Suitability Assessment of Groundwater for Irrigation in Some Villages of Sirsa District, Haryana (India)

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Abstract. To determine the groundwater quality a total of twenty groundwater samples were collected from some villages of Sirsa district, Haryana, India, which is one of the most important agricultural areas of the state. The groundwater samples were collected in November 2016 from different villages of the city Sirsa. The suitability of groundwater for irrigation was assessed by determining the Sodium Absorption Ratio, \% Na, Kelly’s Index, Permeability index, EC, Chloro-alkaline indices and Residual Sodium Carbonate. The CAI analysis shows the reverse cation exchange for most of the stations. The Gibbs diagrams show the precipitation dominance for most of the stations. The Piper diagram shows the alkali dominance for most of the samples. On the basis of the values of different parameters the quality of ground water at different stations was categorized into three different classes mainly excellent, good or unsuitable.

Keywords. Groundwater quality, Irrigation, Sodium absorption ratio, Kelly’s Index, Piper diagram

1. Introduction
The groundwater is a chief source of water for every human being which is most widely used for drinking, industrial and agricultural uses [1]. The quantity of surface water is limited and therefore it cannot meet all the requirements, hence the dependence on groundwater is continuously increasing. For most of the parts of the country groundwater is the only available source of fresh water for domestic and agricultural purposes [2]. This overexploitation is the main reason to decrease the quality of groundwater. The groundwater quality is mainly decided with the help of physico chemical parameters. In India, the groundwater quality varies from distance to distance because of different land uses and without strict environmental norms. The groundwater gets polluted due to the discharge of domestic sewage, agricultural and industrial wastes, use of fertilizers and pesticides [3]. Water pollution has adverse effects on water quality as well as on human health [4]. Keeping this in mind, the physicochemical analysis of groundwater was carried out in the study area. The Sirsa district is a major agricultural part of the Haryana state where people mainly depend upon agriculture for their livelihood. The groundwater is the main source of water for both drinking and irrigation uses.

2. Description of the study area
The region Sirsa is arranged in the territory of 29\textdegree{}14’ and 30\textdegree{} north extension and 74\textdegree{}29’ and 75\textdegree{}18’ east longitudes, forming the west corner of Haryana. It is connected by Punjab and Rajasthan on three sides whereas its own state is only on one side.
Figure 1. Study Area

3. Collection of water samples and their analysis -
Agriculture is the main profession of the people of the villages of the study area. Samples collection was done in November 2016 from the tube-wells situated in agricultural land. The people of the area are using this water for irrigation and drinking. The samples were collected after running the water for 30 minutes from the tube-well. The samples were stored in cleaned plastic bottles rinsed with distilled water. EC and pH were measured at the sampling site using portable meters. The Rest of the parameters were analyzed in the laboratory. All the chemicals used were of A.R. grade. Double distilled water was used for the preparation of solutions. Standard methods were used for analysis of various parameters as given by American Physical Health Association (APHA) [5]. Microsoft excel 2007 was used to plot various graphs. Piper diagram was plotted by using U.S. Groundwater charts.

4. Results and discussion
4.1 Suitability for irrigation
The total concentration of soluble salts, relative amount of Na+ to other major cations (Mg2+, Ca2+, K+) concentration of bicarbonate ions and the concentration of other elements which may be harmful to plants are the important characteristics of water which determine its quality for irrigation. The important factors that decide the suitability of groundwater for irrigation are given in table 2.
Table 1. Physico Chemical Analysis

| Sr. No. | pH  | EC  | TDS  | Ca$^{2+}$ | Mg$^{2+}$ | Na$^+$ | K$^+$ | HCO$_3^-$ | Cl$^-$ | SO$_4^{2-}$ | N$^-$ | F$^-$ | CO$_3^{2-}$ |
|---------|-----|-----|------|-----------|-----------|--------|--------|------------|--------|------------|-------|-------|-----------|
| 1       | 8.5 | 2610| 1700 | 56        | 32        | 390    | 65     | 780        | 340    | 112        | 33    | 2.0   | 32.5      |
| 2       | 8.5 | 2582| 1680 | 52        | 31        | 373    | 60     | 635        | 45     | 84         | 36    | 1.5   | 28.7      |
| 3       | 8.4 | 8648| 5000 | 100       | 192       | 1572   | 89     | 2400       | 1960   | 275        | 42    | 1.5   | 37.8      |
| 4       | 7.1 | 312 | 225  | 20        | 14        | 70     | 36     | 116        | 160    | 59         | 38    | 0.7   | 14.8      |
| 5       | 8.0 | 640 | 405  | 44        | 24        | 142    | 83     | 228        | 100    | 23         | 33    | 2.3   | 27.6      |
| 6       | 7.5 | 450 | 290  | 20        | 17        | 100    | 57     | 108        | 100    | 35         | 34    | 1.6   | 12.4      |
| 7       | 8.3 | 922 | 595  | 32        | 52        | 192    | 67     | 256        | 170    | 91         | 09    | 2.2   | 22.0      |
| 8       | 8.5 | 870 | 550  | 260       | 96        | 174    | 84     | 236        | 180    | 98         | 11    | 0.1   | 24.2      |
| 9       | 8.2 | 5640| 3640 | 220       | 312       | 1025   | 51     | 1870       | 990    | 213        | 14    | 0.8   | 30.6      |
| 10      | 9.3 | 910 | 605  | 40        | 60        | 198    | 66     | 326        | 100    | 19         | 40    | 2.4   | 18.6      |
| 11      | 8.5 | 650 | 445  | 40        | 36        | 118    | 53     | 190        | 180    | 10         | 18    | 1.4   | 9.2       |
| 12      | 7.5 | 480 | 318  | 20        | 17        | 106    | 45     | 150        | 130    | 89         | 19    | 1.9   | 10.8      |
| 13      | 8.5 | 640 | 440  | 140       | 96        | 116    | 48     | 120        | 150    | 91         | 16    | 2.0   | 12.0      |
| 14      | 7.5 | 690 | 480  | 32        | 60        | 128    | 57     | 330        | 110    | 50         | 37    | 0.7   | 18.4      |
| 15      | 7.5 | 620 | 405  | 20        | 24        | 118    | 52     | 228        | 180    | 45         | 18    | 1.3   | 12.6      |
| 16      | 7.5 | 8710| 5220 | 128       | 526       | 1420   | 72     | 2550       | 2000   | 600        | 16    | 3.0   | 31.4      |
| 17      | 7.8 | 650 | 445  | 20        | 24        | 128    | 52     | 250        | 100    | 30         | 11    | 3.0   | 19.5      |
| 18      | 7.8 | 8412| 4225 | 180       | 327       | 1278   | 77     | 2000       | 1620   | 300        | 22    | 2.5   | 12.7      |
| 19      | 8.0 | 8658| 4763 | 200       | 463       | 1470   | 68     | 2430       | 1650   | 250        | 20    | 2.0   | 19.7      |
| 20      | 8.1 | 3315| 2142 | 164       | 216       | 690    | 63     | 1310       | 1200   | 450        | 23    | 4.5   | 32.4      |
| M       |     |     |      |           |           |        |        |            |        |            |       |       |           |
| Min.    |    | .45 | .65   | 0         | 95        | 4      | 25     | 5          | 5      | 2          | 5     | 7     |           |
| Max.    |    |    |      |           |           |        |        |            |        |            |       |       |           |
| Range   | 2.2 | 83.9| 4995  | 240       | 512       | 1502   | 53     | 2442       | 1955   | 590        | 33    | 4.4   | 28.6      |
| St. dev.| 0.5 | 3236| 1812  | 78.2      | 157.      | 538.   | 13.    | 899.1      | 703.2  | 157.       | 10.   | 0.9   | 8.73      |
S/ cm. If such water is continuously used it may lead to the formation of saline soils. In %Na (EC) in water used for irrigation. Higher value of SAR adversely affects the osmotic activity of plants and

RSC can be calculated by using Eq. (2)

% Na in groundwater is a very important parameter to assess its suitability for irrigation and can be calculated by using Eq. (1). The importance of Sodium ion is due to the reaction of sodium with soil that reduces its permeability. In our study three samples are in good range and eight samples are in unsuitable range.

RSC = (CO$_3^{2-} + $HCO$_3^{-}$) – (Ca$^{2+} + $Mg$^{2+}$)

SAR is a very important factor to determine the quality of water used for irrigation. Higher value of SAR adversely affects the osmotic activity of plants and

Table 2. Irrigation Quality Parameters.

| S No. | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| %Na   | 77 | 77 | 91 | 59 | 36 | 70 | 65 | 31 | 55 | 59 | 56 | 70 | 29 | 51 | 68 | 56 | 69 | 61 | 57 | 54 |
| .2    | .3 | .3 | .7 | .9 | .5 | .1 | .6 | .3 | .5 | .4 | .4 | .4 | .5 | .2 | .0 | .7 | .3 | .4 | .7 |
| SAR   | 10 | 10 | 37 | 2. | 2. | 3. | 5. | 2. | 10 | 4. | 3. | 4. | 1. | 3. | 4. | 12 | 4. | 13 | 12 | 8. |
| .2    | .1 | .5 | 64 | 32 | 95 | 08 | 23 | .1 | 60 | 46 | 19 | 84 | 05 | 20 | .3 | 55 | .0 | .9 | 33 |
| KI    | 3. | 3. | 10 | 1. | 0. | 1. | 1. | 1. | 1. | 1. | 0. | 0. | 1. | 1. | 1. | 1. | 1. | 1. | 1. |
| .2    | .1 | .5 | 64 | 32 | 95 | 08 | 23 | .1 | 60 | 46 | 19 | 84 | 05 | 20 | .3 | 55 | .0 | .9 | 33 |
| PI    | 0. | 0. | 0. | 1. | 0. | 1. | 0. | 1. | 1. | 1. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. |
| 91    | 90 | 99 | 77 | 39 | 83 | 75 | 33 | 61 | 70 | 68 | 88 | 32 | 65 | 86 | 61 | 88 | 67 | 62 | 62 |
| RSC   | 8. | 6. | 33 | -  | -  | -  | -  | -  | -  | -  | -  | 0. | -  | -  | 1. | -  | 1. | -  | -  | -  |
| 39    | 19 | .9 | 0. | 9. | 0. | 0. | 16 | 5. | 1. | 1. | 4. | 12 | 0. | 16 | 7. | 75 | 3. | 8. | 3. |
| 3     | 28 | 55 | 24 | 47 | .3 | 33 | 04 | .58 | .6 | 58 | .02 | 04 | 08 | 66 |
| 7     | 3  |
| MAR   | 48 | 49 | 25 | 62 | 84 | 58 | 80 | 38 | 70 | 71 | 60 | 58 | 53 | 75 | 66 | 87 | 66 | 75 | 79 | 68 |
| .8    | .8 | .0 | .5 | .5 | .6 | .3 | .2 | .4 | .0 | .6 | .3 | .7 | .7 | .8 | .7 | .1 | .4 | .7 |

4.2 Electrical conductivity (EC)
Electrical conductivity expresses the amount of total soluble salts present in water. The observed variation in EC was in the range from 312 to 8658 with a mean value of 2820.45. Water with EC below 750 μS/cm is suitable for irrigation. 40% of the water samples were unfit and having EC more than 2,250 μS/cm. If such water is continuously used it may lead to the formation of saline soils. In general, Water having EC in between 750 to 2,250 μS/cm is most widely used.

4.3 Percentage sodium (% Na)
% Na in groundwater is a very important parameter to assess its suitability for irrigation and can be calculated by using Eq. (1). The importance of Sodium ion is due to the reaction of sodium with soil that reduces its permeability. In our study three samples are in good range and eight samples are in permissible limits whereas nine samples are above the permissible limit.

% Na = (Na$^+ + K^+ / Ca^{2+} + Mg^{2+} + Na^+ + K^+$) × 100 (1)

4.4 Residual sodium carbonate (RSC)
The total of bicarbonate and carbonate over the total of magnesium and calcium in water has its effect on the suitability of groundwater for irrigation. It influences the soil by dissolving the organic matter in soil. RSC can be calculated by using Eq. (2). In our study RSC varies from -0.24 to 33.93. A total of fifteen samples are in suitable range and five in unsuitable range.

RSC = (CO$_3^{2-} + $HCO$_3^{-}$) – (Ca$^{2+} + $Mg$^{2+}$) (2)

4.5 Sodium absorption ratio (SAR)
SAR can be expressed as a sodium hazard and it is a very important factor to determine the quality of water used for irrigation. Higher value of SAR adversely affects the osmotic activity of plants and
hence prevents water to reach the branches and leaves of the plants and thereby reduces the crop yield.  

\[ \text{SAR} = \frac{\text{Na}^+}{(\text{Ca}^{2+} + \text{Mg}^{2+})^{1/2}} \]  

(3)

In our study SAR varies from 1.84 meq/l to 37.54 meq/l. The total of thirteen samples lie in suitable range and the rest seven in unsuitable range.

**4.6 Permeability index (PI)**

For a long time of use, the presence of Na\(^+\), Mg\(^{2+}\), Ca\(^{2+}\) and HCO\(_3^-\) content affect the soil permeability which also affects the irrigation water quality. The PI can be calculated by using Eq. (4).  

According to the criteria of PI water can be classified into three classes. The water with PI more than 75% is categorized as good for irrigation (class I and class II) whereas PI with 25% is not considered to be suitable for irrigation. In our study nine samples are excellent and rest eleven are good.

\[ \text{PI} = \frac{\text{Na}^+ + (\text{HCO}_3^-)^{1/2}}{(\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^+)} \]  

(4)

**4.7 Kelly’s index (KI)**

Kelly proposed criteria to classify water for irrigation. The KI > 1 shows the excess of sodium and KI < 2 shows deficiency of sodium (Kelly 1940). KI can be calculated by using Eq. (5). In our study KI varies from 0.34 to 10.24. The KI < 1 is fit for irrigation and KI > 1 and higher values are unfit. In our study four samples are fit for irrigation and sixteen are unfit.

\[ \text{KI} = \frac{\text{Na}^+}{\text{Ca}^{2+} + \text{Mg}^{2+}} \]  

(5)

**4.8 Hydro-chemical processes**

**Chloro-alkaline indices** - To understand the change in chemical composition of the groundwater through its path of flow, Schoeller\(^{11}\) proposed chloro - alkaline indices (CAIs). The CAIs help to explain the base-exchange between the groundwater and its prevailing environment. The positive values of CAIs means there is a direct ion exchange between Ca and Mg from the rocks and Na and K from the water. The negative value of CAIs means the exchange of Ca and Mg from water and Na and K from the rocks. The CAI 1 and CAI 2 were calculated using equations 6 and 7 respectively.

\[ \text{CAI 1} = \frac{\text{Cl}^- - (\text{Na}^+ + \text{K}^+)}{\text{Cl}^-} \]  

(6)

\[ \text{CAI 2} = \frac{\text{Cl}^- - (\text{Na}^+ + \text{K}^+)}{(\text{CO}_3^{2-} + \text{HCO}_3^- + \text{SO}_4^{2-} + \text{NO}_3^-)} \]  

(7)

All the concentrations were taken in meq/l. In our study the CAI 1 varies from -12.97 to 0.12. The total two samples have positive CAI 1 and rest eighteen have negative value. The CAI 2 varies from -1.21 to 0.13. Only one sample have positive value of CAI 2 whereas nineteen have negative values. The study clearly showed the exchange of Ca\(^{2+}\) and Mg\(^{2+}\) from water and Na\(^-\) and K\(^+\) from the rocks as described in figure 2.
The use of groundwater for domestic and irrigation purposes can be determined by the groundwater chemistry, which is mainly controlled by the groundwater interactions with aquifer minerals. Gibbs (1970) [12] has proposed a scatter diagram to explain the three important mechanisms that control the major ions chemistry of groundwater and the water-rock interactions, precipitations and evaporation.

Gibbs ratio 1 and Gibbs ratio 2 were calculated using equations 8 and 9 respectively.

\[
\text{Gibbs ratio 1 (G.R. 1)} = \frac{(\text{Na}^+ + \text{K}^+)}{(\text{Na}^+ + \text{K}^+ + \text{Ca}^{2+})}
\]  
(8)

\[
\text{Gibbs ratio 2 (G.R. 2)} = \frac{\text{Cl}^-}{\text{Cl}^- + \text{HCO}_3^-}
\]  
(9)

The TDS were plotted against G.R. 1 and G.R. 2 for cations and anions respectively as shown in fig 3 and 4. The total 80 % samples were found to be precipitation dominance and rest 20 % were in rock dominance categories.
4.10 Groundwater classification

Based upon the regional flow patterns, resident time and lithology, the hydro-chemical properties of the groundwater vary from place to place [13]. To understand the groundwater body, the groundwater classification can be used [14]. Depending upon the chemical composition, water can be classified into three main types: sulphate, chloride and bicarbonate types. For this purpose, the Piper diagram can be used. The water samples can be classified according to the symbolic area occupied in the diagram.

1. Sulphate (SO\textsubscript{4}\textsuperscript{2-}) type, 2. Ca\textsuperscript{2+} - Mg\textsuperscript{2+} - SO\textsubscript{4}\textsuperscript{2-} and Cl\textsuperscript{-} type, 3. Ca\textsuperscript{2+} - Mg\textsuperscript{2+} - HCO\textsubscript{3}\textsuperscript{-} type, 4. Na\textsuperscript{+} and HCO\textsubscript{3}\textsuperscript{-} type, 5. Na\textsuperscript{+}–K\textsuperscript{+} type, 6. Mg\textsuperscript{2+} type, 7. No dominance, 8. Ca\textsuperscript{2+} type, 9. No dominance, 10. SO\textsubscript{4}\textsuperscript{2-} type, 11. Cl\textsuperscript{-} type, 12. HCO\textsubscript{3}\textsuperscript{-} type.

In the present study, approximately 90% of the samples were found to be alkali dominant and of Na\textsuperscript{+}–K\textsuperscript{+} type as in figure 5.
Table 3. Showing the percentage of samples in different categories

| Parameters | Reference         | Value | Classification | Samples within the prescribed range |
|------------|-------------------|-------|----------------|--------------------------------------|
| % Na       | Wilcox (1955)     | < 20  | Excellent      | 0                                    |
|            |                   | 20-40 | Good           | 3                                    |
|            |                   | 40-60 | Permissible    | 7                                    |
|            |                   | >60   | Unsuitable     | 10                                   |
| Kelly’s Ratio | Kelly (1940)   | < 1   | Suitable       | 4                                    |
|            |                   | >1    | Unsuitable     | 16                                   |
| SAR        | Richards (1968)   | < 10  | Excellent      | 13                                   |
|            |                   | 10-18 | Good           | 7                                    |
|            |                   | 18-26 | Doubtful       | 0                                    |
|            |                   | >26   | Unsuitable     | 0                                    |
| RSC        | Eaton (1950)      | < 1.25 meq/l | Suitable      | 16                                   |

5. Conclusions
Based on our observation, we observed that most of the samples had the amount of one or more ingredient above the prescribed limit. Since most of the samples had high value of SAR, RSC, % Na, PI and KI so water from these stations can be taken as unsuitable for irrigation for long time. Most of the water samples were of sodium–bicarbonate–chloride type and having high to very high salinity hazard. Therefore water from these stations should either be treated before its use or be used occasionally.

References
[1] Jalali, M. 2009 Geochemistry characterization of groundwater in an agricultural area of Razan, Hamadan, Iran. Environ Geol 56, 1479–1488
[2] Mondal, N. C., Singh V.P., Singh V.S., Saxena V.K. 2010 Determining the interaction between groundwater and saline water through groundwater major ions chemistry. Journal of Hydrology 388, 1-11
[3] Nasly M.A., Saher F.N., Kadir A., Yahaya E.M. 2013 Adaptation and application of computer added Pahang river management in Malaysia. Research Journal of Recent Sciences, 2(12), 86-91.
[4] Milovanovic M. 2007 Water quality assessment and determination of pollution sources along the Axios/Vardar River, Southeastern Europe. Desalination 213(1-3):159-173
[5] APHA 1998 Standard methods for the examination of water and wastewater 20th edition
[6] Wilcox L V1955 Classification and use of irrigation waters Circular 969 USDA Washington
[7] Eaton F M1950 Significance of carbonate in irrigation water Soil Sci. 62(2) 123–133
[8] Richards L A 1954 Diagnosis and improvement of saline and alkaline soil Washington
[9] Doneen L D1964 Notes on water quality in agriculture University of California
[10] Kelley W P1940 Permissible composition and concentration of irrigated waters ASCF 66 607
[11] Schoeller H 1977 Geochemistry of groundwater In: Groundwater studies- an international guide for research and practice UNESCO Paris 15, 1-18
[12] Gibbs R J1970 Mechanism controlling world’s river catchment Water Chem. Sci. 170 1088-1090
[13] Domenico P A1972 *Concepts and models in groundwater hydrology* Mcgraw- Hill New York

[14] Mahlknecht, J., Steinich B. and Navarro De León I. 2004 Groundwater chemistry and mass transfers in the Independence aquifer, central Mexico, by using multivariate statistics and mass-balance models. *Environmental Geology* 45(6) 781-795

[15] Chebotarev I 1955 *Geochim. Cosmochim. Acta* 8 137-170