Geographical Information System (GIS) Based Groundwater Quality Mapping in the Western Doon Valley, Dehradun, Uttaranchal State

A.S. Jasrotia *, B. D. Bhagat
P.G. Department of Geology, University of Jammu, Jammu- 180 006, India
e-mail: asjasrotia@Yahoo.co.uk

Key Words: GIS, Groundwater Quality Mapping, Western Doon Valley, Dehradun

ABSTARCT

Groundwater is the major source of drinking water in both urban and rural India, besides, it is an important source of water for the agricultural and the industrial sectors. In the Western Doon Valley groundwater quality mapping has been carried out using geographical information system (GIS). The study area is typically covered by Siwaliks and pre-tertiary of Miocene to Pre-Cambrian in age. The study reveals the zones and quality of water that are suitable for drinking, agricultural and industrial purposes. Further, it is possible to understand the change in quality due to rock water interaction or any anthropogenic influence. This valley receives the heavy rainfall and it frequently facing the water quality problem in some specific area. Geographical Information System (GIS) based groundwater quality mapping in this region with the help of hydro chemical data generated from the chemical analysis of water samples collected from the different dug wells and tube wells. Groundwater samples show the quality in exceeding the highest desirable limit such as Calcium (Ca), Magnesium (Mg), Total Hardness (TH) and Nitrate (No_3). These parameters indicate the level of quality of groundwater for drinking purposes. Arc View GIS software has been used for generation of various thematic layers and spatial analysis and final integration for groundwater quality. The groundwater quality map shows groundwater zones which are desirable and undesirable for drinking and irrigation purposes.

Introduction

Over the last 20 years there has been an enormous increase in the use of groundwater in India. Due to ever increase demand for potable and irrigation water and inadequacy of available surface water the importance of groundwater is increasing everyday. Several parts of India are facing an acute shortage of drinking water owing to poor quality of groundwater. As well as providing a critical source of domestic and irrigation water, groundwater also plays a vital role in supporting the livelihoods of the poor. The study area is being developed and the agricultural land converted into non agricultural uses with its deleterious effects on groundwater quality, it is essential to know the hydrochemical parameters which reveal the zone and quality of the water are suitable for drinking, agricultural and industrial purposes. The chemical composition of groundwater is determined by a number of processes, which include atmospheric input, interaction of water with soil and rock and input of chemical derived from human activities. Further it is possible to understand the change in quality due to rock water interaction or any type of anthropogenic influence. Groundwater quality is very essential in a sense of practical utility for domestic, agriculture and industrial purpose. Hence, present utility and future development programs are depending on the physical, chemical and bacterial character of the water. This quality as such depends upon environmental, geological and soil conditions. Therefore, it is necessary to study the groundwater quality before water is used for domestic, agricultural and industrial purposes.

Geographical Information System (GIS) using in this study to understand the groundwater quality of Western Doon valley through pictorially represent. GIS is an effect tool for storing large volumes of data that can be correlated spatial and retrieved for the spatial analysis and integration to produced desirable result. GIS has been used by scientist of various disciplines for spatial quarries, analysis and integration for the last three decades (Burrough and McDonnell 1998). Dhiman and Keshari (2002) presented a methodology to use GIS to quantify the spatial geologic data and performed statistical analysis to determine the relation between groundwater quality parameters and geological units. Anbazhagan and Nair (2004) Geographical Information System and groundwater quality mapping in Panvel Basin, Maharashtra, India. Roy (1991, 1995) was conducted studies based on hydromorphogeological mapping for Groundwater targetting and development and constraints related to water resources in Doon valley. Goyal et al. (1999), the groundwater exploration is based upon terrain characteristics along with lithology, landuse and other parameters. This thematic information can be generated through remote sensing technique and integrated in GIS for evaluation of groundwater resources. GIS have been used by the various scientists to determine the potential sites for groundwater exploration (Krishnamurthy and Srinivas 1995; Saraf and Choudhury 1997, 1998; Obi Reddy, et al 2000).

Geological Setting of the Study Area

The study area covers approximately 680 Sq Km area and is bounded by latitude N30° 15' to N30° 30'and longitudes E 77° 40' to E78° 0' and covers geographically, Western Doon Valley (Fig.1). The summers are hot with temperatures rising to about 40^0 C, while winters are cool with maximum temperature 20^0C. The average annual rainfall is about 2000 mm out of which monsoon rainfall is 1600 mm. Physiographically, it is bounded by lesser Himalayas in the north, siwalik in the south, Yamuna river in the west and Bindal river in the east. The major drainages present in the area are braided, dendritic, sub-dendritic, parallel to subparallel and trellis. The area is drained by Yamuna river and its main tributaries Asan and Tons. Asan river follows the axis of the Doon syncline. The main tributaries of Asan in the north are Sitla Rao, Surna, Chorkhala, Bhainsi Rao, Kasumri Rao, Darwat Rao which are in semi perennial condition. The southern side of the tributaries of Asan river is starting from the upper region of Siwalik belt which is having more

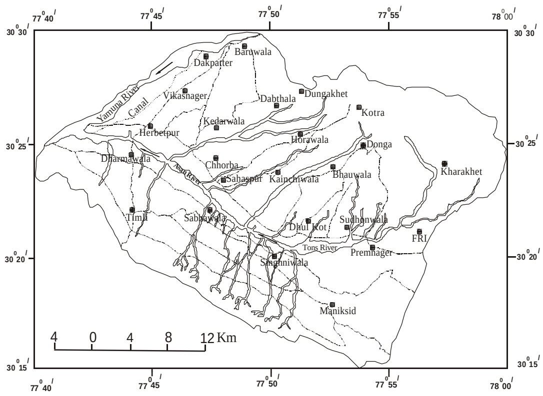

Fig.1: Location Map of the Study area.

dissected zones, active deep gorges and controlled by lithology.

Geologically, Doon Valley is an asymmetrically, longitudinal structurally synclinal valley formed of Siwalik rocks of sedimentary origin having the trend of NW-SE of Upper Tertiary age (Fig.2). Later it has been filled up by Doon Gravels derived from the two mountain/hill ranges (Lesser Himalayas in the north and Siwalik in the south), consists of loose unconsolidated material of Sub-Recent age. The Pre-Tertiary group of rocks is exposed in the study area as lesser Himalayas. These rocks are mainly of Pre-Cambrian age and consist of meta-sedimentary rocks. The Middle Siwalik representing a multistory sandstone complex, exhibit vertical facies variation from sandstone-mudstone to sandstone to mudstone-conglomerate. The Upper Siwalik is made of predominantly conglomerate with subordinate sandstone and mudstone facies. Older Doon Gravel comprises of boulders, pebbles embedded in reddish clay matrix and these boulders are of quartzite, schist, gneiss and broken fragments of quartzite. Younger Doon Gravel is the middle portion of the fan covering major part of the area belonging to early Holocene age and lithologically the

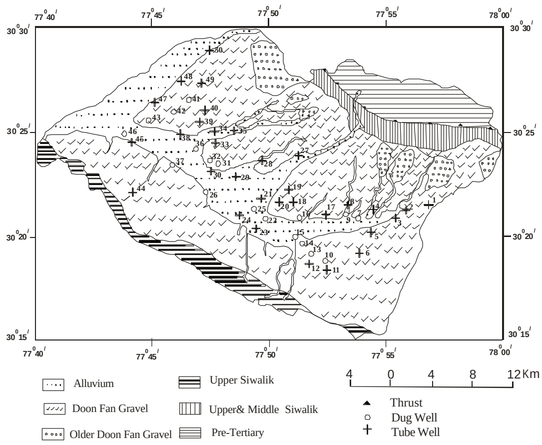

Fig.2: Geological map of study area along with samples location

boulders are sub-rounded to sub-angular in the river section. The lowest part of the study area which is fluvial deposition in nature and covered with erosion formation of recent age. Alluvium consists of boulders, pebbles, gravels with sand, silt and clay.

Methodology

The study is carried out with the help of remote sensing, topographic data, data available and data collected form the field (Fig. 3) flow chart showing the methodology. In the present study Indian Remote Sensing Satellite-1D (IRS-1D), Panchromatic (PAN) + multispectral (LISS-III) merged data. Survey of India (SOI) topographic maps on 1:50,000 scale. The existing data such as observation well data, rainfall data and litholog data form the bore wells as well hydrogeological data collected from the CGWB. The field work includes water table, well inventory and groundwater samples from fifty Dug wells and Tube wells from the different parts of the study area were collected during Pre-Monsoon and Post –Monsoon season of

2004 and analyzed their cations and anions. The PH, EC and TDS are measured by PH, EC and TDS meters, the temperature is measured by Thermometer immediately after sampling, TH, TA, Ca^{2+}, Hco_3^-, Cl^- are analysed by volumetrically. Mg^{2+} is calculated from TH and Ca^{2+} contents. F^- is determined by ion analyzer meter. Na^+ and K^+ are determined by flame photometer. So_4, No_3^- and Sio_2 are determined by using Spectrophotometer. All concentration are expressed in milligrams/l except PH, EC and Temp. The analytical precision for the measurement of ion is about ±5%. Thematic layers of the water quality analysis were prepared and spatial

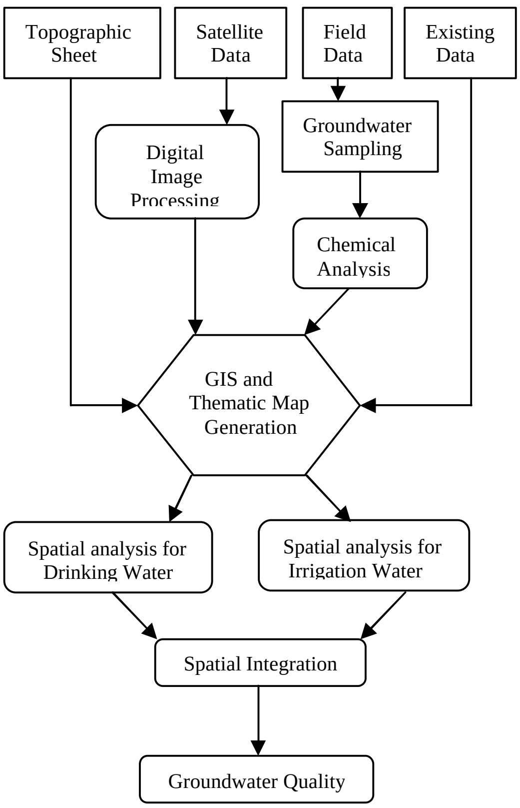

Fig. 3 Flow Chart showing the Methodology of study area

analysis and integration were carried out or drinking and irrigation water quality in the Arc View software.

Groundwater Quality

Groundwater quality assessment is a key issue to decision makers. Through the use of the developed open GIS system a rapid global "at a glance" appraisal of groundwater quality can be achieved. Produced maps are designed in a way to offer this facility to decision makers, taking into account that they are not necessarily water specialists and therefore they require clear, easy to comprehend and valid information. Utilising existing data, water quality maps were compiled rather than single ion areal distribution maps. Using Arc View and Spatial Analyst, several grids have been created to represent groundwater quality for irrigation and domestic use.

The piper diagram is extensively used to understand problems concerning the geochemical evaluation of groundwater. The hydrochemistry of groundwater is evaluated by plotting the cations and anions in percent of total meq/l Piper's Trilinear diagram (Todd 1980). The overall characteristic of the water is represented in the diamond-shapes field by projecting the position of the plots in the triangular fields. In the Piper's Trilinear diagram (Fig. 4) , the plot of the groundwater samples of the study area of pre-monsoon data and post-monsoon data falls in the field 1 and 3 which suggest that alkaline earth exceeds alkalies , weak acids exceed strong acids respectively and carbonate hardness ("secondary alkalinity") exceeds 50 percent. These features indicate that alkaline and weak acids dominance over the study area and carbonate hardness exceeds 50 percent.

The higher concentration of HCO_3 and its positive correlation with Ca and Mg indicates their common source, from dissolution of carbonate.

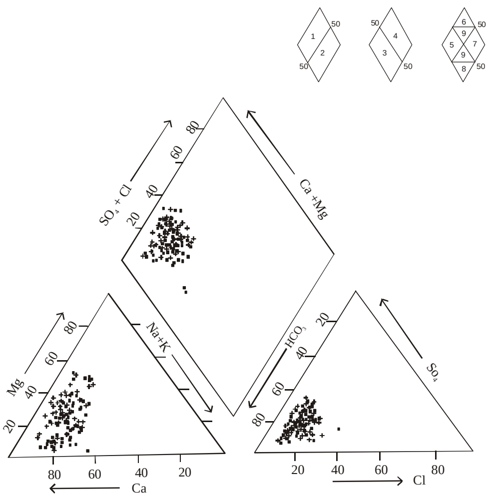

Fig.4: Piper trilinear diagram of groundwater of study area; ?- samples of pre-monsoon, and + - samples of Post-monsoon periods.

Groundwater Quality Mapping for Drinking Water

The quality of the groundwater samples has been analysed for drinking and irrigation purposes. Groundwater quality for drinking water purposes was analysed by considering the WHO (1971) and ISI (1983) standard (Table 1). It has been found that some samples show Ca, Mg, TH, No_3 above the desirable limit. These values were plotted in the respective samples locations and contours were generated using the simple method of triangulation and interpolation techniques. Water quality maps were generated for TH, Ca, Mg, No_3 of the study area falling under desirable and undesirable limit. A salinity hazard map was also prepared after generating contours. The salinity hazard map shows the groundwater quality for irrigation of the study area.

Table 1. Comparison of the Quality Parameters of Groundwater of the Study area with WHO and ISI for drinking purpose.

S. No.	Water Quality Parameters Units	WHO (1971) Hig. Des. Lim.	WHO (1971) Max. Per. Lim.	ISI (1983) Hig Des. Lim.	ISI (1983) Max. Per. Lim.	Conc. in study area
1.	pH	7.0	8.5	6.5	8.5	6.5 -7.9
2.	TDS (Mg/l)	500	1500	500	1500	90 – 400
3.	Calcium (Mg/l)	75	200	75	200	10 – 89
4.	Magnesium (Mg/l)	30	150	30	100	0.97 – 32.4
5.	Potassium (Mg/l)					0.03 – 7.2
6.	Sodium (Mg/l)		200		200	3.5 – 28
7.	Bicarbonate (Mg/l)					50 – 261
8.	Chloride (Mg/l)	200	600	250	1000	5.2 - 62
9.	Sulphate (Mg/l)	200	400	150	400	5 – 83
10.	Nitrate (Mg/l)	45		45	100	0.5 – 52
11.	Fluoride (Mg/l)			1.0	1.5	0.008 – 0.24
12.	Total Hardness as $CaCo_3$	100	500	300	600	40 -300

Hig. Des. Lim. = Highest Desirable Limit
Max. Per. Lim. = Maximum Permissible Limit

Calcium Concentration

The study area is composed of sedimentary rocks, calcium occur as carbonate (Calcite, aragonite) and calcium sulphate (gypsum and anhydrite). Most of the geological materials of aquifers will be composed of calcium. It will present in groundwater as a materials of suspension. Where as calcium bicarbonate readily goes into solution and it is prime cause of hardness in water. However the concentration of calcium in groundwater is found to vary between 10- 89mg/l for pre-monsoon and 15-70 mg/l for post-monsoon periods. As per WHO (1971) and ISI (1983) the desirable limit of calcium is 75 mg/l. In the study area it has been found that certain locations the calcium concentration exceeds this limit for pre-monsoon samples. Calcium concentrations were plotted in the respective samples locations and contours were generated using the simple method of triangulation and interpolation techniques. The contour map was digitized and imported into the GIS environment as a parameter for quality analysis. The area having the calcium concentrations above the desirable limit were delineated and differentiated forms the area below the desirable limit (Fig.5). A rank of '1' was assigned for area having calcium values within the desirable limit and rank of '2' was assigned for area having calcium values above the desirable limit. The concentration of calcium above the desirable limit, encrustation in water supply structure and adverse effect on domestic uses.

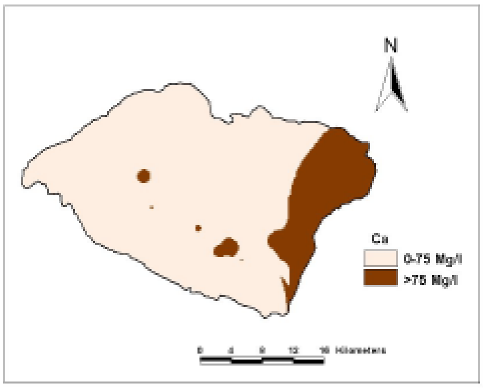

Fig.5 Calcium distribution in Western Doon valley

Magnesium

In this sedimentary terrain magnesium occurs as magnesite and other carbonate some time mixed with calcium carbonate. Accordingly to WHO (1971) and ISI (1983) the maximum desirable limit of magnesium is 30 mg/l. The concentration of calcium in groundwater is found to vary between 0.97- 21.2 Mg/l for pre-monsoon and 1.8- 32.4 mg/l for post-monsoon periods. In the study area it has been found that certain locations the magnesium concentration exceeds this limit for post-monsoon samples. Contours were generated using the same procedure as for the Calcium to delineated areas of desirable magnesium value from area with the undesirable magnesium value (Fig. 6). A rank of '1' was assigned for area having magnesium values within the desirable limit and rank of '2' was assigned for area having magnesium values above the desirable limit.

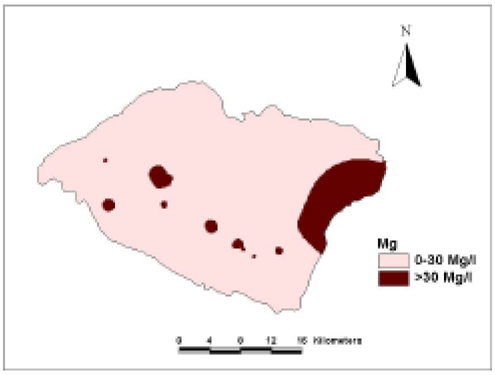

Fig.6 Magnesium distribution in Western Doon valley

Total Hardness

Water hardness is caused primarily by the presence cations such as calcium and magnesium and anions such as carbonate, bicarbonate, chloride and sulphate in water. The concentration total hardness of in groundwater is found to vary between 42- 260mg/l for pre-monsoon and 64 -300 mg/l for post-monsoon periods. According to Sawyer and McCartly (1967) classification for hardness are given in (Table 2) – samples fall soft class, –l moderately class and –under hard class. Excess concentration of TH has no adverse effect; however some evidence indicates its role in heart disease. Hard water is unsuitable for domestic use. The desirable limit for WHO is 100 Mg/l (WHO-1971) while the Indian standard is 300 mg/l (ISI-1983). In the study area it has been found that certain locations the total hardness concentration exceeds this limit for post-monsoon samples. Contours were generated using the same procedure as for the Calcium and Magnesium to delineated areas of desirable hardness value from area with the undesirable hardness value (Fig. 7). A rank of ‘1’ was assigned for area having TH values within the desirable limit and rank of ‘2’ was assigned for area having TH values above the desirable limit.

Table 2 Classification of water based on hardness by Sawyer and McCartly (1967)

Hardness as $CaCo_3$	Water Class	Pre-monsoon Samples	Post-monsoon Samples
0-75	Soft	15	4
75-150	Moderately hard	23	28
150-3,000	Hard	12	18
>3,000	Very hard		

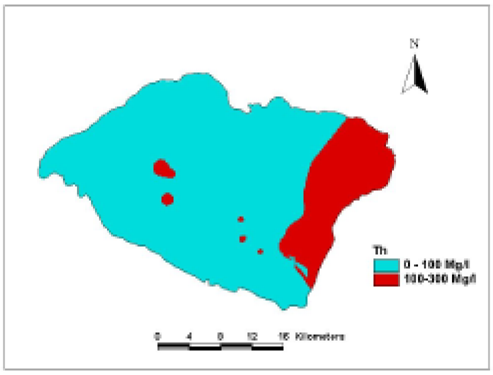

Fig.7 Total Hardness distribution in Western Doon valley

Nitrate

Nitrate occurrence in groundwater is also very common. It is mainly due to aerobic decomposition of nitrogen from organic matter. Nitrate from other sources like fertilizer, industrial effluents and septic tanks contribute nitrate in the form of pollutants. As such high concentration of nitrate is found in localised area. Unpolluted groundwater may contain less then 5 ppm of nitrate while polluted water may have up to 100 ppm. The concentration of Nitrate from in groundwater is found to vary between 0.5- 26 mg/l for pre-monsoon and 3.6-52 mg/l for post-monsoon periods. As per WHO (1971) and ISI (1983) the desirable limit of calcium is 45 mg/l. In the study area it has been found that certain locations the Nitrate concentration exceeds this limit for post-monsoon samples. Contours were generated using the same procedure as for the total hardness to delineated areas of desirable nitrate value from area with the undesirable nitrate value (Fig. 8). A rank of ‘1’ was assigned for area having TH values within the desirable limit and rank of ‘2’ was assigned for area having nitrate values above the desirable limit.

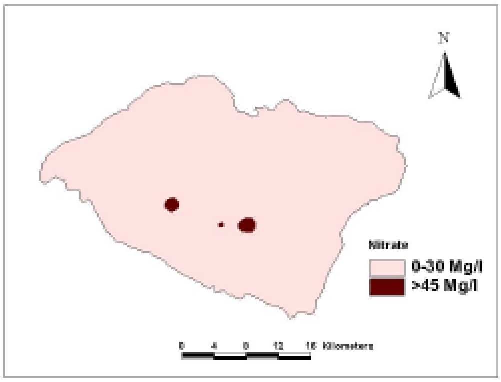

Fig.8 Nitrate distribution in Western Doon valley

Spatial Analysis for Groundwater Quality mapping

The four thematic maps with parameters such as Ca, Mg, TH, and No_3 having desirable and undesirable classes were integrated using mosaic of maps calculation of the overlay module available in the Arc View and Boolean logic condition. The final out put is a pictorial representation of groundwater quality for drinking in the Western Doon valley (Fig. 9). The majority of the area is covered by groundwater with decent quality. The zone of undesirable category is located towards eastern side of the study area.

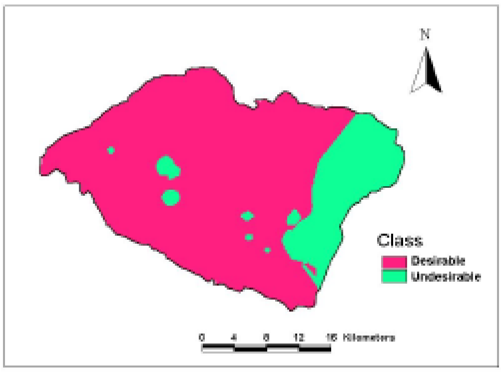

Fig.9 Groundwater Quality for drinking purposes in Western Doon valley

Groundwater Quality Mapping for Irrigation Water

Water quality, soil types and cropping practices play an important role in irrigation. The study area is being developed day by day and agriculture is found to one of the major landuse practices. In the Western Doon valley majority of the cultivated land is irrigated by groundwater either by the dugwells or tubewells. The surface water facilities for irrigation is available only some villages along the streams/rivers, other wise the groundwater is the main source of irrigation. Therefore, it is necessary to perform the analysis of chemical quality of groundwater for irrigation purposes. The suitability of groundwater for irrigation is affected by the total content of soluble salts and relative proportion of bicarbonate to calcium and magnesium and relative proportion of sodium to calcium. The EC and Na concentration are important in classifying irrigation water.

The EC distribution in groundwater in the study area range from 120-670 µs/cm (Table 3). According to classification of groundwater for irrigation, the groundwater of the study area is of excellent to good.

The sodium or alkali hazard (Table 4) in the use of water for irrigation is expressed by sodium absorption ratio (SAR) which is given by (Karanth 1987).

$$SAR= \frac{Na^{+}}{(v\ (Ca^{++} + Mg^{++}))/2}$$

The calculated values of SAR in the study area are very between 0.144-0.815. Low sodium water (S1) can use for irrigation on almost all soils. As both pre-monsoon and post-monsoon

Table 3 Salinity Hazard Classes

Salinity Hazard Class (Alkalinity)	EC in mmhos cm	Remark of quality	Pre-Monsoon Samples	Post-Monsoon Samples
C1	100-250	Excellent	27	23
C2	250-750	Good	23	27
C3	750-2,250	Doubtful		
C4 and C5	>2,250	Unsuitable		

groundwater samples fall in the low sodium (S1) category shown in (Table 4), there is no hazard of alkalinity (Richards, 1954).

According to Residual sodium concentration (RSC) value of groundwater samples of the study is within the safe limit (Table 5). Hence the groundwater of study area is excellent for irrigation purposes.

$$RSC = (CO_3 + HCO^-_3) - (Ca^{++} + Mg^{++}) \text{ meq/l}$$

Table 4 Sodium Hazard Classes

Sodium hazard Class	SAR in Eqs. per mole	Remark of quality	Pre-Monsoon Samples	Post-Monsoon Samples
S1	10	Excellent	0.20-0.82	0.14-0.56
S2	10-18	Good		
S3	18-26	Doubtful		
S4 and S5	>26	Unsuitable		

Salinity Hazard

The EC values of groundwater samples will give the salinity hazard. Groundwater samples of pre-monsoon and post–monsoon periods near about equal fall in the low and medium salinity hazard. Groundwater samples that fall in the low salinity hazard (C1) can be used for irrigation of most crops and the majority of soils. Groundwater samples that fall in the medium salinity hazard (C2) can be used if moderate amount of leaching occurs. The salinity hazard (Table 3) shows that groundwater quality is excellent to good for irrigation purposes. The EC values for the samples will give salinity value for the area. The groundwater samples from the study area fall in two classes of salinity hazard. The contours map was prepared and imported into the GIS environment as a parameter for quality analysis. The western doon valley was divided in two polygon and two classes of polygon were digitized. The salinity hazard map shows that according to the classification of groundwater for irrigation, the groundwater of the study area is excellent to good.

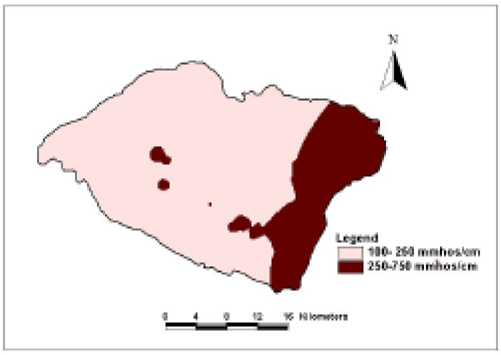

Fig.10 Groundwater Quality for irrigation purposes in Western Doon valley

Conclusion

Geographical Information System (GIS) technique has been used in this study to understand the groundwater quality of Western Doon valley through pictorially represent. The ground water of the study area indicates that the alkaline earths exceeds the alkalies and weak acid exceeds the strong acids and Carbonate hardness (secondary alkalinity) exceeds 50% that is total hydrochemistry is dominated by alkaline earth and weak acid. From the hydrochemical analysis, it is inferred that calcium, magnesium, total hardness and nitrate at some locations above the desirable limit. The four thematic maps with parameters such as Ca, Mg, TH, and No_3 having desirable and undesirable classes were integrated using mosaic of maps calculation of the overlay module available in the Arc View and Boolean logic condition. The final out put is a pictorial representation of groundwater quality for drinking in the Western Doon valley. Similarly considerable the area in the western Doon valley for salinity hazard, the salinity hazard map shows that according to the classification of groundwater for irrigation, the groundwater of the study area is excellent to good.

Acknowledgements

The authors are highly thankful to the Head of the Department of Geology, University of Jammu, Jammu for providing us the facility to carry out this work

References

Anbazhagan, S. and Nair, A.M. 2004. Geographical Information System and groundwater quality mapping in Panvel Basin, Maharashtra, India. Environmental Geology, 45: 753-761.

Burrough, P.A., and McDonnell R.A. 1998. Principles of Geographical Information System. Oxford University press, Oxford, pp 333.

Dhiman, S. D. and Keshari, A. K. 2002. GIS based correlation between groundwater Quality parameters and geological units. Map India, 2002, GIS Development.

Goyal, S., Bharadwaj, R.S., and Jugran, D.K. 1999. Multi criteria analysis using GIS for ground water resource evaluation in Rawasen and Pili Watersheds, U.P. GIS Development.

ISI. 1983 Indian Standard Institution- Indian standard specification for drinking water, IS: 10500. pp 1-5.

Karanth, K. R. 1987 Groundwater assessment, development and management, tate Mc Graw Hill, New Delhi, pp 720.

Krishnamuraty, J. and Srinivas, G., 1995. Role of Geological and Geomorphological factors in groundwater exploration: a study using IRS-LISS data, International . J. Remote Sensing, 16 (14): 2595-2618.

Richards L.A. 1954. Diagnosis and improvement of saline and alkali soils. Agric handbook 60, US dept. Agric, Washington, Dc, pp 160.

Roy, A..K. 1991. Hydromorphogeological mapping for Groundwater targetting and development in Dehradun Valley, U.P. In P.N.Gupta and A.K.Roy (eds): Mountain Resource Management and Remote

Sensing, Surya publication, Dehradun, 1-2-107.

Roy, A.K. 1995, Water Resources in Doon valley: Development and Constraints related to Hydrogeologic Environment, Journal of Himalayan Geology, 6: No.2.

Obi Reddy, G.B., Chandra Mouli, K., Srivastav, S.K., Srinvas, C.V., and Maji, A.K. 2000. Evaluation of groundwater potential zones Using Remote Sensing data- A case study of Gaimukh Watershed, Bhandara District, Maharashtra. Jour. of the Ind. Soc. of Remote Sensing, 28(1): 19-32.

Saraf, A. K. and Choudhury, P. R. 1997. Integrated Application of Remote Sensing and GIS Groundwater exploration in hard rock terrain, Proceedings. Int. Symp. On emerging trends in Hydrology, Department of Hydrology, Roorkee, September 25-27, 1997, I: 435-442.

Saraf, A. K. and Choudhury, P. R. 1998. Integrated Remote Sensing and GIS for Groundwater Exploration and Identification of artificial recharge sites, International Journal of Remote Sensing. 19(10): 1825-1841.

Sawyer, G.N. and McCartly, D.L. 1967. Chemistry of Sanitary Engineers, 2nd Ed. McGraw Hill, New York, pp 518. Todd, D.K. (1980). Groundwater hydrology. Wiley, New York, pp 533.

World Health Organization (1971) International standards for drinking water Geneva.