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APPLICATION OF GIS IN VALIDATING GROUNDWATER RECHARGE ZONE USING OXYGEN ISOTOPE

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Abstract- The conventional approach for groundwater recharge assessment has some limitations in spite of its simplicity and wide applicability in varied hydro-geological setup lacks the spatial variability 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. The Geographical Information system (GIS) has capability of conducting spatial searches, overlays and association of the spatial data with the non-spatial data to eventually generate new information. Therefore, an integrated geospatial technique has been used to identify the area suitable for recharge by Weighted overlay analysis and demarcate the suitability zones for groundwater recharge which can also be used as sites for artificial recharge.

Further, groundwater samples from shallow and deeper aquifers were collected from some selected sites in the study area representing the specific hydrogeological environment. They were then analyzed for oxygen isotope ($\delta^{18}O$‰). $\delta^{18}O$ isotopic concentration of groundwater sample shows considerable variation in stable isotopic values ranging between -3.16 to 1.06 ‰. The depleted values are indicating that the area is being recharged from surface water, while enriched values are from coastal plain area, which indicate salinity ingress. Moreover, the negative $\delta^{18}O$‰ values indicates zone of recharge while positive values indicate zones of non-recharge. $\delta^{18}O$‰ iso-line has also been superimposed over the weighted overlay map to validate the area of recharge. Both the integrated maps of oxygen isotope variation of the study area and weighted overlay map are in confirmation and substantiate the ground water recharge zones.

Keywords- Groundwater, GIS, Recharge, Oxygen Isotope, Weighted overlay analysis

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Introduction

The quality of groundwater dependent upon factors like mineral composition of the water bearing formations/host rock, residue time in aquifer, recharge and discharge within the groundwater basin and salinity ingress which can be grouped in contamination caused by natural processes. There are anthropogenic contaminations caused by different types of pollutants like industrial, agricultural and sewerage etc. Ground water quality in the study area is highly diverse and complex due to influence of sea water intrusion (coastal salinity), inherent sediments salinity, quality deterioration due to overexploitation and pollution. As a result, there is variation in its water bearing properties both in quality and quantity, mainly due to natural processes. The chemical and isotopic properties of groundwater can be used to determine the process responsible for groundwater quality. 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 [1].

An integrated remote sensing and GIS based methodology is widely in use to identify areas, suitable for recharge. Using this technique one can demarcates areas from poor to good based on its recharge potential and accordingly suitable recharge structures can be suggested /implemented for groundwater development.

The Study Area

The study area lies between 72º 30' E and 73º 43' E longitudes and 21º 40' N and 22º 53' N latitudes, and is part of Mahi - Narmada inter-stream region of Gujarat state. It has a distinct physiographic boundary which is bordered by the Gulf of Cambay in the West, the rocky uplands in the East, Mahi River in the North and Narmada River in the South [Fig-1]. Area is characterized by rock formation ranging in age from Precambrian to Recent and groundwater distribution is reflected in the geological environment of the study area.

The Eastern part of the study area is covered by hard rocks consisting of Deccan Trap, Granite, Gneiss, Quartzite, Phyllite, Slate, Schist, Marble, Sandstone, Dolomite and Limestone [2]. While the central and western side being part of "Gujarat alluvial plains" comprises huge thickness of marine, fluvial and aeolian sediments deposited during the Quaternary period [3]. These sediments consist of intercalations of sand, silt, clay and gravel fractions with the perceived development of clacretised bands. These unconsolidated sediments and serve as repository for groundwater in unconfined, semi-confined and confined conditions [4] [Fig-1].

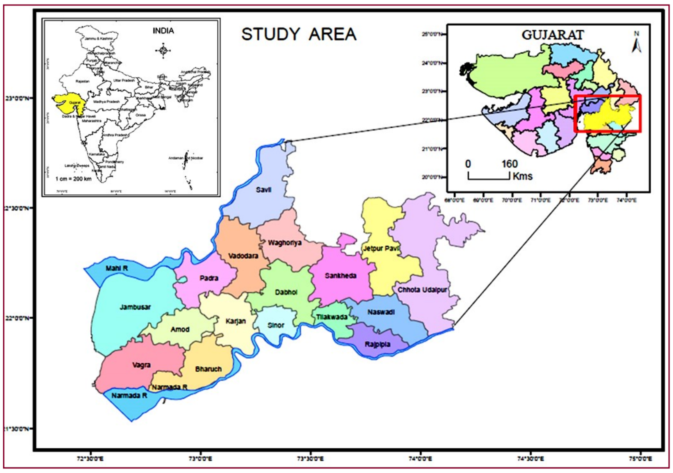

Fig. 1- Location Map of the Study Area. (*Source: Dabral & Sharma* [8])

Material and Method

The groundwater samples were collected and analyzed for the δ18 O‰ isotope presences in the study area. And secondary data were obtained related to the Geology, Soil, Slope, Drainage density.

Remote Sensing and GIS

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 [5-6].

For study area, integrated remote sensing and GIS technique have been used to generate various groundwater potential maps and thereby predicting areas 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 recharge areas. Thereafter, weighted indexing method has been used to identify and demarcate the suitable zones for groundwater recharge which can also be used as sites for artificial recharge [7]. 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 [Fig-2]. Wherein the classes with higher values indicate the most favorable zones for natural recharge and also those areas can be developed for artificial recharge structures [8].

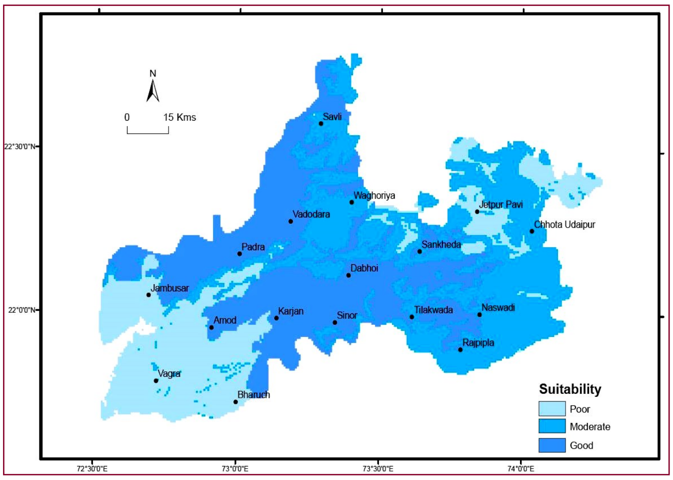

Fig. 2- Weighted Overlay Map of the Study Area Showing Suitable Areas for Groundwater Recharge (*Source: Dabral & Sharma* [8])

Oxygen Isotope Behaviour in Groundwater of the Study Area

Ground water recharge sources can be identified using isotopes of oxygen and hydrogen combined with correlation of the average isotopic data of precipitation [9].

Environmental isotopes provide information about the history of water that cannot be obtained in any other way. Environmental isotopes, at concentrations set by natural and anthropogenic processes, give a "finger print" to a body of water which can be used as a trace of the water even as it moves from one system to another. Isotope assessment techniques are therefore especially useful for identifying the sources of salinity and the inflow of fresh groundwater [10]. Isotope techniques have been used for identifying the sources of salinity and recharge rate of groundwater. The environment isotope compositions of hydrogen ∂^2H and oxygen ∂^{18}O are excellent parameters for determining the origin of salinity in groundwater and widely used in studying natural water circulation and groundwater movement [11].

Environmental isotopes are routinely used in geochemical and hydro-geological investigations. Oxygen and hydrogen isotopes of water are widely used as tracers to understand hydro-geological processes such as precipitation, groundwater recharge, groundwater-surface water interactions, and basin hydrology [12].

Gupta & Deshpande [13] based on δ^{18}O distributions of groundwater, has broadly subdivided India into three contiguous regions A (δ^{18}O > –2‰), B (δ^{18}O < –4‰) and C (δ^{18}O around –3‰ to –4‰) with transition areas in between. The study area partly falls in region A, wherein the coastal parts of this region being dominated by heavy rainfall from the Arabian Sea branch of the SW monsoon, groundwaters largely reflect isotopic characters of the rainfall.

δ^{18}O measurements were carried out on selected samples well spread over the study area, to have understanding on status and mechanism of recharge, evapotranspiration and salinity ingress in the area. The δ^{18}O‰ measurements were done at Physical Research Laboratory (PRL), Ahmedabad using a Stable Isotope Ratio Mass Spectrometer (GEO 2020, PDZ Europa U.K.) with automatic water equilibration system. The δ^{18}O‰ values are with respect to the V-SMOW and NRM (Narmada water, δ^{18}O = -4.5 ‰) was used as a laboratory water standard.

Results and Discussion

The samples were selected to ensure the spatial representation. The data on δ^{18}O‰ in groundwater is presented in [Table-1].

Table 1- Concentration of δ^{18}O‰ and chloride of the selected sample sites

S No	Village	Depth (m)	Well type	^{18}O‰	Chloride (mg/l)
1	Kaliari	12	Hand Pump	-3.16	87
2	Kora	17	Tube Well	0.27	1260
3	Nadiad	Not Available	Tube Well	-3.16	146
4	Dabha	52	Tube Well	-1.1	889
5	Jambusar city	39	Tube Well	-2.21	1060
6	Machhhcsara	15	Tube Well	-1.3	541
7	Dadapor	36	Tube Well	-1.34	197
8	Dora	73	Tube Well	-2.7	890
9	Keshwan	18	Tube Well	-0.9	3499
10	Janiadara	24	Hand Pump	1.06	995
11	Kakam	33	Tube Well	-0.48	1410
12	Manad	24	Hand Pump	-2.03	1014
13	Sarnar	39	Tube Well	-0.51	2473
14	Vasdada	20	Tube Well	-3.15	105
15	Uparali	45	Tube Well	-2.18	1012
16	Kavitha	39	Tube Well	-2.03	762
17	Masar	39	Tube Well	-1.11	890
18	Dhobikuva	45	Tube Well	-2.48	816
19	Darapura	100	Tube Well	-2.79	1140
20	Chorbhuj	67	Tube Well	-2.58	720
21	Kiya	67	Tube Well	-1.54	75
22	Kanthariya	76	Tube Well	-1.76	895
23	Shankarda	73	Tube Well	-2.5	923
24	Sewasi	28	Tube Well	-2.46	186
25	Vadodara City	36	Tube Well	-2.14	167
26	Ankhi	76	Tube Well	-2.07	772
27	Amarapura	76	Tube Well	-2.7	41
28	Gothada	61	Tube Well	-0.93	1085
29	Manjusar	61	Tube Well	-2.05	22
30	Manjusar	45	Tube Well	-1.06	39
31	Khakharia	61	Tube Well	-1.29	84
32	Kamrol	Not Available	Hand Pump	-1.24	1318
33	Nava Rampura	30	Hand Pump	-1.26	20
34	Falod	36	Tube Well	-1.27	30
35	Nariya	91	Tube Well	-1.83	187
36	Dholar	30	Tube Well	-1.76	34
37	Tarsana	61	Tube Well	-2.2	544
38	Bhimpura	48	Tube Well	-1.57	55
39	Asodara	Not Available	Tube Well	-2.3	43
40	Anandpura	33	Tube Well	-0.47	426
41	Wandarda	15	Hand Pump	-2	70
42	Khunvad	45	Tube Well	-1.73	322
43	Ladhod	29	Tube Well	-2.14	211
44	Sardarpura	Not Available	Hand Pump	-1.6	385
45	Uchad	150	Tube Well	-1.32	172
46	Tarsal	55	Tube Well	-1.74	42
47	Nanahabipura	91	Tube Well	-2.01	167
48	Vaniad	82	Tube Well	-1.96	58
49	MotaFofaliya	Not Available	Tube Well	-2.29	101
50	Ambada	Not Available	Tube Well	-2.06	24
51	Gulvani	27	Hand Pump	-2.77	24
52	NaniTakri	67	Tube Well	-2.12	43
53	Bediya	65	Tube Well	-1.96	93
54	Hanf	28	Hand Pump	-2.78	23
55	Nanivant	28	Hand Pump	-1.5	68

The δ^{18}O‰ values from study area have helped in delineating the following inferences:

- The frequency distribution histogram of δ^{18}O‰ have clearly shown that the 80% of the samples are in the range of -2.5‰ to -1.5‰ [Fig-3].
- The depleted values of δ^{18}O ‰ indicates that area is being recharged from surface water, while enriched values δ^{18}O‰ from coastal area are in conformity with the coastal salinity ingress process, obtained from geochemical analysis of ground water samples[4].
- The highlands and the alluvial plains are showing depleted δ^{18}O‰ values (-3.5‰ to -1.5‰). This is in conformity with the fact that highlands and alluvial plains are the main zones of recharge to groundwater mainly through rainfall infiltration.
- The samples from coastal area along the Gulf of Cambay representing Keshwan, Kalam and Sarnar villages has shown relatively enriched δ^{18}O‰ values. Groundwater samples from Kora and Janiadara villages have shown very high relative enriched values of δ^{18}O‰ (+ve values) suggesting that these areas have strong influence of salinity ingress.
- The enriched δ^{18}O‰ value observed from few locations in the high rocky areas and alluvial plains is attributable to the factors like poor recharge, high evaporation or isolated older water mass etc. Some locations of Waghodia, Pavi-Jetpur taluka have also shown relatively enriched δ^{18}O‰ values.
- Based on the δ^{18}O‰ values it is imperative to assume that over ±60% of the study area serve as good recharge surface [4].
- There is a good correlation between Cl and δ^{18}O, this is very obvious in the area along the Gulf of Cambay, where salinity ingress has contributed to the high Cl concentration and the δ^{18}O value are also enriched. The high Cl concentration away from the Gulf and not associated with the enriched δ^{18}O values indicates surface contamination while pockets of groundwater having high Cl concentration and enriched δ^{18}O value, indicates that the recharge is poor and hence high evaporation leads to enriched value for both Cl and δ^{18}O.

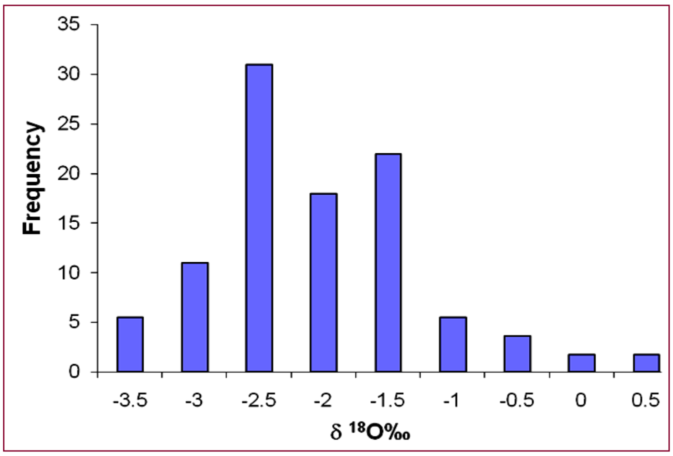

Fig. 3- Frequency Distribution Diagram of δ^{18}O‰ in Groundwater

Conclusion

δ^{18}O‰ isoline has been superimposed over the weighted overlay map to validate the area of recharge [Fig-4]. The negative contour values δ^{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. The map of oxygen isotope variation with weighted overlay map is in conformation and substantiates the area of recharge and non-recharge. Moreover, study also demonstrates that the recharge sites are in conformity with the land use pattern of the area [4]. The coastal area has high TDS values and the correlation coefficient 'r' between Ec and $\delta^{18}O$ is positive (r = 0.34). Plot of chloride vs. $\delta^{18}O$ shows high chloride at high isotope concentration thereby indicative of long storage and no recharge, same way nitrate also gives similar correlation. The outcome of this study in the form of weighted overlay map shall be useful for future development and management of water resources.

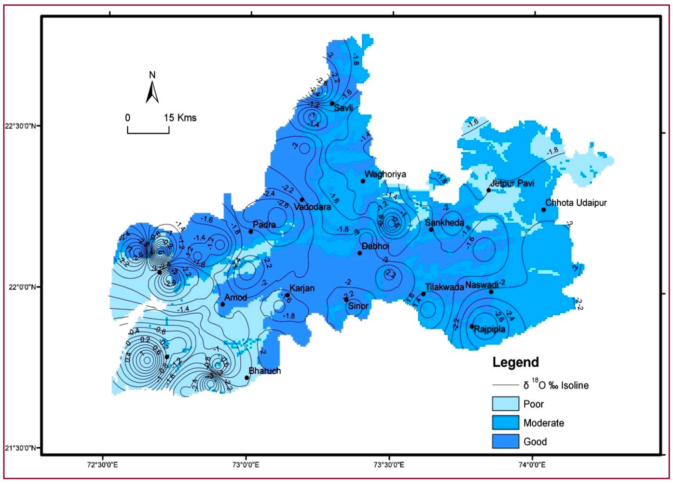

Fig. 4- Overlay of $\delta^{18}O$‰ and Weighted Overlay Index Map Depicting the Area of Groundwater Recharge.

Finally, it is concluded that the geospatial technology has great potential to revolutionize groundwater monitoring and management in the future by providing unique data to correspond the conventional field data.

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Conflicts of Interest: None declared.

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