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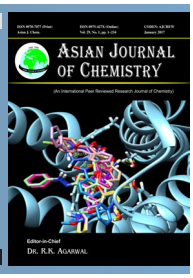

Hydrochemical Analysis and Evaluation of Groundwater Quality of Ellenabad Block of Sirsa District, India

SANJAY KUMAR[1,*], MUKARUKUNDA JEANE[1], RAJPAUL[2], RAM PRAKASH[2], S.K. SHARMA[2], SATYAVAN[2] and R.K. JHORAR[1]

[1]Department of Soil and Water Engineering, Chaudhary Charan Singh Haryana Agricultural University, Hisar-125 001, India
[2]Department of Soil Science, Chaudhary Charan Singh Haryana Agricultural University, Hisar-125 001, India

*Corresponding author: E-mail: sanjay7228@yahoo.com

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Chemical analysis of groundwater for a region is very important to the irrigation engineers and policy makers for site specific management of this important natural resource. Therefore, a study was planned to work out the chemical composition (Na^+, Ca^{2+}, Mg^{2+}, K^+, CO_3^{2-}, HCO_3^-, Cl^-, SO_4^{2-}) and other quality parameters (pH, EC, SAR and RSC) of groundwater (117 samples) for Ellenbad block of Sirsa district, Haryana. Sodium and chloride were found as major anion and cation, respectively, in the groundwater samples. Through this chemical analysis, the groundwater quality of the block was interpreted according to three different classification criteria *i.e.* AICRP, USSL and Piper to check its suitability for irrigation purpose. To study the spatial distribution of different parameters (EC, pH and water quality according to AICRP criteria), thematic maps were generated using inverse distance technique in geographic information system. According to AICRP criteria, out of seven categories, maximum 44.4 % of samples were found in good and minimum 6.8 % were found in saline as well as in marginally alkali categories. According to USSL criteria, groundwater quality of the block was observed under C2S1, C3S1, C3S2, C4S2, C3S3, C4S3 and C4S4 categories. According to Piper criteria, 25.6 % samples was under good category (Ca^{2+}-Mg^{2+}-Cl^- and Ca^{2+}-Na^+-HCO_3^- type) suitable for irrigation and 74.4 % was under poor category (Na^+-Cl^- type) unsuitable for irrigation.

Keywords: EC, GIS, Groundwater, Piper, Salinity, Sodicity, USSL.

INTRODUCTION

Groundwater plays an important role in Indian agriculture and accounts for more than half of the net irrigated area with 60 % of irrigated food production [1]. Groundwater is a mixture of various contents since flows below ground and during its passage it comes in contact with various formations and residence, which makes it for serving into various purposes. The principles governing the chemical characteristics of groundwater were well documented in many parts of the world [2-4]. The suitability of groundwater for drinking, agriculture and industrial purposes can be revealed through its hydrochemical analysis. Groundwater consists of several major chemicals, which play a significant role in classifying and assessing water quality. Classification of waters by considering the combined chemistry of all the ions like electric conductivity, RSC and SAR gives better results rather than by individual or paired ionic characters. Therefore, a better understanding of the chemistry of groundwater is highly essential to properly evaluate groundwater quality for irrigation purpose. Regular monitoring of groundwater resources plays a key role in sustainable management of water resources which involve the analysis of various ions present in the groundwater composition (Na^+, Ca^{2+}, Mg^{2+}, K^+, CO_3^{2-}, HCO_3^-, Cl^-, SO_4^{2-}), calculation of their related parameters (Na %, EC, pH, SAR, RSC) and preparation of spatial variable maps of their ionic composition and groundwater quality. Geographic information system (GIS) has emerged as a powerful tool for storing, analyzing and displaying spatial data and using these data for decision making in several areas including engineering and environmental fields. In view of above, the present study was aimed to analyze the chemical composition of groundwater sample, characterize the groundwater quality and delineate its spatial variations in Ellenabad block of Sirsa district, Haryana, India.

EXPERIMENTAL

Study area: Ellenabad block lies between 29°41'58" to 29°19'36"N latitudes and 74°32'00" to 74°58'02"E longitudes angles with a total geographical area of 58924 ha in Sirsa district. The topography of the area is almost flat with a gentle slope towards south west direction. A seasonal river Ghaggar passes through Baragudha, Ellenabad, Rania and Sirsa blocks of the district from eastern side to western side. Canal water in the block is supplied through Ottu feeder of Rori branch

derived from Bhakra main canal through Ellenabad and Sheranwali distriburtories.

Chemical composition analysis and classification of groundwater: Groundwater samples were collected from the 117 existing tube wells and their locations were recorded through global positioning system (GPS). Water samples were analyzed for pH, electrical conductivity (EC), anions (CO_3^{2-}, HCO_3^-, Cl^- and SO_4^{2-}) and cations (Ca^{2+}, Mg^{2+}, Na^+ and K^+) as per the procedure explained in Agriculture Handbook No. 60 [5]. To categorise the quality of groundwater, sodium adsorption ratio (SAR) and residual sodium carbonate (RSC) were worked out by using the following formulae:

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

$$RSC\ (me/L) = (CO_3^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+})$$

Based on chemical constituents of groundwater samples and other computed quality parameters, the groundwater samples were categorized as per AICRP (1989) [6], USSL (1954) [7] and Piper (1944) [8] criteria. AICRP (1989) criteria classify groundwater on the basis of EC, SAR and RSC into three categories *i.e.* good, saline (sub categorized as marginally saline, saline and high SAR saline) and alkali (sub categorized as marginally alkali, alkali and high alkali). USSL (1954) criteria classify groundwater based on salinity hazards and sodium hazards into sixteen classes. These 16 categories were further divided into three groups (I, II and III). Group I (suitable for irrigation) consists of C1–S1 and C2–S1, group II (conditionally suitable) consists of C1–S2, C2–S2, C3–S1 and C3–S2 and group III (unsuitable) consists of C1–S3, C1–S4, C2–S3, C2–S4, C3–S3, C3–S4, C4–S1, C4–S2, C4–S3 and C4–S4 categories. Piper (1944) criteria classify water on the basis of tri-linear diagram representing dominating ions into the following six categories.

• Ca^{2+}-HCO_3^- type: typical of shallow, fresh groundwater: suitable for irrigation.

• Na^+-Cl^- type: typical of marine and deep ancient groundwater (high saline): unsuitable for irrigation.

• Ca^{2+}-Mg^{2+}-Cl^- type: no dominating chemical composition.

• Ca^{2+}-Na^+-HCO_3^- type: no dominating chemical composition.

• Ca^{2+}-Cl^- or Ca^{2+}-SO_4^{2-} type: typical of gypsum groundwater and mining drainage, continuous uses can increase the salinity. It has to be mixed with canal or good water.

• Na^+-HCO_3^- type (high alkali): typical of deeper groundwater influenced by ion exchange, not good for irrigation.

RESULTS AND DISCUSSION

Hydrochemical analysis of the groundwater: The range and mean of the major chemical components and different parameters *i.e.* electrical conductance (EC), pH, CO_3^{2-}, HCO_3^-, Cl^-, SO_4^{2-}, Ca^{2+}, Mg^{2+}, Na^+, K^+, RSC and SAR was worked out and is presented in the Table-1. Range of these hydro-chemical components and parameters showed a lot of variation in the groundwater samples. Chloride and sodium were the major anion and cation, respectively, in the different groundwater samples. Variation in electrical conductivity reflects the variation of total salt concentration and ultimately the salinity of the groundwater samples. To study the spatial distribution of EC and pH, maps were prepared by using ArcGIS (Fig. 1). In the block, EC ranged from 0.3 to 8.7 with an average of 2.7 (Table-1). In spatial variability map of EC (Fig. 1a), samples were grouped into 5 classes with a class interval of 2 dS m^{-1}. The most dominating range of EC of groundwater was 0-2 dS m^{-1}, lying in central part to eastern side of the block. The next dominating EC range was 2-4 dS m^{-1} which was covering a large portion of eastern and western parts of the block, having patches of even higher EC. In study area, pH ranged from 7.2 to 9.0 with an average of 8.4 (Table-1). The suitable pH range is from 6.5 to 7.5. The lower limit of groundwater in the study area doesn't have any harmful impact on crop because it lies close to suitable range but the upper limit was high as compared to the desired limit. The most dominating range of pH is 8.4-8.8 (Fig. 1b) and the highest range 8.8-9.2 was observed at five spots in the block. Residual sodium carbonate (RSC) ranged from 0.0 to 3.6 (Table-1) and was absent in all samples having EC greater than 3 dS m^{-1}. Sodium adsorption ratio (SAR) ranged from 0.7 to 21.9 with an average of 7.2 $(mmol\ L^{-1})^{1/2}$ (Table-1). The SAR increased with the increase in EC, its average value in the samples having EC > 10 was recorded as 26.8 $(mmol\ L^{-1})^{1/2}$

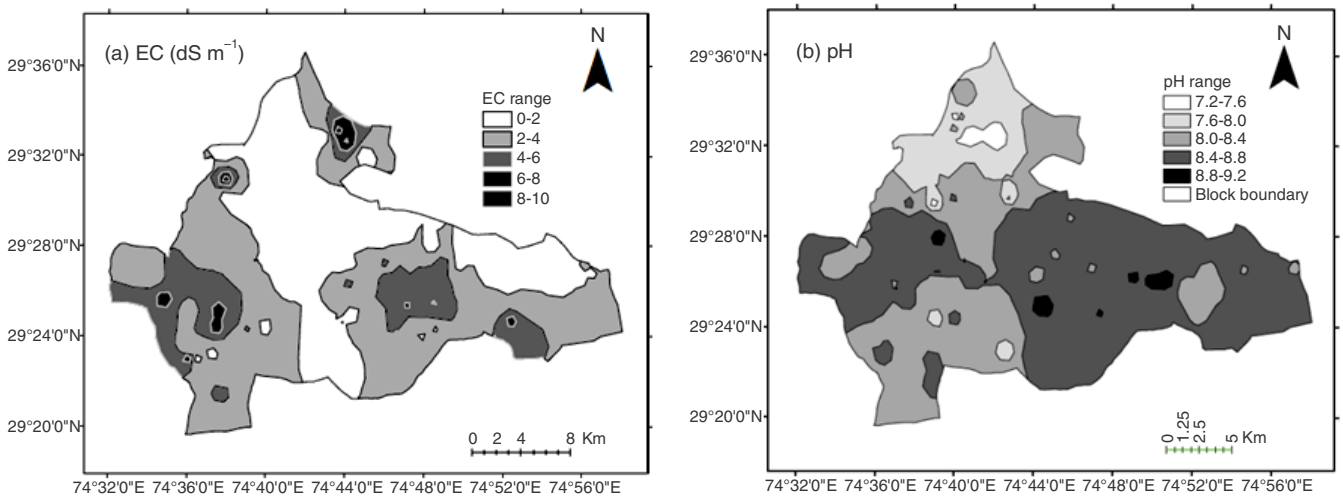

Fig. 1. Spatial variability of EC and pH of Ellenabad block of Sirsa district

TABLE-1
RANGE AND MEAN OF CHEMICAL COMPOSITION AND PARAMETERS OF THE GROUNDWATER SAMPLES OF ELLENABADBLOCK

Parameter/chemical components	Range	Mean
EC (dS m^{-1})	0.3-8.7	2.7
pH	7.2-9.0	8.4
CO_3^{2-} (me L^{-1})	0.0- 3.5	0.8
HCO_3^- (me L^{-1})	0.5-8.5	4.1
Cl^- (me L^{-1})	2.1-68.9	17.5
SO_4^{2-} (me L^{-1})	0.1-19.5	4.1
Na^+ (me L^{-1})	1.1-64.3	16.8
Ca^{2+} (me L^{-1})	0.5-6.1	2.3
Mg^{2+} (me L^{-1})	1.2-18.0	7.1
K^+ (me L^{-1})	0.1-0.5	0.3
RSC (me L^{-1})	0-3.6	0.5
SAR (mmol $L^{-1})^{1/2}$	0.7-21.9	7.2

and its lowest average value was recorded as 4.5 (mmol $L^{-1})^{1/2}$ in the samples having EC 0-1. With the increase in EC, Na^+ contents increased with a higher rate as compare to Ca^{2+} and Mg^{2+} due to which SAR increased with the increase in EC.

Classification of groundwater: According to AICRP criteria, out of seven categories, maximum 44.4 % (Table-2) of samples were found in good and minimum 6.8 % were found in saline as well as marginally alkali, whereas, no sample was found in alkali and high alkali categories. To study the spatial variability of groundwater quality, a map was prepared according to AICRP criteria (Fig. 2). On comparing spatial variable map of EC (Fig. 1a) with water quality (Fig. 2) it was found that the most of the area where EC was more than 4 dS m^{-1} under high SAR saline in comparison to saline condition, whereas, in both condition EC is more than 4 dS m^{-1} but under saline category, SAR is < 10 and under high SAR category, SAR is > 10. As observed earlier, Na^+ increased at a higher rate in comparison to Ca^{2+} and Mg^{2+} with the increase in EC, with this fact area under high SAR saline was increased. Marginally alkali category was found scattered in area surrounded by good water category because in both category EC is less than 2 dS m^{-1} but the area where RSC equal to or greater than 2.5 me L^{-1} reached under marginally alkali. By using different features of GIS, area of Ellenabad block under different categories was calculated and their percentage is represented in Table-2. It was found that out of seven categories, the maximum area (25462 ha) was estimated under good category which comprise of 43.2 % area of the block followed by marginally saline category with estimated area of 24624 ha. The minimum area (428 ha) of the block was estimated under saline, whereas, no area was estimated under alkali and high alkali as no sample

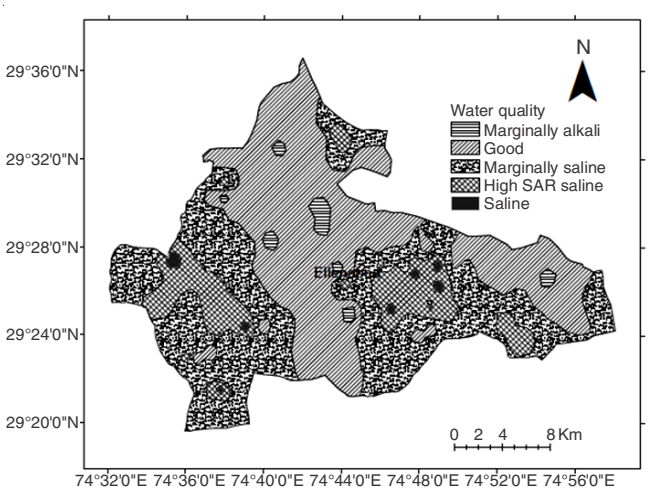

Fig. 2. Spatial variability of groundwater quality of Ellenabad block according to AICRP criteria

was found under this category. Classification of area under different quality of groundwater is more significant on the basis of mapping as they were prepared by considering the location of the sampling point through GIS then percent samples lies in different categories [9,10]. Spatial and temporal variability maps for groundwater depth and NO_3 concentrations were also prepared by using GIS [11].

Groundwater samples were categorized according to salinity and sodium hazard as per USSL criteria (Fig. 3). Samples were found highly scattered in C2S1, C3S1, C3S2, C3S3, C4S2, C4S3 and C4S4 categories by covering 7 classes out of 16 classes. Among the salinity hazard, maximum percentage (48.7) of samples was found under C3 categories (750 < EC > 2250 micromhos cm^{-1}). In the sodium hazard, maximum percentage (35.9) of samples was found under S1 (0 < SAR < 10) category. In both salinity and sodium hazards, maximum percentage (32.5) of samples was found under C3S1 category. To check the suitability of the groundwater samples, these categories were further distributed into 3 groups and 3.4, 47.9 and 48.7 % samples were found in group I, II and III, respectively. Thus, 48.7 % samples were unsuitable for irrigation as they were distributed under group III.

The concentrations of major ionic constituents of groundwater samples were plotted in the Piper trilinear diagram to determine the groundwater quality (Fig. 4). The diamond shaped field between the two triangles was used to represent the composition of water with respect to both cations and anions. In study area, majority of groundwater samples were dominating in Na^+ and Mg^{2+} in case of cation and in case of anion, Cl^- and SO_4^{2-} ions were varying inversely (Fig. 4), whereas,

TABLE-2
PERCENT SAMPLES AND PERCENT AREA IN DIFFERENT CATEGORIES OF GROUNDWATER ACCORDING TO AICRP CRITERIA

Category	Symbol	Number of samples	Samples (%)	Area under different categories (ha)	Area (%)
Good	A	52	44.4	25462	43.2
Marginally saline	B1	30	25.7	24624	41.8
Saline	B2	8	6.8	428	0.7
High SAR saline	B3	19	16.3	7404	12.6
Marginally alkali	C1	8	6.8	1006	1.7
Alkali	C2	0	0.0	0	0.0
High alkali	C3	0	0.0	0	0.0

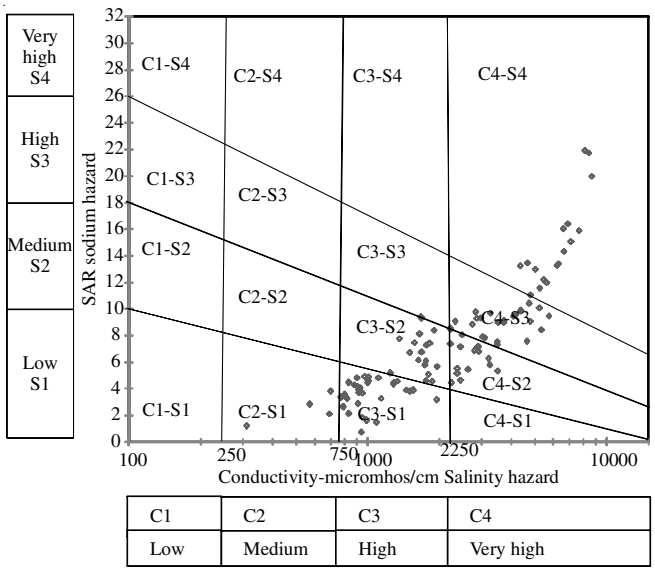

Fig. 3. Groundwater quality of Ellenabad block according to USSL criteria

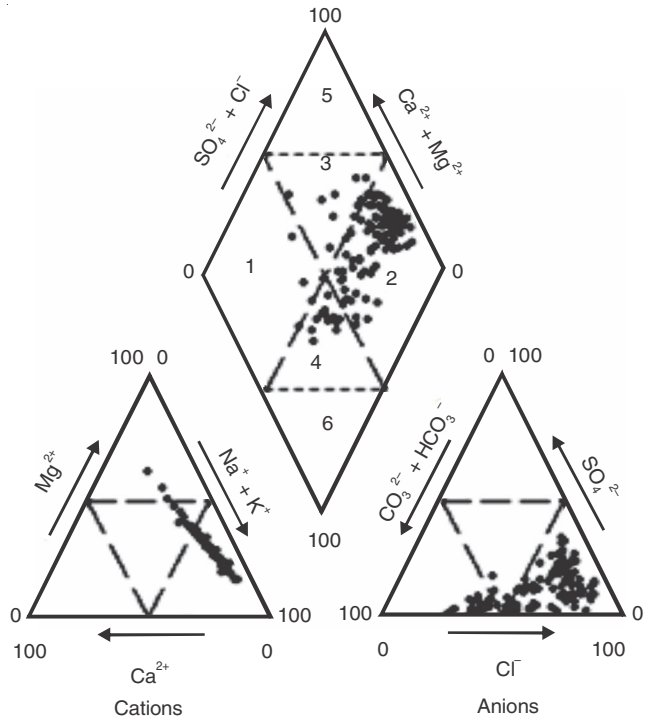

Fig. 4. Groundwater quality of Ellenabadblock according to Piper criteria

groundwater quality was confined in four types (1, 2, 3 and 4 classes). No sample was found in type 5 and 6, means groundwater of the area did not have any problem of alkali as it was observed in AICRP criteria also. According to Piper criteria, maximum percentage (74.4) of samples were found under Na^+-Cl^- category, 21.4 % samples were found under good quality which comprises of two categories *i.e.* Ca^{2+}-Mg^{2+}-Cl^- and Ca^{2+}-Na^+-HCO_3^- and 4.2 % were found in Ca^{2+}- HCO_3^-.

Among the three classification criteria, good category groundwater in Ellenabad block was found highest (44.4 % samples) according to AICRP criteria, whereas, according to USSL and Piper criteria, it was found as 3.4 and 21.4 %, respectively. In AICRP criteria, good quality was considered when EC < 2 dS m^{-1}, whereas, in USSL criteria, it was considered when EC < 0.75 dS/m and in Piper criteria, classification of water was done on basis of its ionic composition. Due to this reason, percentage of good quality water was extremely high in AICRP criteria in comparison to USSL and Piper criteria. According to spatial distribution of groundwater quality, area under good quality water was found to be 43.2 % followed by 41.8 % in marginally saline category.

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