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Application of Geoinformatics for Groundwater Characterization

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Groundwater is the main source of irrigation in most arid and semi-arid regions of India. Therefore, there is a need to appraise quality of groundwater for sustainable crop production in these regions. In present study eighty one groundwater samples collected from tubewells across the block Gohana were analyzed for pH, electrical conductivity (EC), major cations namely, sodium (Na^+), potassium (K^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}), and anions namely, carbonate (CO_3^{2-}), bicarbonate (HCO_3^-), chloride (Cl^-), sulphate (SO_4^{2-}), nitrate (NO_3^-) and fluoride (F^-) and specific irrigation water quality indices *viz*., sodium adsorption ratio (SAR) and residual sodium carbonate (RSC). The pH of groundwater varied from 7.19 to 9.72 with a mean value of 8.18 and EC from 0.29 to 15.76 dS m^{-1} with a mean value of 2.74 dS m^{-1}. Among different cations, Na^+ was found as the most dominant cation followed by Mg^{2+}, Ca^{2+} and K^+. In case of anions, Cl^- was the dominant anion followed by SO_4^{2-}, HCO_3^-, CO_3^{2-}, NO_3^- and F^-. The SAR of groundwater varied from 4.03 to 24.16 (mmol L^{-1})$^{1/2}$ with a mean value of 10.59 (mmol L^{-1})$^{1/2}$. Correlation matrix indicated that EC is highly correlated with Cl^-, CO_3^{2-}, SO_4^{2-}, Na^+, Mg^{2+}, Ca^{2+} and K^+. The results from the laboratory were imported to ArcGIS (Arc Map 9.2 software) to generate the spatial variability maps of EC, SAR, RSC and water quality. The water quality map will furnish firsthand information to authorities and devisers about the ground water quality of the study area. Hence, geoinformatics plays a pivotal role in the study of earth resources.

Key words: Characterization, electrical conductivity, pH, residual sodium carbonate, sodium adsorption ratio, spatial variability, geoinformatics

Owing to degradation of resources, there is an increasing fear about the sustainable development and its influence on environment. In addition, there is not enough precise and up-to-date information for perpetual monitoring, identification, analyzing and mapping the areas of pollution or contamination. Moreover, the primary weakness in the present planning system, usually, is the scattering of the data. Therefore, geographic information system (GIS) in conjunction with global positioning system (GPS) is regarded as dynamic system assisted with databases, maps, locations, rules, *etc*. Thus, devisers, agencies and administrators need such a system for environmental monitoring (Ahmed and Azmi 2014). Geoinformatics is the application of information technology for study and management of earth resources. Remote sensing data can furnish precise spatial information and can be economically employed over conventional techniques of hydrogeological surveys. The GIS technique helps in integration and investigation of large volumes of data which facilitate in further validation of field studies results (Solomon and Quiel 2006).

On account of deficit rainfall, water scarcity is a serious problem in arid and semi-arid areas throughout the world; therefore, enormous pressure is brought on groundwater (Mehnaz *et al*. 2012). The groundwater resources of north Indian states in Indo-Gangetic plains depleted at the rate of 109 km^3 with average yearly depletion of 4.0±1.0 cm yr^{-1} from 2002 to 2008 (Rodell *et al*. 2009). The study area falls in the Indo-Gangetic plains and there is a serious problem in groundwater quality because of overuse for agricultural purposes as the region is under intensive cultivation. With the advent of industrialization and increasing population, the range of requirements for water has enhanced together with higher demands for better water quality. In parallel with the water use for

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different kinds of human activities, since antiquity water has been considered as the most desirable medium to clean, disperse, transport and dispose wastes. Groundwater aquifer which is the principal source of water in arid and semi-arid areas of India is at risk to salinity and sodicity jeopardising crop productivity (Kamra *et al*. 2002). Agriculture sector is the major user (89%) of this resource but the estimates showed that the growing demands from municipalities, industry and energy generation will claim about 23% (24.3 Mha-m yr^{-1}) of the total water resources (105 Mha-m yr^{-1}) by the year 2025 AD, thereby, further reduce the good quality water supply for irrigation (Minhas and Tyagi 1998). In India supplementary irrigation with tubewells is important as one-third of the land surface falls under arid and semi-arid climate and rainfall is, by and large, seasonal and erratic. Unlike surface water, groundwater is not always suitable for irrigation, its salt content and composition depends upon the location and geo-climatic factors (Sharma *et al*. 2012). Exploring geochemical processes that control groundwater chemical composition could lead to better understanding of hydrochemical systems of arid and semi-arid regions. Therefore, to improve the management and usage of groundwater, elucidating the relationship among groundwater quality, aquifer lithology and recharge type is important (Jalali 2009). In Haryana, the major sources of irrigation are canal and tubewells which often contain water of dubious quality. In the state, 37% of water is of good quality, 8% normal and 55% is of poor quality. Out of this poor quality water, 11% is saline, 18% is alkali and 26% as saline-alkali (Manchanda 1976). In recent years, a large number of shallow wells or tube wells have been installed to provide supplemental irrigation to rice-wheat cropping sequence in Gohana block of Sonipat Haryana. Therefore, an appraisal on the nature, properties and quality of irrigation water is essential for sound irrigation planning so as to assess any possibility of development of secondary salinization/ sodification in this region. Hence, the study was undertaken to characterize the groundwater quality by application of geoinformatics.

Materials and Methods

Study area

The study area (Gohana) forms a part of the Indo-Gangetic plains and displays flat terrain with general slope from north to south. The area is devoid of any high topographic features. Nevertheless, there is a natural depression in north and northwest of block. The maximum elevation of the plain is about 230 m above mean sea level. Gohana is situated at 28º57' and 29º12' N latitude to 76º38' and 76º52' E longitude (Fig. 1). The soils of the block are classified as Psammaquents and Haplaquepts (Soil Survey Staff 1999). The climate of the area is subtropical, semi-arid with hot dry summer and cold winter. Around 80% of the total rainfall occurs during the southwest monsoon (July-September). July is the wettest month of year with 7.5 rainy days and 169 mm rainfall. January is the coldest month with maximum and minimum temperature of 21.3 °C and 7.3 °C, respectively. Usually there is an increase in temperature in April and *rabi* (winter) crops ripe a week earlier than *Baisakhi* (Summer). The temperature continues to rise until June, which is the hottest month (CGWB 2008).

Sample collection and analysis

For evaluating groundwater quality of block Gohana, samples from tubewells across the block were collected and their locations were recorded in the form of latitudes and longitudes by using handheld GPS

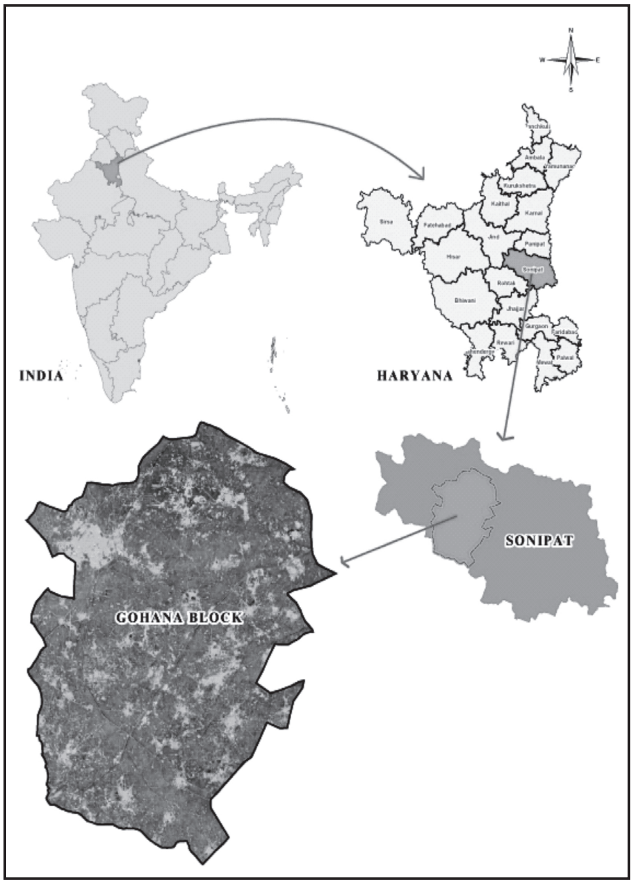

Fig. 1. Location map of the study area (Gohana)

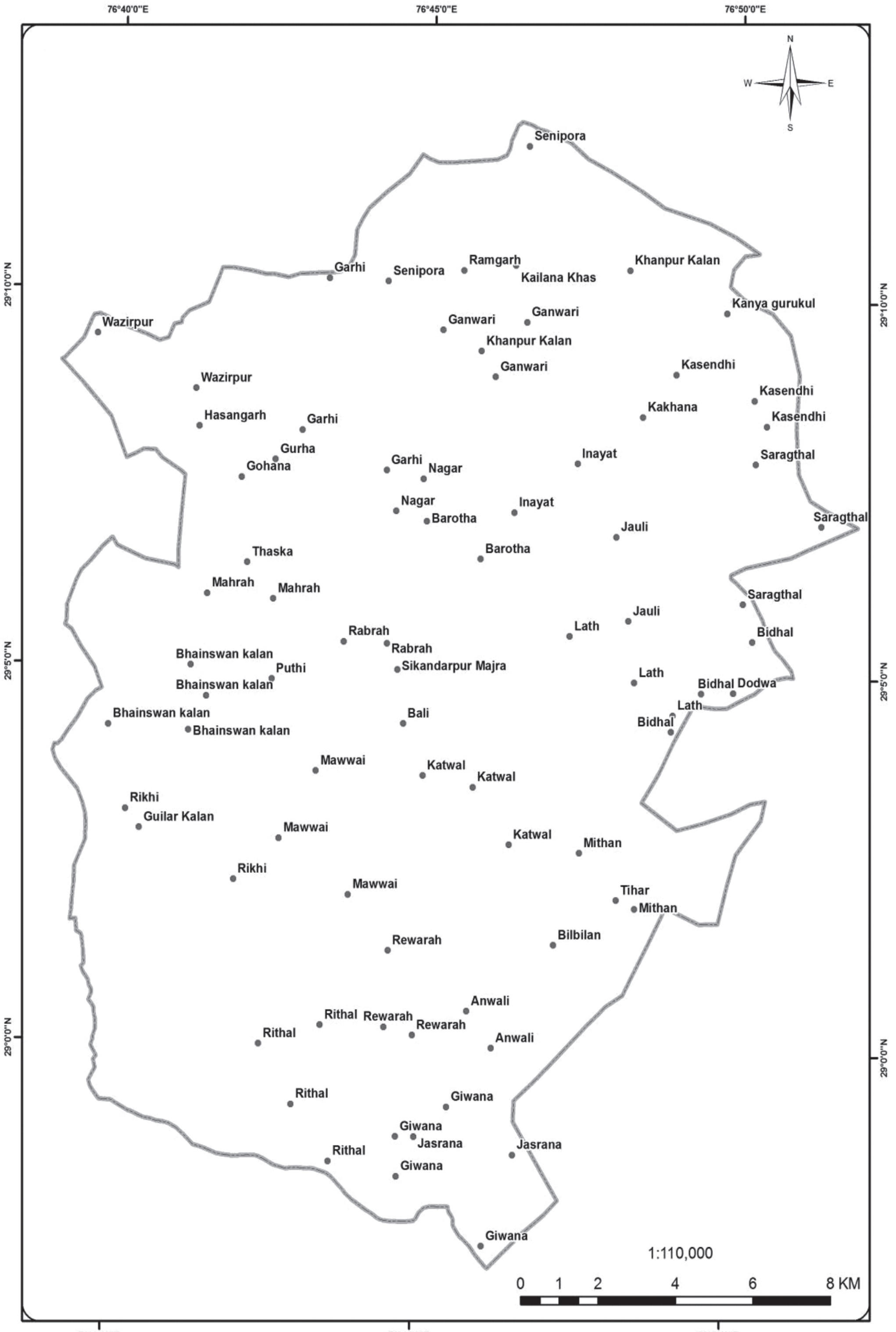

Fig. 2. Water sample location sites of Gohana recorded by handheld GPS

(Fig. 2). Sampling was done in winter season of 2014 in the month of February. The water samples were collected in thoroughly cleaned, properly labelled and carefully corked plastic bottles before chemical analysis. The samples were filtered in the laboratory and one to two drops of toluene were added to inhibit the microbial growth; subsequently were analyzed for pH, EC, soluble cations like calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+) and potassium (K^+) and anions namely, carbonate (CO_3^{2-}), bicarbonate (HCO_3^-), chloride (Cl^-), sulphate (SO_4^{2-}), nitrate (NO_3^-) and fluoride (F^-) by their standard procedures. The pH and EC were measured using pH meter and conductivity meter, respectively (Richards 1954). Sodium and K^+ were measured by flame photometry (Jackson 1973) while Ca^{2+} and Mg^{2+} were determined titrimetrically using standard ethylene diamine tetraacetic acid (EDTA) and by standard silver nitrate ($AgNO_3$) titration method. The CO_3^{2-} and HCO_3^- were determined by titration with standard H_2SO_4 (Richards 1954). Sulphate was determined colorimetrically by measuring the turbidity produced by barium chloride ($BaCl_2$) at 420 nm wavelength as described by Chesnin and Yien (1951). Nitrate was determined by spectrophotometric method (Richards 1954). Fluoride was determined colorimetrically by using Zirconium-Erichrome Cyanide-R Lake Method in presence of p-nitrophenol as an indicator at a wavelength of 527.5 nm (Megregian 1954). The water quality indices, SAR (Ayers and Westcot 1985) and RSC (Eaton 1950), are calculated by the following equations:

$$\text{SAR (mmol L}^{-1})^{\frac{1}{2}} = \frac{Na^+}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}}$$

$$\text{RSC}\left(\text{meq L}^{-1}\right) = \left(HCO_3^- + CO_3^{2-}\right) - \left(Ca^{2+} + Mg^{2+}\right)$$

Methodology for map preparation

The methodology essentially involves geo-referencing of satellite data, delineation of salt affected categories through on screen visual interpretation technique based on legacy data and limited ground truth. Three seasons Resource Sat -1 LISS III satellite data *viz*. *kharif*, *rabi* and *zaid* for 2008-2009 were used for delineation of salt affected areas. The satellite data was geo-coded and rectified using ortho-rectified LandSat ETM+ images. The details of the satellite data used for the study are given in table 1.

Image interpretation

Based on the standard image characteristics such as tone, texture, pattern, shape, size, location, association *etc*. on screen visual interpretation of remotely sensed data was carried out using a hybrid approach. Interpretation "keys" were developed for various salt affected categories. These interpretation "keys" formed the base for delineation of the satellite data. Based on these interpretation keys, satellite data was classified into various salt affected classes based on their occurrence in the block. Different salt affected categories were delineated by following a standard legend. These maps were put in GIS format to create the database. The datum and projection system of the satellite data was taken as WGS 84 and UTM, respectively. Arc GIS Desktop 9.2 and ERDAS Imagine were used for generation of vector layer and geo-referencing, respectively (ESRI 2009).

Table 1. Details of satellite data

Satellite	Sensor	Date of acquisition	Spatial resolution
IRS-P6	LISS-III	May, 2009 11 March, 2009 13 October, 2008	23.5 m

Ground verification

Due to variability of salt affected classes and terrain characteristics in the study area, ground truth in the block was collected along with the ground photographs. The doubtful areas in the pre-field interpreted maps were checked during the ground truth and the pre-field maps were modified by incorporating field observations, if any. After due corrections, attributes were attached.

The maps were composed in Arc Map 9.2 software to display the different layers of the extracted information in an effective manner for this purpose, the different layers of extracted information in .shp format were loaded in Arc Map and the maps were composed having legend to represent the categories of different classes. The Arc Map was also used to create various thematic maps like EC, SAR and RSC of the study area. The correlation coefficient was computed to determine the relationship among various parameters using SPSS software (Levesque 2007).

Results and Discussion

The range and mean of various water quality parameters are presented in table 2. The pH is one of the most crucial characteristics influencing the suitability of water for irrigation purpose. The pH of the study area ranged from 7.19 to 9.72 with the mean value of 8.18 indicating that the water is neutral to alkaline in nature. The lowest pH was observed in Hasangarh village and highest in Gohana.

The EC is the ease with which electrical current passes through water and is proportional to the salt concentration in the water. By analogy, total salt concentration in a soil or irrigation water can be

Table 2. Range and mean of different water quality parameters of block Gohana

Parameters	Range	Mean
pH	7.19 - 9.7	8.18
EC (dS m^{-1})	0.29 -15.7	2.74
RSC (me L^{-1})	0 - 9.2	2.22
SAR (mmol $L^{-1})^{1/2}$	4.03 - 24.1	10.59
Ca^{2+} (me L^{-1})	0.20 - 12.0	1.93
Mg^{2+} (me L^{-1})	0.40 - 36.2	5.56
Na^{+} (me L^{-1})	2.85 -114.6	20.58
K^{+} (me L^{-1})	0.05 -0.99	0.49
CO_3^{2-} (me L^{-1})	0- 4.00	0.24
HCO_3^{-} (me L^{-1})	0.50 - 12.4	4.81
Cl^{-} (me L^{-1})	0.80 - 115.4	17.79
SO_4^{2-} (me L^{-1})	0.15 - 31.4	4.92
NO_3^{-} (mg L^{-1})	0.59-55.0	12.25
F^{-} (mg L^{-1})	0.08 - 1.52	0.91

estimated by measuring EC, the higher the EC, greater the salt concentration. The EC of the samples varied from 0.29 to 15.76 dS m^{-1} with a mean value of 2.74 dS m^{-1}. The lowest EC was recorded in Saragthal village and highest in Rikhi village. The correlation matrix of the groundwater samples exhibits excellent positive correlation between EC and Ca^{2+}, Mg^{2+}, Na^{+}, Cl^{-} and SO_4^{2-} (Table 3).

The concentration of Na^{+}, Ca^{2+}, Mg^{2+} and K^{+} in groundwater samples varied from 2.85 to 114.6, 0.20 to 12.00, 0.40 to 36.2 and 0.05 to 0.99 me L^{-1}, respectively with mean value of 20.5, 1.93, 5.56 and 0.49 me L^{-1}, respectively. The cationic concentration followed the order: $Na^{+} > Mg^{2+} > Ca^{2+} > K^{+}$. Concentration of Na^{+}, Mg^{2+} and Ca^{2+} increased with the increase in EC while K^{+} showed the steady trend. The cation exchange between Na^{+} and Ca^{2+} or Mg^{2+} may be the reason for excess Na^{+} concentration. The Ca^{2+} and Mg^{2+} showed positive correlation (r = 0.98; Table 3) which suggests a common source. Since, it could be anticipated that dissolution of carbonate rocks leads to formation of HCO_3^{-} in the aquifer by the activity of percolating waters having enriched with CO_2 after being in contact with atmosphere (Jalali 2010). However, no correlation was found between Ca^{2+} and HCO_3^{-} indicating that calcite may not be the source of Ca^{2+}. Calcium and SO_4^{2-} (r = 0.93; Table 3) showed a positive correlation indicating gypsum is the source of Ca^{2+}. In groundwater, the Ca^{2+} ions may be contributed by the dissolution of anorthite (Jalali 2010). The positive correlation between Mg^{2+} and SO_4^{2-} (r = 0.94; Table 3) proposes that a portion of SO_4^{2-} and Mg^{2+} might be derived from the weathering of magnesium sulphate mineral (Jalali 2010). High SO_4^{2-} concentration in conjunction with high Ca^{2+} and Mg^{2+} concentration have been explicated by the weathering of reduced pyrite (Jalali 2010). Generally, high $SO_4^{2"}$ concentration may be derived either by sulphide or SO_4^{2-} weathering. Therefore, dissolution of gypsum and pyrite weathering both may add to the SO_4^{2-} load of the groundwater (Jalali 2010). The relationship between Na^{+} and Cl^{-} has frequently been applied to determine the mechanisms for acquisition of salinity and saline intrusions in semi-arid regions (Sami 1992). The high concentration of Na^{+} and Cl^{-} observed in various samples may be due dissolution of chloride salts. Equal concentration of Na^{+} and Cl^{-} are released into the solution by the dissolution of halite in water with a strong correlation between them (r = 0.98; Table 3). The positive correlation (r = 0.94; Table 3) between Na^{+} and SO_4^{2-} indicates that excess of sodium in groundwater by and large result from dissolution of sodium sulphate minerals. On the other hand, the K^{+} concentration of groundwater was negligible which may be ascribed to the resistance of potassium

Table 3. Correlation matrix for the groundwater parameters

Parameters	EC	pH	Cl^{-}	CO_3^{2-}	HCO_3^{-}	SO_4^{2-}	NO_3^{-}	F^{-}	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	SAR
EC	1.00												
pH	-0.46**	1.00											
Cl^{-}	0.98**	-0.54**	1.00										
CO_3^{2-}	0.36**	-0.04	0.33**	1.00									
HCO_3^{-}	-0.16	0.62**	-0.27**	0.10	1.00								
SO_4^{2-}	0.94**	-0.43**	0.92**	0.32**	-0.21	1.00							
NO_3^{-}	0.17	-0.08	0.16	-0.03	-0.03	0.19	1.00						
F^{-}	0.04	0.01	0.03	0.09	0.10	0.01	-0.04	1.00					
Ca^{2+}	0.97**	-0.50**	0.96**	0.37**	-0.19	0.93**	0.21	0.05	1.00				
Mg^{2+}	0.97**	-0.51**	0.97**	0.33**	-0.20	0.94**	0.19	0.05	0.98**	1.00			
Na^{+}	0.99**	-0.44**	0.98**	0.37**	-0.14	0.94**	0.16	0.04	0.95**	0.95**	1.00		
K^{+}	0.32**	-0.16	0.30**	-0.03	0.04	0.36**	0.13	0.02	0.35**	0.35**	0.30**	1.00	
SAR	0.78**	-0.16	0.75**	0.19	0.07	0.72**	0.12	0.07	0.67**	0.67**	0.82**	0.19	1.00

** Significant at 0.05 probability level minerals to decomposition by weathering. The concentration of CO_3^{2-}, HCO_3^-, Cl^- and SO_4^{2-} in groundwater samples varied from 0 to 4.00, 0.50 to 12.40, 0.80 to 115.4 and 0.15 to 31.4 me L^{-1}, respectively with a mean value of 0.24, 4.81, 17.79 and 4.92 me L^{-1}, respectively. The concentration of NO_3^- and F^- varied from 0.59-55.0 and 0.08-1.52 mg L^{-1} with a mean value of 12.25 and 0.91 mg L^{-1}, respectively. The results reveal that Cl^- was the dominant anion followed by SO_4^{2-}, HCO_3^-, CO_3^{2-}, NO_3^- and F^-. The concentration of CO_3^{2-} was negligible in water samples. The reasons for low CO_3^{2-} and HCO_3^- concentrations in groundwater can be ascribed to carbonate weathering as well to the dissolution of carbonic acid in the aquifers (Kumar *et al*. 2006). In groundwater, the occurrence of SO_4^{2-} is the consequence of oxidation of sulphur in igneous rocks, the solution of the other sulphur bearing minerals and the oxidation of certain compounds like merasite and pyrite (Matthess 1982). Shahid *et al*. (2008) reported similar trend of enhancement of Na^+ and Cl^- in ground water in arid and semi-arid areas. High correlations between Ca^{2+} and Cl^-; Mg^{2+} and Cl^-; Na^+ and Cl^-; Ca^{2+} and SO_4^{2-}; Mg^{2+} and SO_4^{2-}; Na^+ and SO_4^{2-} (Table 3) indicate that these soluble salts are predominant in water samples.

Water quality indices

Sodium adsorption ratio (SAR): Excessive Na^+ in water produces undesirable effects of changing soil properties and reducing soil permeability. Hence, assessment of Na^+ concentration is necessary while considering the suitability for irrigation. The degree to which irrigation water tends to exchange positive ions (cations) in the soil and cations in the irrigation water can be represented by the SAR. Sodium replacing adsorbed Ca^{2+} and Mg^{2+} is hazardous as it causes damage to the soil structure. It becomes compact and impervious. The SAR is an important parameter for the determination of the suitability of irrigation water because it is responsible for the Na^+ hazard.

The SAR ranged from 4.03 to 24.16 (mmol L^{-1})$^{1/2}$ with a mean value of 10.59 (mmol L^{-1})$^{1/2}$. The highest SAR was found in Rikhi village and lowest in Saragthal village. Sharma *et al*. (2012) reported that SAR varied from 0.24 to 28.18 (mmol L^{-1})$^{1/2}$ with a mean value of 9.18 (mmol L^{-1})$^{1/2}$ in the ground water samples of Mundlana Block (Sonipat).

Residual sodium carbonate (RSC): The RSC exists in irrigation water when the CO_3^{2-} plus HCO_3^- content exceeds the Ca^{2+} plus Mg^{2+} content of the water. The RSC is a significant factor that has a great influence on the suitability of water for irrigation purposes. When the RSC value is lower than 1.25 me L^{-1}, the water is considered to be of good quality; if the RSC value exceeds 2.5 me L^{-1}, the water is considered harmful. In the present study, RSC was absent in many of the samples because the concentration of Ca^{2+} plus Mg^{2+} was more than sum of CO_3^{2-} and HCO_3^-. The RSC values ranged from 0 to 9.2 me L^{-1} with a mean value of 2.22 me L^{-1}, the highest being in Jauli village and lowest in Hasangarh. Sharma *et al*. (2012) reported that RSC varied from nil to 9.10 me L^{-1} with an average value of 3.81 me L^{-1} in the ground water samples of Mundlana block (Sonipat).

The average chemical composition and related quality parameters in different EC classes of block Gohana are presented in figures 3, 4, 5 and 6. The EC values were grouped into different classes with an interval of one unit up to 8 dS m^{-1}; remaining samples having EC > 8 dS m^{-1} were confined in one group. Out of 81 samples collected, 22.2% samples had EC < 1 dS m^{-1} followed by 39.5% in the range of 1-2 dS

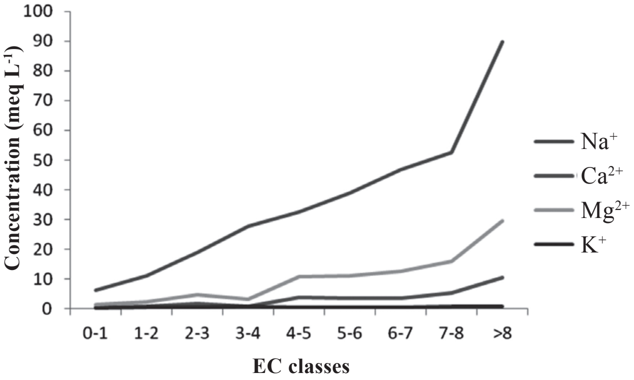

Fig. 3. Average cationic concentration (Ca^{2+}, Mg^{2+}, Na^+ and K^+) of water samples in different EC classes

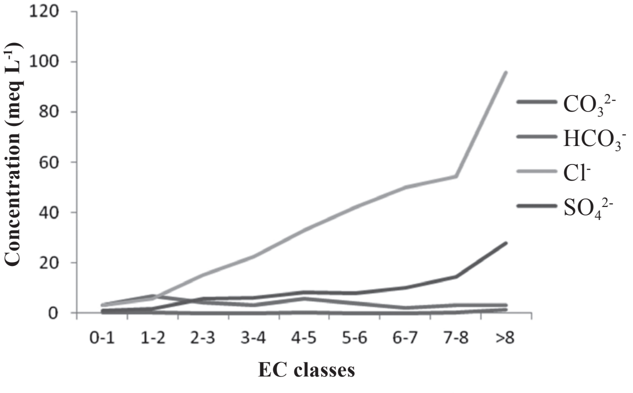

Fig. 4. Average anionic concentration (CO_3^{2-}, HCO_3^-, Cl^- and SO_4^{2-}) of water samples in different EC classes.

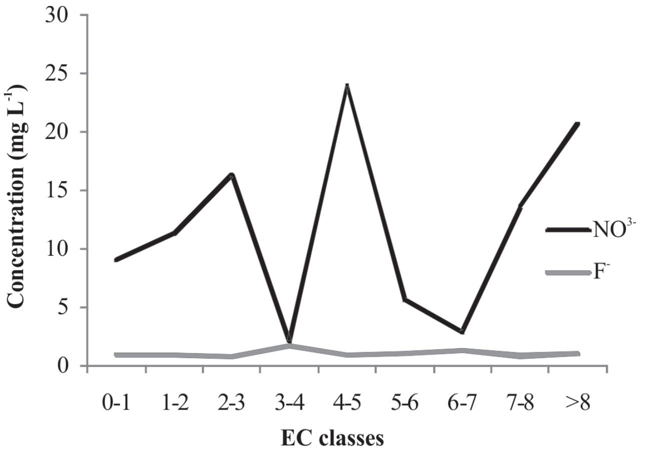

Fig. 5. Average nitrate and fluoride concentration of water samples in different EC classes

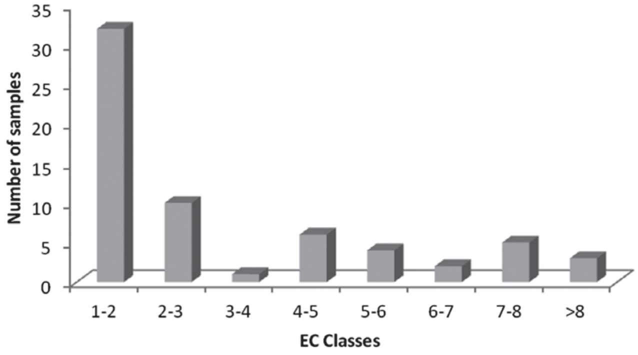

Fig. 6. Number of samples in different EC classes

m^{-1}, 12.3% in 2-3 dS m^{-1}, 1.23% in 3-4 dS m^{-1}, 7.4% in 4-5 dS m^{-1}, 4.9% in 5-6 dS m^{-1}, 2.47% in 6-7 dS m^{-1}, 6.17% in 7-8 dS m^{-1} and 3.7% samples had EC more than 8 dS m^{-1}. The groundwater samples having higher EC were less in number. On the basis of EC, SAR and RSC, water samples were classified into different categories as per the classification of All India Coordinated Research Project (AICRP) on management of salt affected soils and use of saline water in agriculture (Gupta *et al*. 1994). Consequently, 28.4% samples were found to be of good quality, 9.9% marginally saline, 6.2% saline, 18.5% high SAR saline, 13.6% marginally alkali, 8.6% alkali and 14.8% highly alkali as represented in fig. 7.

EC, RSC, SAR and Water quality maps: The maps display the spatial distribution of EC, RSC and SAR of water samples. The EC values were divided into five classes < 2, 2-4, 4-6, 6-8 and > 8 dS m^{-1} in the study area (Fig. 8). Maximum area was found below the EC range of < 2 dS m^{-1}. Higher EC was found in northern and southern parts of the study area. The RSC values were divided into ten classes 0, 0-1, 1-2, 2-3, 3-4, 4-5, 5-6, 6-7, 7-8, and > 8 me L^{-1} in the study area (Fig. 9). Maximum area was found below the RSC range of 0-1 me L^{-1}. Higher RSC was found in eastern and western parts of the study area. The SAR values were divided into five classes < 5, 5-10, 10-15, 15-20 and > 20 (mmol L^{-1})$^{1/2}$ in the study area (Fig. 10). Maximum area was found below SAR value of < 5 (mmol L^{-1})$^{1/2}$. Higher SAR was found in northern and central but highest in southern parts of the block.

Water quality map of block Gohana was constructed to illustrate the spatial distribution of different categories of ground water. Since, the water classification is based on EC, SAR and RSC, these maps were overlayered and combined to construct a single map depicting the spatial distribution of water quality of Gohana (Fig. 11). The different colours in water quality map shows all identified categories of groundwater like good, saline, marginally saline, high SAR saline, marginally alkali, alkali and highly alkali. Maximum area was found under good quality water.

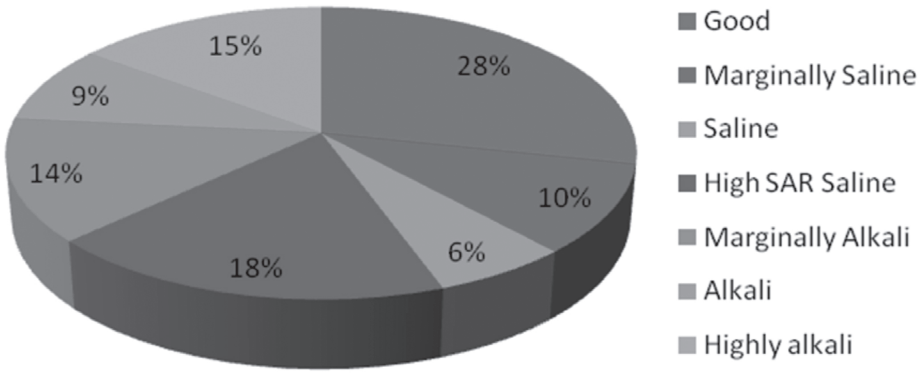

Fig. 7. Pie chart depicting distribution of water quality of block Gohana

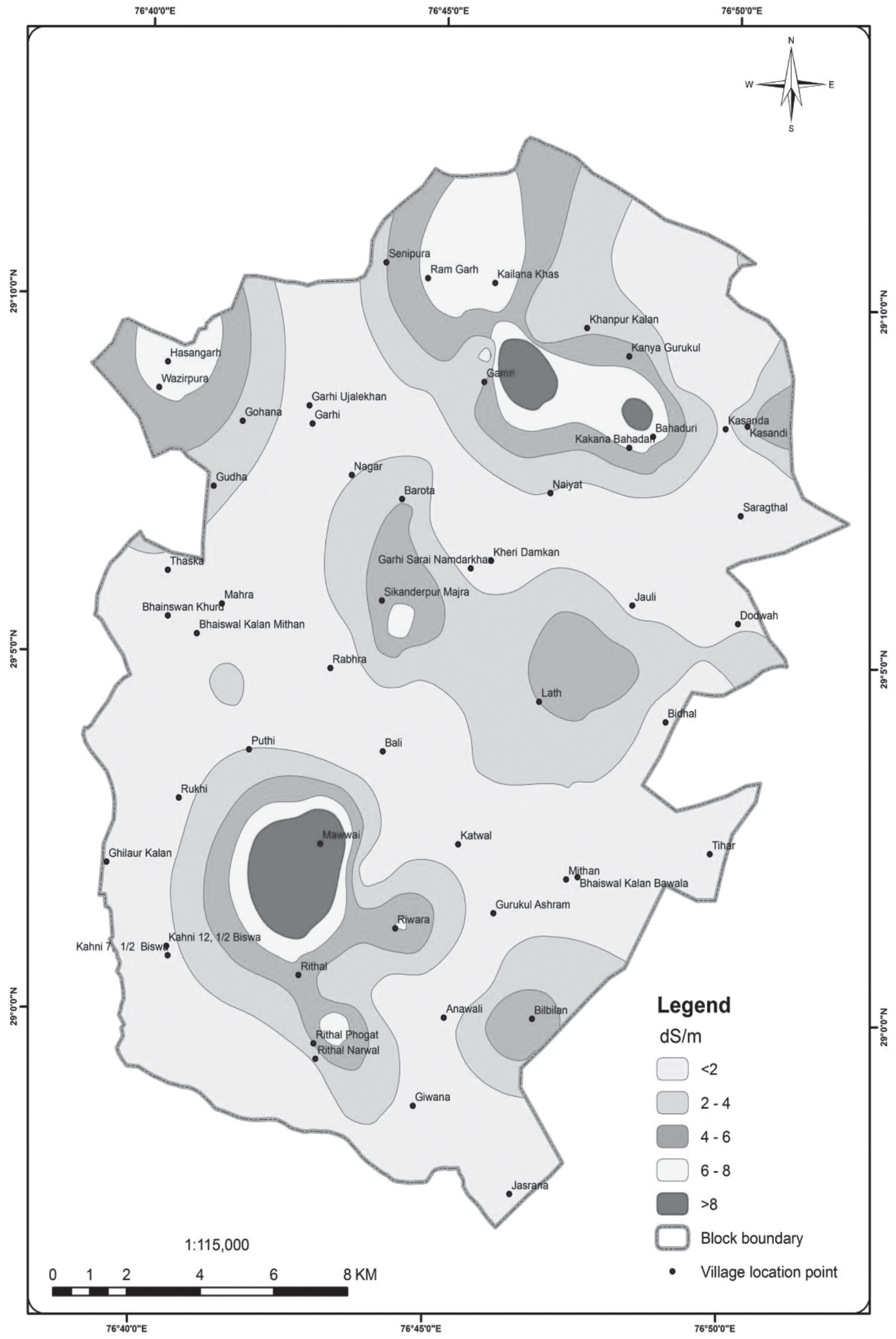

Fig. 8. Map showing spatial variability of EC of groundwater

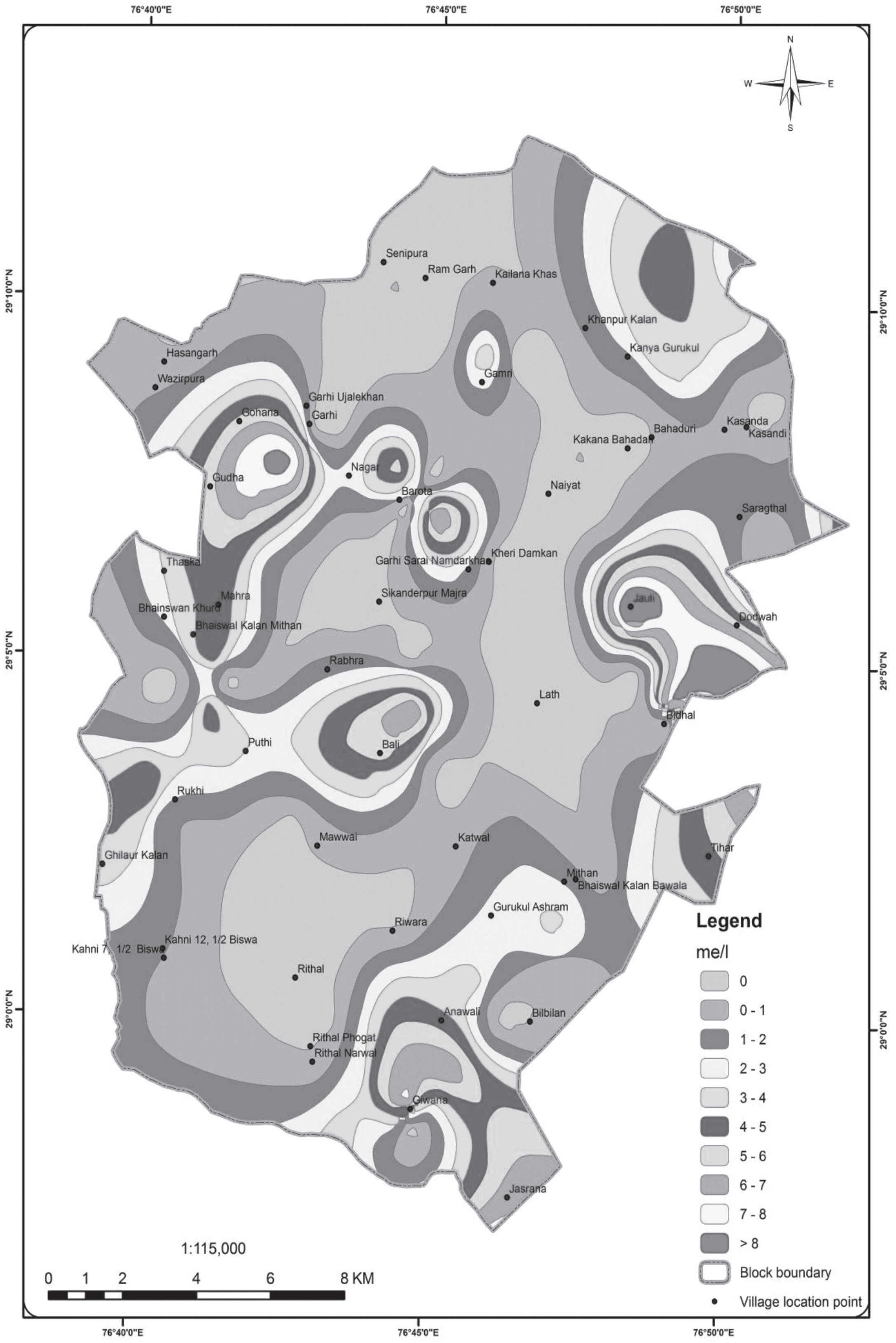

Fig. 9. Map showing spatial variability of RSC of groundwater

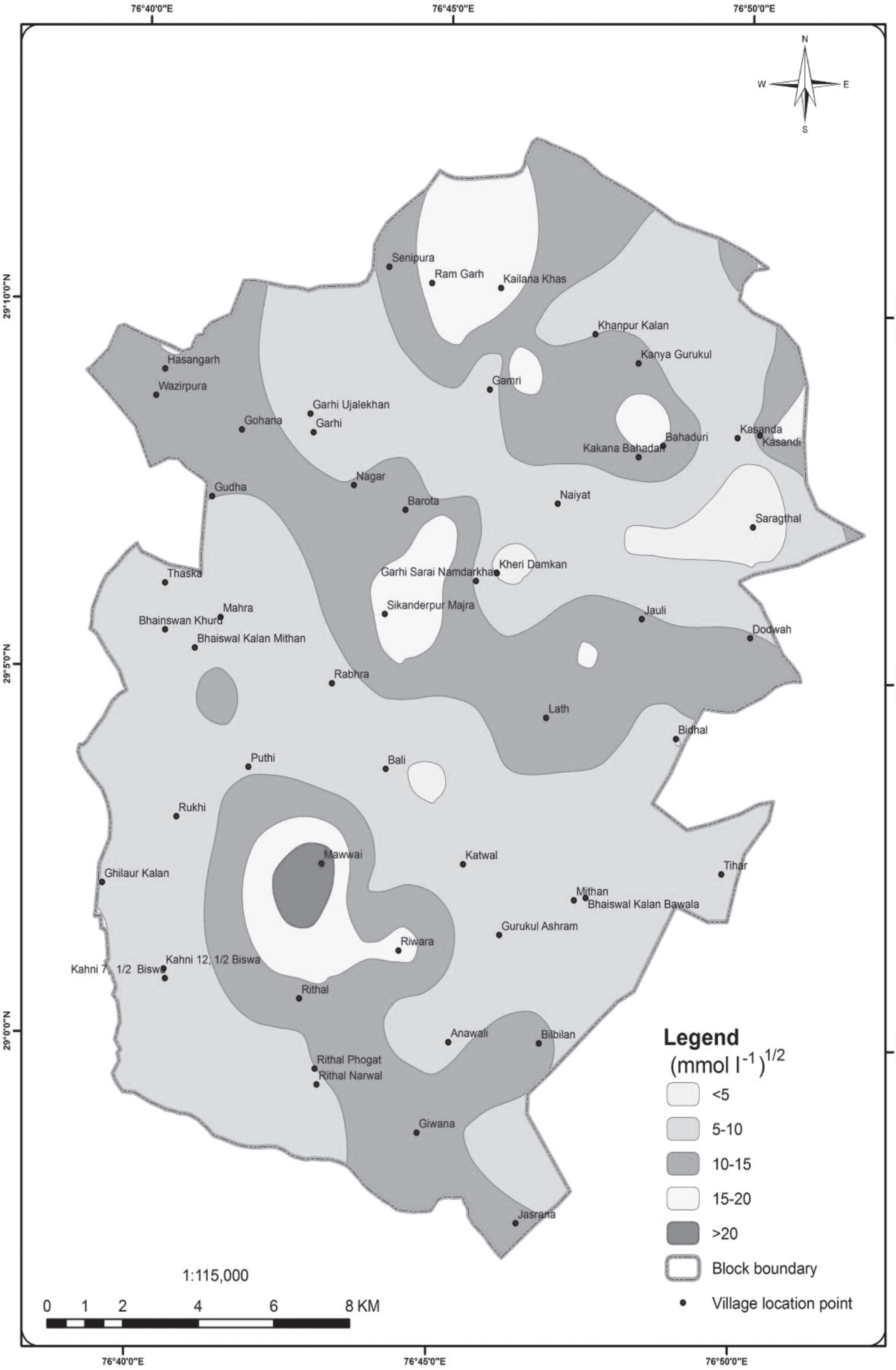

Fig. 10. Map showing spatial variability of SAR of groundwater

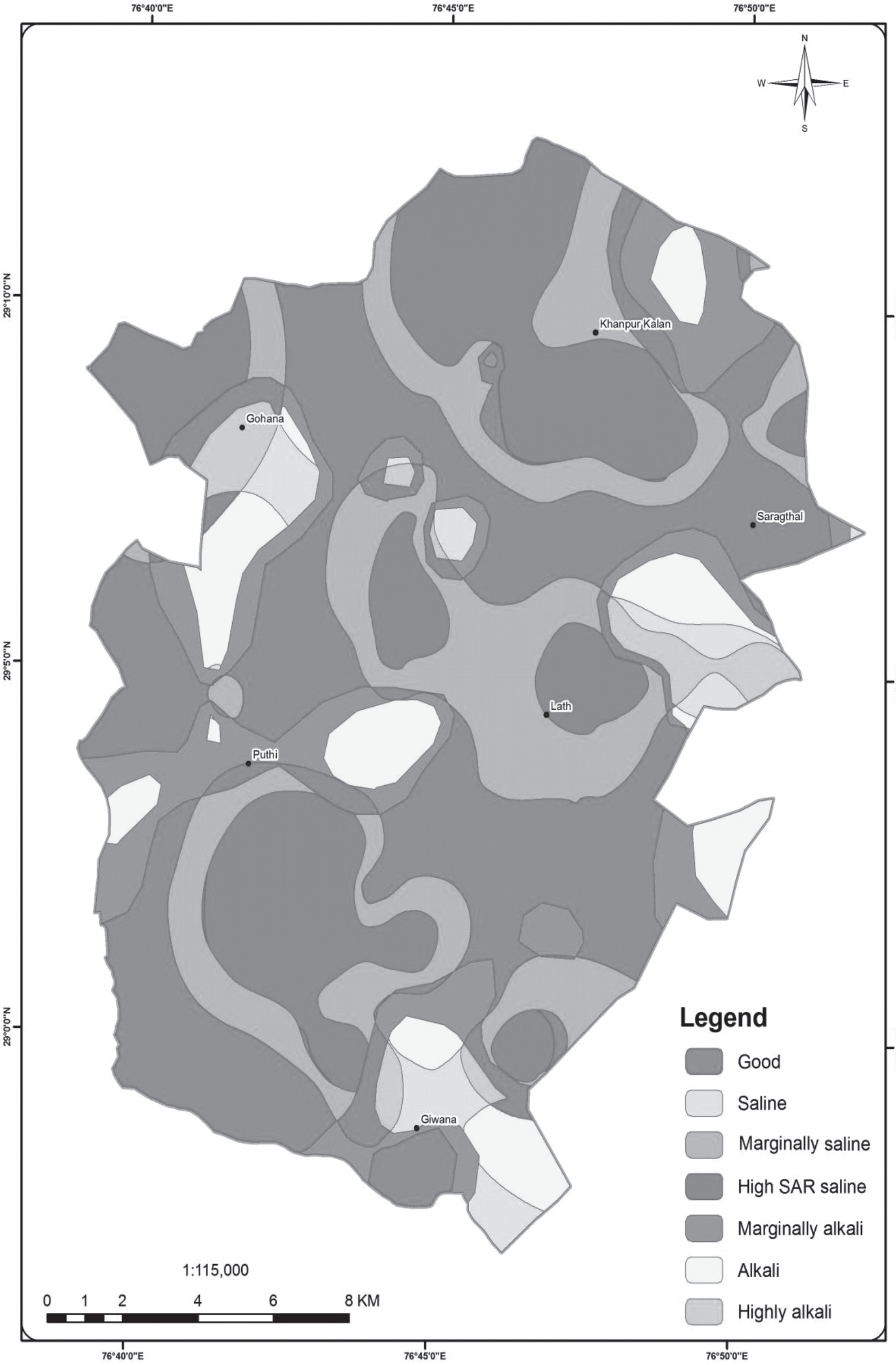

Fig. 11. Map showing spatial variability of different categories of groundwater in Gohana

Conclusions

The groundwater of Gohana is Na-Mg-Ca type dominated by chloride and the brackish water is generally saline and alkali in nature. Conjunctive or alternative use with good quality water and proper soil water management practices will help in maintaining a favourable salt-water balance and the crop yields would be affected to the minimum. Geoinformatics has proved as a novel tool for characterization of groundwater. The final map prepared will furnish firsthand information to authorities and devisers about the ground water quality of the study area.

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References

Ahmed, S.A. and Azmi, M.T. (2014) A precise methodology integrates low-cost GPS data and GIS for monitoring groundwater quality parameters in Majmaah region, KSA. *International Journal of Environmental Monitoring and Analysis* **2**, 279-288.

Ayers, R.S. and Westcot, D.W. (1985) *Water Quality for Agriculture*. FAO Irrigation and Drainage Paper 29, Rome.

CGWB (2008) *Hydrogeological Information Booklet of Sonipat district, Haryana*. Central Groundwater Board, Ministry of Water Resources, Government of India North Western Region, Chandigarh.

Chesnin, L. and Yien, C.H. (1951) Turbidimetric determination of available sulfates. *Soil Science Society of America Proceedings* **15**, 149-151.

Eaton, F.M. (1950) Significance of carbonates in irrigation waters. *Soil Science* **69**, 123-133.

ESRI (2009) *GIS and Mapping Software*. Environmental Systems Research Institute. http://www.esri.com/.

Gupta, R.K., Singh, N.T. and Sethi, M. (1994) Ground water quality for irrigation in India. CSSRI, Karnal, Technical Bulletin, 19 p.

Jackson, M.L. (1973) *Soil Chemical Analysis*. Prentice Hall of India (Pvt.) Ltd., New Delhi, India.

Jalali, M. (2009) Geochemistry characterization of groundwater in an agricultural area of Razan, Hamadan, Iran. *Environmental Geology* **56**, 1479-1488.

Jalali, M. (2010) Groundwater geochemistry in the Alisadr, Hamadan, western Iran. *Environmental Monitoring and Assessment* **166**, 359-369.

Kamra, S.K., Khajanchi, L., Singh, O.P and Boonstra, J. (2002) Effect of pumping on temporal changes in groundwater quality. *Agricultural Water Management* **56**, 169-178.

Kumar, M., Ramanathan, A.L., Rao, M.S., and Kumar, B. (2006) Identification and evaluation of hydrogeochemical processes in the groundwater environment of Delhi, India. *Environmental Geology* **50**, 1025-1039.

Levesque, R. (2007) *SPSS Programming and Data Management: A Guide for SPSS and SAS Users*. 4th Edn., SPSS Inc., Chicago.

Manchanda, H.R. (1976) Quality of underground water of Haryana, Haryana Agricultural University, Hisar. 160 p.

Matthess, G. (1982) *The Properties of Groundwater*. John Wiley, New York, pp. 1-406.

Megregian, S. (1954) Rapid spectrophotometric determination of fluoride with zirconium eriochrome cyanine R lake. *Analytical Chemistry* **26**, 1161-1166.

Mehnaz, R., Lone, M.A. and Ahmed, S. (2012) Integrating geospatial and ground geophysical information as guidelines for groundwater potential zones in hard rock terrains of south India. *Environmental Monitoring and Assessment* **184**, 4829-4839.

Minhas, P.S. and Tyagi, N.K. (1998) Guidelines for irrigation with saline and alkaline waters. *Technical Bulletin* No. 1/98, CSSRI, Karnal. pp.1.

Richards, L.A. (Ed.) (1954) *Diagnosis and Improvement of Saline and Alkali Soils*. Handbook No. 60. United States Department of Agriculture, Washington D.C. 160.

Rodell, M., Velicogna, I. and Famiglietti, J.S. (2009) Satellite based estimates of groundwater depletion in India. *Nature* **460**, 999-1003.

Sami, K. (1992) Recharge mechanisms and geochemical processes in a semi-arid sedimentary basin, Eastern cape, South Africa. *Journal of Hydrology* **139**, 27-48.

Shahid, M., Singh, A.P., Bhandari, D.K. and Ahmad, I. (2008) Groundwater quality appraisal and categorization in Julana block of Jind district, Haryana. *Journal of the Indian Society of Soil Science* **56**, 123-125.

Sharma, R., Pardeep, Sharma, S.K., Kumar, S. and Negi, B.S. (2012) Assessment of underground water quality in Mudlana block of Sonipat district in Haryana. *Journal of Soil and Water Conservation* **11**, 307-310.

Soil Survey Staff (1999) *Keys to Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys*. Second Edition. Agricultural Hand Book No. 436, United States Department of Agriculture, Washington, D.C., USA

Solomon, S. and Quiel, F. (2006) Groundwater study using remote sensing and geographic information systems (GIS) in the central highlands of Eritrea. *Hydrogeology Journal* **14**, 729-741.

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