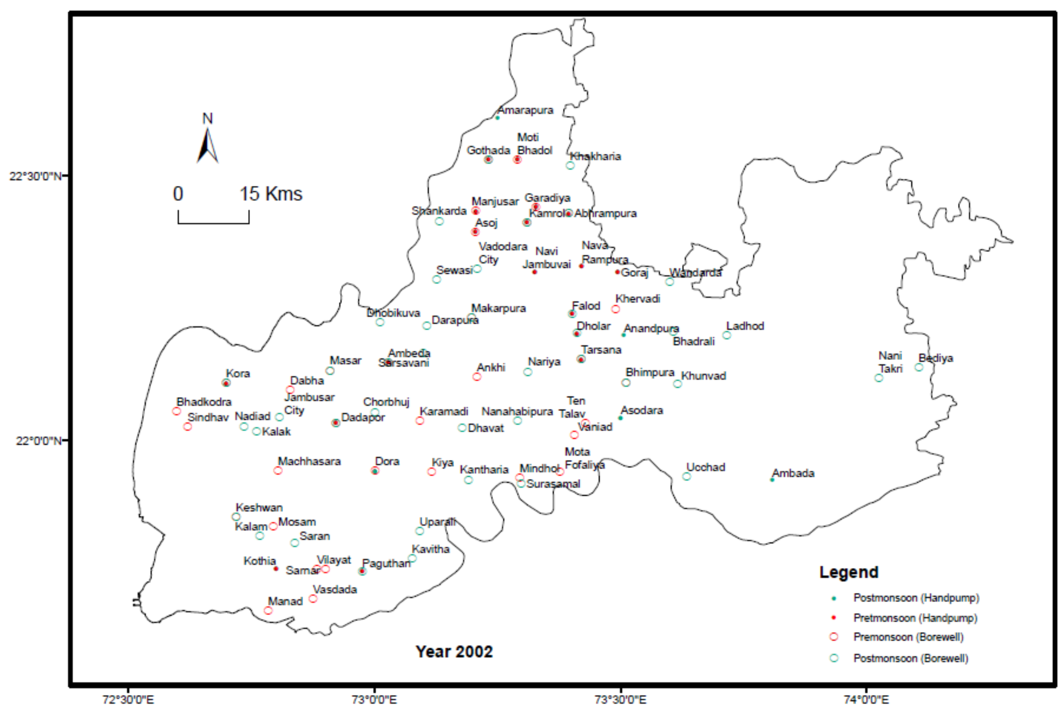

Figure 3. Locations of Water Samples in the Study Area (Pre and Post-monsoon 2002)

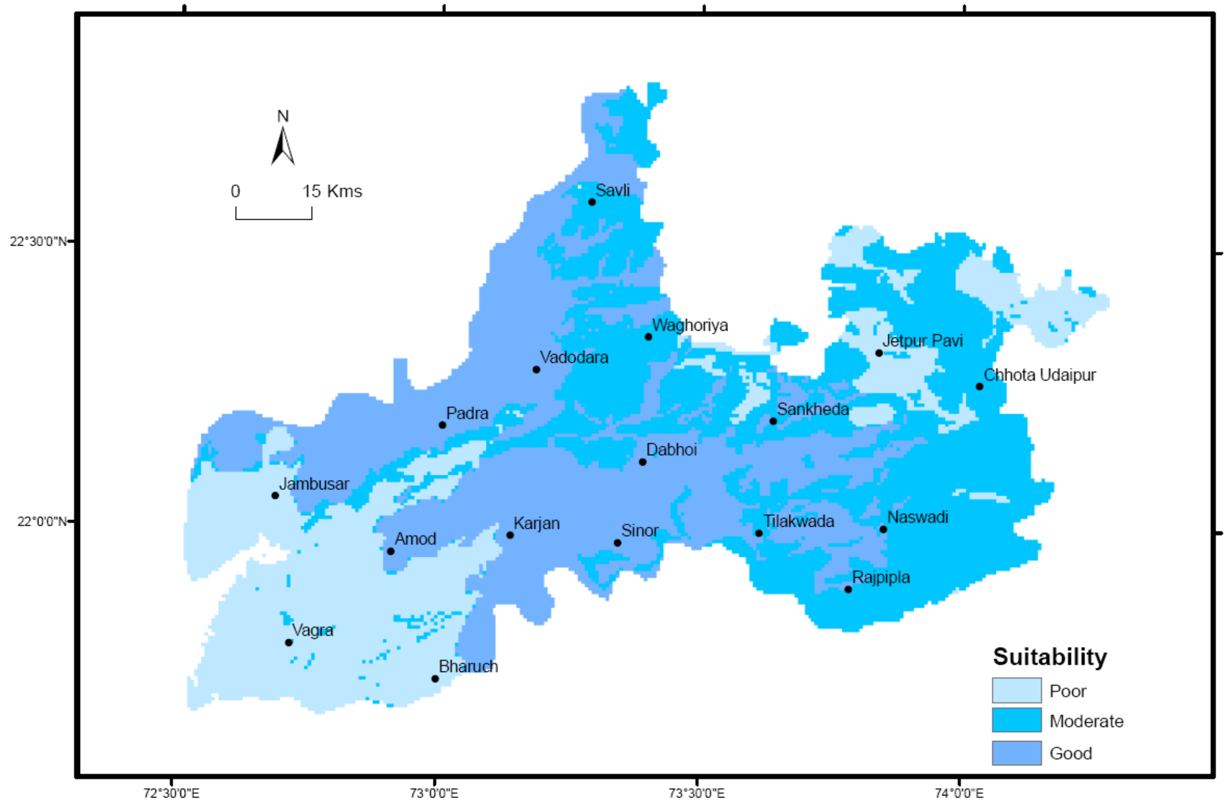

Figure 4. Final Weighted Overlay Index Map of the Study Area Showing Suitable Areas for Groundwater Recharge.

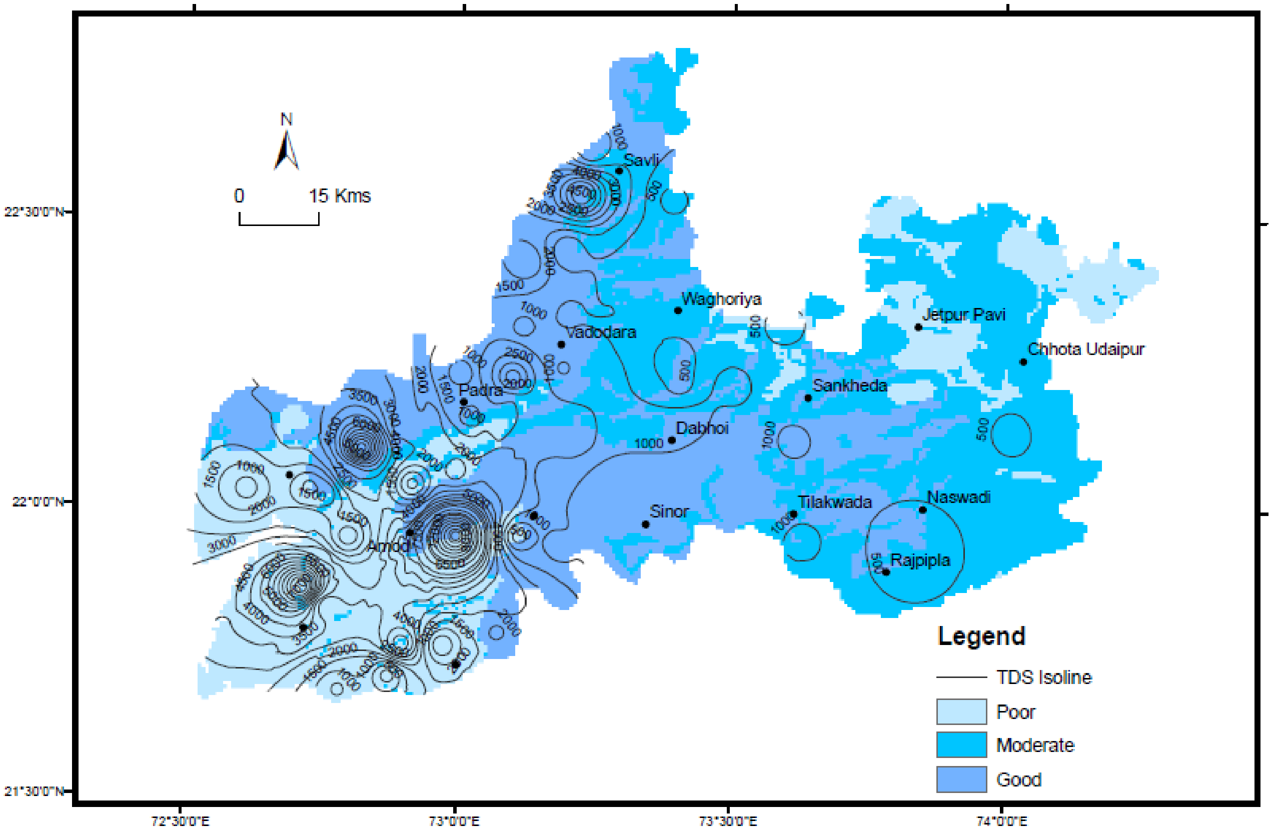

Figure 5. Overlay of TDS Isoline and Weighted Overlay Index Map