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Research Article

Groundwater Quality Assessment in a Coastal Sand Aquifer: Implications for Drinking Water and Agricultural Use

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Abstract: In many countries, specifically those located in semi-arid zones, groundwater is the major source of drinking water, domestic and agriculture use. The present hydro geochemical study was carried out in the coastal sand aquifer of Thiaroye Dakar, Senegal. A total of 36 groundwater samples were collected from different dug wells, piezometers and boreholes in the study area to decipher hydro geochemistry and groundwater quality for determining its suitability for drinking and agricultural purposes. The analytical results of hydro geochemical parameters such as Na^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-} of groundwater samples in the study area reveals that over 66% were found to be well within the safe range with respect to the world Health Organization for drinking water indicating that most of groundwater sampling sites are fit for drinking with respect of these parameters. The K^+ concentrations show that 56% of groundwater is suitable for drinking water. On the other hand, NO_3^- concentration show high levels exceeding the maximum permissible limits for drinking standard at almost 61% of groundwater samples indicating groundwater which is unfit for drinking water thus suggesting the need for treatment or precautionary measures to use for drinking water purpose. The TDS and EC values of groundwater indicate respectively that 69.5 and 61% are suitable for drinking water. According to the irrigation quality parameters such %N, SAR, RSC, KR and Ca^{2+}/Mg^{2+} ratio it was demonstrated that over 80% of groundwater samples in the study area are suitable for irrigation purpose. Furthermore, the interpretation of graphical plots such as Wilcox and US Salinity Laboratory for the classification of groundwater shows that most of the groundwater samples in the study area are suitable for irrigation purpose except for few groundwater samples.

Keywords: Dakar, drinking water, groundwater quality, irrigation purpose, Senegal

INTRODUCTION

Because of the surface water scarcity and quality deterioration, groundwater resource assessments and sustainability considerations are of utmost importance in arid and semiarid regions where water is commonly of critical economy and social significance. In these regions, groundwater is generally the primary resource for drinking water, irrigation and industrial use. However, in several aquifers, groundwater quality poses enormous problems for population drinking water supply but also for agricultural and industrial use. Groundwater quality deterioration is mainly marked in coastal aquifers where it is encountered a great water demands related to the high population density. In fact, coastal areas of arid and semi-arid regions of developing countries constitute vulnerable ecosystems subject to severe anthropogenic pressure and natural hazards such as sea-level rise, land subsidence, coastal erosion and flooding, groundwater pollution and above all salinization of groundwater. The degradation of groundwater quality leads to a limitation of drinking water supply and to a decrease of groundwater use for irrigation purpose. This situation is one of the major concern in big cities where the fast growth of population leads to an over extraction of urban aquifers. The unconfined quaternary sand aquifer of Thiaroye is of great important resource because it is used for drinking water supply of the population of Dakar region and for the multiple domestic uses. It is also exploited in agricultural areas, mainly in the Niayes area, for irrigation purpose. However, owing to the petrographic nature of the aquifer and its low water level, the aquifer is highly vulnerable to surface-derived contamination which could restrict it for drinking water supply and for agricultural use. Several previous studies (Fall, 1991; Tandia *et al*., 1997; Cissé Faye *et al*., 2004; Diédhiou, 2011; Diédhiou *et al*., 2012) showed that groundwater quality deterioration is mainly due to high nitrate pollution. So, we are dealing with a shallow aquifer where the pollution of groundwater acts as a limiting element to drinking water supply as well as to agricultural use. Thus, understanding and determining groundwater quality in this shallow aquifer is an

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important step for preventing further deterioration of resource. The present study is aimed to investigate groundwater quality and to evaluate the suitability of groundwater for drinking and irrigation purposes.

Study area description: The study area is located in the region of Dakar which is undergoing rapid industrialization and urbanization which led to immense pressure on groundwater resource and it results the deterioration of groundwater quality. It extends from Dakar Peninsula in the West to the Thies plateau in the East and covers approximately 300 km^2 (Fig. 1). The study area is part of the Quaternary sand system which extends along the Senegal northern coastal zone from Dakar. The system is underlain uncomfortably by Eocen-aged marl to clay formations which outcrop in the south. The Quaternary deposits which constitute the aquifer reservoir are composed mainly of unconsolidated clayey sands, coarse sands, eolien sands which form the Ogolian dunes in the coastal band. Thickness of the sediments is strongly related to the morphology of the marly basement and varies from 5 m in the southeastern edge to 75 m towards the Nord west. Hydrodynamic parameters are variable in the study area. Transmissivity varies between 1×10^{-5} and 6.7×10^{-3} m^2/sec (OMS, 1972) and hydraulic conductivity between 1×10^{-5} and 7.8×10^{-4} m/sec. The area is characterized by a semi-arid climate and by marked seasonal contrasting climate variables. The rainy season occur between July and October with mean annual precipitation ranges from 450 to 500 mm. The annual average temperature varies between 21 and 29°C. The aquifer is unconfined throughout the study area and recharge is by infiltration of precipitation and also contributions from other sources such as waste and irrigation waters that contaminate the groundwater.

MATERIALS AND METHODS

Ground waters were collected from a network of 36 points selected to represent the study area. The groundwater and better managing the groundwater

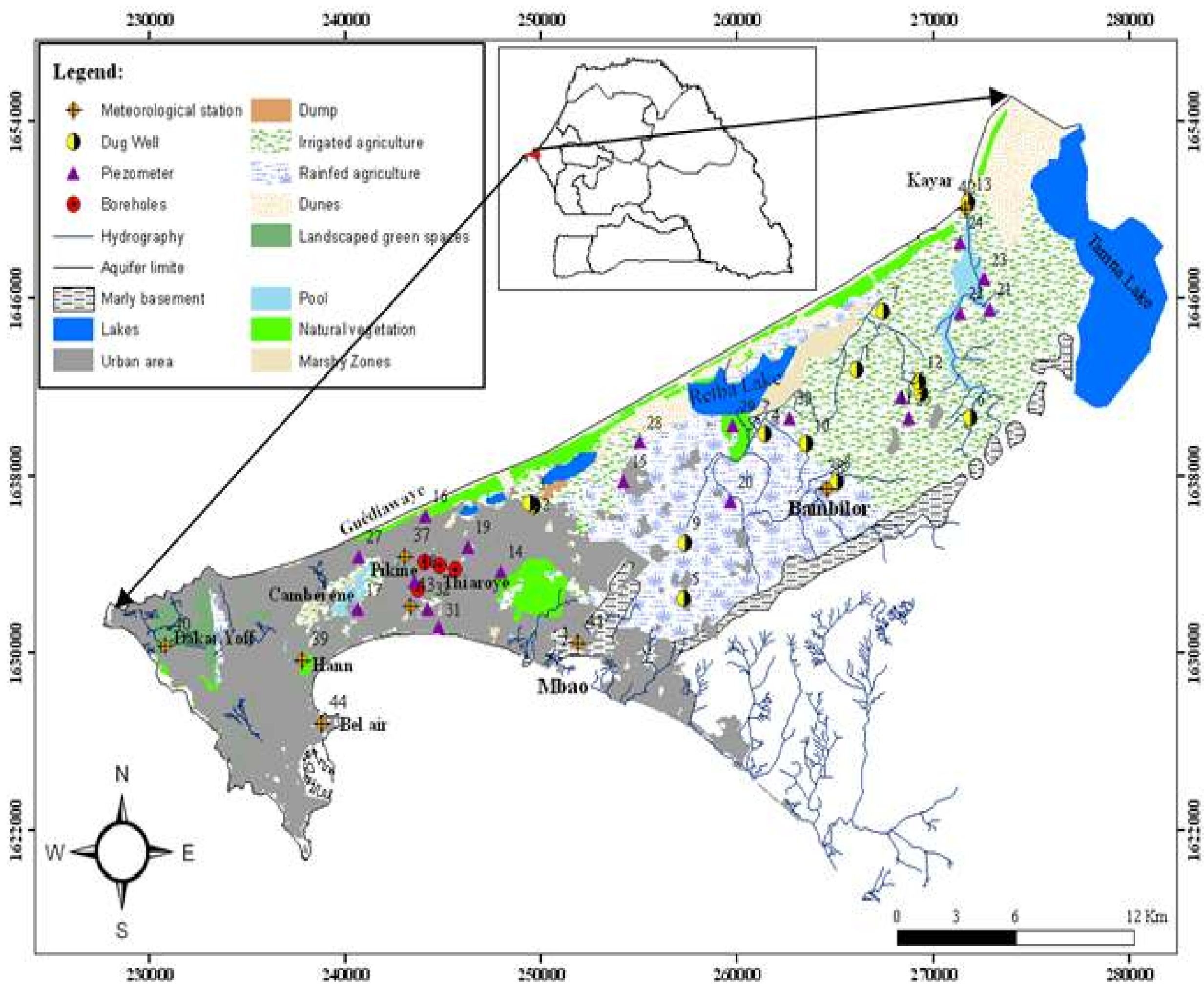

Fig. 1: Location map of the study area showing the sampling sites and land use

network comprises both municipal boreholes, piezometers and dug wells (Fig. 1) and sampling campaigns were carried out during February-March 2005 and March 2007. Samples from dug wells and piezometers were collected after pumping the wells for at least 10 min. This latter procedure was not necessary prior to sampling in municipal boreholes due to continuous pumping for water supply. *In situ* measurements such as pH, Temperature (T°), Electrical Conductivity (EC) and alkalinity were made at the well head. Samples for analysis of major inorganic constituents were filtered through 0.45 µm membrane filter and filled in an acid-washed polyethylene bottle, one aliquot being acidified to pH less than 2 by addition of high-purity HNO_3 for analysis of cations. Other un-acidified water samples were collected, cooled and conserved for stable isotopes and tritium analyses. Samples for nitrate isotopes were collected in 400 mL plastic bottles that were refrigerated on return to the laboratory. Major ions for the 36 samples were measured by ion chromatography Dionex DX 500 at Ruhr University of Bochum (Germany).

RESULTS AND DISCUSSION

Suitability of groundwater for drinking purpose: The results of the hydrochemical analysis of the groundwater samples taken from the study area are shown in Table 1. In order to ascertain the suitability of groundwater for drinking water purposes, hydrochemical parameters of the study area are compared with the guidelines recommended by World Health Organization (WHO, 2004) (Table 2).

Electrical Conductivity (EC): Electrical Conductivity is the measure of capacity of a substance to conduct the electric current. It indicates the amount of material dissolved in water. The most desirable limit of EC in drinking water is prescribed as 1500 µS/cm (WHO, 2004). The Electrical conductivity of groundwater samples in the study area showed values ranging from 107 to 4770 µS/cm. The observed results show that around 39% of groundwater sample exceed the maximum permissible limit of WHO (2004). Higher electrical conductivity in the study area indicates the

Table 1: Chemical composition of groundwater of the study area (in mg/L except for pH, T° and EC)

Wells	Localities	pH	T°C	C.E µS/cm	TDS	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	NO_3^-	SO_4^{2-}	HCO_3^-
Pts 02	Déni B. Ndao	5.82	26.1	2530	1572	271	82.3	36.8	107.0	326	557	134	24.40
P2-6	Boune	6.46	26.0	1487	994	138	13.0	47.1	81.6	253	362	36.7	48.80
P2-7	Tivaouane Peulh	7.87	27.8	484	537	56.8	17.9	18.4	57.9	71.1	153	44.8	100.65
Pts 58	Mbeubeuss	5.16	25.9	1766	1142	175	13.2	35.1	107.0	382	278	132	6.10
Pts 58 b	Mbeubeuss	5.52	26.8	554	331	57.2	9.6	11.2	23.7	106	89.10	17.6	3.05
Pts 128	Wayambame	6.93	27.6	720	594	39.8	8.9	9.2	92.1	66.2	9.80	148	198.25
Pts 202	Kounoune	6.62	24.3	4770	3390	469	68.3	113.0	348.0	852	855	439	179.95
Pts 215	Golam	6.52	25.6	739	452	31.2	5.4	12.1	39.0	77.2	128	86.0	57.95
Pts 232	Kaniack	6.20	27.0	301	204	40.4	4.0	3.6	8.4	45.9	54.90	18.3	15.25
Pts 235	Bambilor	7.45	24.5	3180	2553	335	55.4	68.1	294.0	334	471	790	195.20
P2-5	Corniche Guédiawaye	7.42	30.6	1465	717	70.6	5.0	17.4	55.9	169	111	56.1	222.65
F17	Marché Thiaroye	4.88	29.6	1684	972	157	22.8	38.1	70.4	267	298	85.1	15.25
F19	Thiaroye	4.83	28.6	2100	801	113	16.8	30.3	72.2	188	280	71	9.15
F21	Thiaroye	4.65	28.0	2160	597	80.4	13.3	21.0	54.7	137	221	40.4	9.15
F22	Thiaroye	5.12	29.1	1950	675	94.2	15.7	22.6	64.5	155	200	90.7	9.15
P1	Technopole	6.88	22.9	1772	1016	70.9	12.8	16.6	40.1	286	254	156	161.65
P4	Pikine	6.03	24.7	2850	1845	231	53.3	46.1	139.0	478	308	329	228.75
P21	Yeumbeul	3.89	27.4	2890	1879	222	55.0	36.8	123.0	430	743	139	91.50
PS1	Sangalkam	6.98	25.1	242	178	17.9	2.4	2.7	25.7	49.8	0.30	3.2	51.85
PS4	Santhe Mame Gor	5.56	24.2	508	1724	29.8	3.0	9.4	45.4	55.8	1390	169	0
PS5	Mbawane	8.96	24.2	418	243	37.7	3.8	7.2	26.9	65	55.50	8.1	24.40
PS6	Santhe Mame Gor	6.30	25.4	236	143	11.1	1.3	2.5	10.4	39.5	8.20	21.6	30.50
PS7	Kayar	7.55	31.0	606	438	20.8	2.8	10.5	39.5	48.4	0.60	25.5	274.50
PS 10	Gorom 1	6.02	24.6	363	233	30.8	3.5	8.4	17.4	67.4	41.10	29.9	15.25
PS 11	Gorom 2	5.13	25.4	861	530	77.1	3.6	17.6	38.3	117	2.80	240	0
P2-3	Croisement Béthio	8.21	29.0	689	354	25.5	1.9	5.4	9.9	129	80.70	22.3	70.15
P2-8	Tivaouane Peulh	7.90	26.1	639	413	47.5	6.0	10.3	38.4	138	0.20	1.1	155.55
P2-9	Niaga Peulh	7.85	23.8	555	401	36.2	33.1	16.4	26.9	28.7	16.60	139	85.40
P2-10	Gouye Guewel	6.99	28.9	1993	1184	145	6.2	26.3	129.0	524	6.30	142	183
P3-1	Thiaroye sur Mer	6.69	26.4	1060	457	102	6.4	6.6	95.9	95.5	0.80	32.5	91.50
P3-2	Camp Militaire Thiaroye	6.31	24.7	1797	1045	133	33.2	29.0	71.3	346	327	70.6	24.40
Pts 109	Santhiane	7.16	25.9	107	483	53.8	3.3	16.1	61.0	135	12.90	40.3	140.30
Pts 120	Wayambame	6.32	25.4	1376	913	69.3	5.9	33.3	146.0	134	7.90	440	54.90
Pts 209	Bayakh	7.04	24.8	665	402	10.9	0.7	5.9	10.2	107	0.05	47.7	176.90
Pts 210	Darou Bayakh Sylla	5.73	26.6	238	112	9.6	1.1	1.6	3.0	39.1	16.30	9.7	12.20
Pts 234	Kayar	7.40	26.7	2000	1583	189	61.8	30.4	188.0	299	53.20	378	366

Table 2: Groundwater samples of the study area exceeding the permissible limits prescribed by WHO (2004) for drinking purposes

Water quality parameters	WHO international standards 2004		No. of samples exceeding permissible limit	Percentage of samples exceeding permissible limit
	Most desirable limit	Max. allowable limit		
pH	6.5	8.5	17	47.2
E.C (µS/cm)	1500	-	14	39.0
TDS	500	1500	7	19.4
Ca^{2+} (mg/L)	75	200	12	33.3
Mg^{2+} (mg/L)	50	150	2	5.6
Na^{+} (mg/L)	-	200	5	13.9
K^{+} (mg/L)	-	12	16	44.4
Cl^{-} (mg/L)	250	600	12	33.3
SO_4^{2-} (mg/L)	200	400	3	8.3
NO_3^{-} (mg/L)	50	-	22	61.1
HCO_3^{-} (mg/L)	-	-	-	-

Max.: Maximum

Table 3: Classification of groundwater based on TDS (David and De Wiest, 1966)

TDS (mg/L)	Water type	Number of samples	Percentage of samples
<500	Desirable for drinking	15	41.7
500-1000	Permissible for drinking	10	27.8
<3000	Suitable for irrigation	10	27.8
>3000	Unfit for drinking and irrigation	1	2.7

enrichment of salts in the groundwater which can due to the anthropogenic pollution.

pH: pH is one of the important factor of groundwater. It is a measure of the balance between the concentration of hydrogen ions and hydroxyl ions in water and is a quantitative expression for acidity or alkalinity of water. The pH of water provides vital information in many types of geochemical equilibrium or solubility calculations (Hem, 1985). The limit of pH value for drinking water is specified as 6.5-8.5 (WHO, 2004). In the study area, around 67% of groundwater samples have pH values varying from 3.9 to 9, which clearly indicate that the groundwater in the study area is slightly acidic in nature. This may be attributed to the dissociation of carbonic acid resulting from the diffusion of atmospheric CO_2, the decomposition and oxidation of organic matter (Diédhiou, 2011).

Total Dissolved Solids (TDS): Based on the WHO specification, TDS up to 500 mg/L is the highest desirable and up to 1500 mg/L the maximum permissible. Waters can be classified (Davis and De Wiest, 1966) on the basis of total dissolved solids, up to 500 mg/L as desirable for drinking; 500 to 1000 mg/L as Permissible for drinking; up to 3000 mg/L as useful for agricultural purposes and above 3000 mg/L as unfit for drinking and irrigation. In the study area, the TDS values of groundwater samples ranges from 112 to 3390 mg/L. (19.4%) of groundwater samples fall above the maximum allowable limit of groundwater for drinking water (Table 2). According to the classification of groundwater based on TDS (Davis and De Wiest, 1966) (Table 3), 41.7% of the total groundwater sample are below 500 mg/L of TDS indicating low content of soluble salt in groundwater which can be used for drinking without any risk, 27.8% are permissible for drinking, the same percent (27.8%) are suitable for irrigation purposes and only 2.7% are unfit for drinking and irrigation purpose.

Major's ions concentration showed wide variation in the study area. Among the cations Na^{+} and Ca^{2+} are the dominant ions found in the groundwater which indicate that they play an important role in groundwater quality. On the other hand, Cl^{-} and NO_3^{-} are the dominant anions in groundwater. Nitrate content ranged from 0.05 to 1390 mg/L. In comparison with the WHO (2004) drinking water guideline of 50 mg/L for NO_3^{-}, almost 61% of groundwater samples showed higher concentration indicating groundwater which is not suitable for drinking purpose. The higher nitrate concentrations are mainly encountered in the urban area and in the rural area due to agricultural activities. The use of waters with a high nitrate level for drinking purpose reduces the oxygen carrying capacity of the blood and can lead to ‘‘blue disease’’ (methemoglobinaemia) in babies (Craun *et al*., 1981; Gupta *et al*., 1999; Knobeloch *et al*., 2000; Zeman *et al*., 2002). This may be due to the reduction of nitrate to nitrite which reacts with hemoglobin in blood to form methemoglobin. High NO_3^{-} concentrations observed in the study area were mainly due to anthropogenic sources like leakage of septic tanks, sewers, improper disposal of domestic waste, animal and human waste and organic matter (Diédhiou *et al*., 2012). Chloride concentrations in groundwater samples are varying from 28.7 to 852 mg/L and 33.3% of water samples exceeds the most desirable limit of 250 mg/L. Sulphate is one of the major anion occurring in natural water. When sulphate concentration exceeds the maximum allowable limit of 400 mg/L, it become unstable and cause laxative effect on human system with the excess magnesium in groundwater (Subramani *et al*., 2005). The sulphate concentrations of groundwater samples in the study area show great variation and range from 1.10 to 790 mg/L. Based on the maximum allowable limit of sulphate in drinking water, only 8.3% of groundwater samples are unfit for drinking purpose. Although sodium concentrations in potable water are typically less than 20 mg/L (WHO, 2011), sodium concentrations in this study varies from 9.60 to 469 mg/L. According to the maximum permissible limit of sodium in drinking water (200 mL/L), 13.9% of groundwater samples are unfit for drinking water. Calcium is one of the most abundant substances of the natural water. The calcium ion concentration in groundwater of the study area ranged from 3 to 348 mg/L. The desirable limit of calcium in drinking water is 75 mg/L. Most of the groundwater samples (66.7%) are below the desirable limit of calcium in drinking except 12 samples (33.3%). The magnesium ion concentrations in fresh water are generally less than that of calcium because of low geochemical abundance of magnesium. The magnesium content of groundwater in the study area ranged from 1.60 to 113 mg/L. The most desirable limit of magnesium concentration in drinking water is specified as 50 mg/L (WHO, 2004). It is observed that 5.6% of groundwater from the study area exceeds the desirable limit.

Potassium is a naturally occurring element in groundwater. It is an essential element for human, animal and plants and derived in food chain mainly from vegetation and soil. The main sources of potassium in groundwater include rain water, weathering of potash silicate minerals, use of potash fertilizers and use of surface water for irrigation. However, its concentration remains quite lower compared with Ca^{2+}, Mg^{2+} and Na^{+}. Its concentration in drinking water seldom reaches 20 mg/L. The maximum permissible limit of potassium in the drinking water is 12 mg/L. The potassium concentration of groundwater samples in the study area vary from 0.70 to 82.3 mg/L. In the study area, it was observed that around 44% of groundwater samples are above the permissible limit of WHO (2004).

Suitability of groundwater for irrigation purpose: In several countries over the world, especially in developing countries with high population growth, agriculture is a key factor to cover the food needs of the population. However, although the influence of agricultural practices is well known, little is known about how these eventually affect groundwater quality. Various hydro-chemical processes can take place and it is the combination of these processes which determines groundwater composition. Groundwater quality deterioration in these countries constitutes a serious handicap for their use in agriculture. Because the suitability of groundwater for irrigation purposes depends upon its mineral constituents, numerous studies (Mukherjee *et al*., 2005; Bangar *et al*., 2008; Khodapanah *et al*., 2009) were carry out in order to assess their suitability. In this study, groundwater of the quaternary aquifer is mainly used for irrigation in the Niayes area. Thus, it is important to evaluate the quality and the suitability of groundwater for irrigation use. In order to determine the suitability of groundwater for irrigation many parameter such as SAR, %N, RSC, Ca/Mg and KR were used. The results of calculated values are presented in Table 4.

Table 4: Groundwater parameter for irrigation purpose

	SAR	%Na	RSC meq/L	KR meq/L	Ca/Mg meq/L
Pts 02	5.75	62.41	-7.97	1.41	1.76
P2-6	3.02	44.36	-7.15	0.76	1.05
P2-7	1.67	39.94	-2.75	0.56	1.91
Pts 58	3.75	49.14	-8.13	0.93	1.85
Pts 58 b	2.42	56.51	-2.05	1.18	1.28
Pts 128	1.06	26.79	-2.10	0.32	6.07
Pts 202	5.59	45.37	-23.71	0.77	1.87
Pts 215	1.12	33.70	-1.99	0.46	1.95
Pts 232	2.93	72.22	-0.47	2.46	1.42
Pts 235	4.58	44.09	-17.07	0.72	2.62
P2-5	2.12	43.11	-0.57	0.73	1.95
F17	3.75	52.72	-6.40	1.03	1.12
F19	2.81	46.72	-5.95	0.81	1.45
F21	2.35	46.26	-4.31	0.78	1.58
F22	2.58	46.98	-4.93	0.81	1.73
P1	2.37	50.33	-0.72	0.92	1.47
P4	4.33	51.54	-6.98	0.94	1.83
P21	4.51	54.69	-7.67	1.05	2.03
PS1	0.89	35.83	-0.65	0.52	5.77
PS4	1.05	31.12	-3.04	0.43	2.93
PS5	1.67	47.31	-1.13	0.85	2.27
PS6	0.80	41.59	-0.22	0.67	2.52
PS7	0.76	25.62	1.66	0.32	2.28
PS 10	1.52	47.82	-1.31	0.86	1.26
PS 11	2.58	50.64	-3.36	1.00	1.32
P2-3	1.61	55.24	0.21	1.18	1.11
P2-8	1.75	44.54	-0.21	0.75	2.26
P2-9	1.36	47.36	-1.29	0.59	0.99
P2-10	3.05	42.91	-5.60	0.73	2.98
P3-1	2.72	46.33	-3.83	0.83	8.81
P3-2	3.36	52.74	-5.54	0.97	1.49
Pts 109	1.58	35.69	-2.07	0.54	2.30
Pts 120	1.35	24.00	-9.13	0.30	2.66
Pts 209	0.67	33.10	1.90	0.48	1.05
Pts 210	1.13	61.30	-0.08	1.48	1.14
Pts 234	3.37	45.20	-5.88	0.69	3.75

Pts: Well; P and Ps: Piezometer; F: Borehole

Sodium percent (%N): Evaluation of sodium concentration is important for irrigation because Na^{+} reacts with soil to reduce its permeability and its structure. In fact, when the concentration of sodium ion is high in irrigation water, Na^{+} tends to be absorbed by clay particles, displacing magnesium and calcium ions. This exchange process of sodium in water for Ca^{2+} and Mg^{2+} in soils reduces the permeability and eventually results in soil with poor internal drainage. Then in agricultural area the measure of sodium adsorption ratio gives a clear idea about the sustainability of water for use in agricultural irrigation. Furthermore, the use of high percentage sodium water for irrigation purpose may stunt the plant growth and reduces soil permeability (Joshi *et al*., 2009). Sodium content is

Table 5: Suitability of groundwater for irrigation based on sodium percent (%N)

Water class	Range	Number of samples	Percentage of samples
Excellent	<20	Nil	Nil
Good	20-40	9	25
Permissible	40-60	24	66.7
Doubtful	60-80	3	8.3
Unsuitable	>80	Nil	Nil

usually expressed in terms of percentage sodium and is calculated by the following equation:

$$\%N = \frac{[Na^{+} + K^{+}]}{[Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}]} \text{ X } 100$$

where, all ionic concentrations are expressed in meq/L.

In the study area, the %N values ranged from 24 to 72.22% with an average value of 45.42. The classification of groundwater samples based on %N values is shown in Table 5. According to this classification, 25% of groundwater falls in the range of good category of water for irrigation. The permissible category is represented by 66.7% of the groundwater samples whereas 8.3% of the groundwater samples fall in doubtful category.

The plot of analytical data on the Wilcox (1955) (Fig. 2) related to EC and sodium percent indicates that 47.2% of groundwater samples fall in the field of excellent to good category, 11.1% of groundwater samples fall in the field of good to permissible category, 19.4% fall in the field of permissible to doubtful, 16.7% fall in the field of doubtful to unsuitable category and 5.6% of groundwater samples fall in the field of unsuitable for irrigation.

Sodium Adsorption Ratio (SAR): Sodium Adsorption Ratio (SAR) is also an important parameter to determine the suitability of irrigation water because it is responsible for the sodium hazard for crops. It is calculated by the following equation given by Richards (1954) as:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}$$

where, all ionic concentrations are expressed in meq/L.

SAR values are used to calculate the degree to which irrigation water tends to enter into cation exchange section in the soil. In fact, if water used for irrigation is high in Na^{+} and low in Ca^{2+},

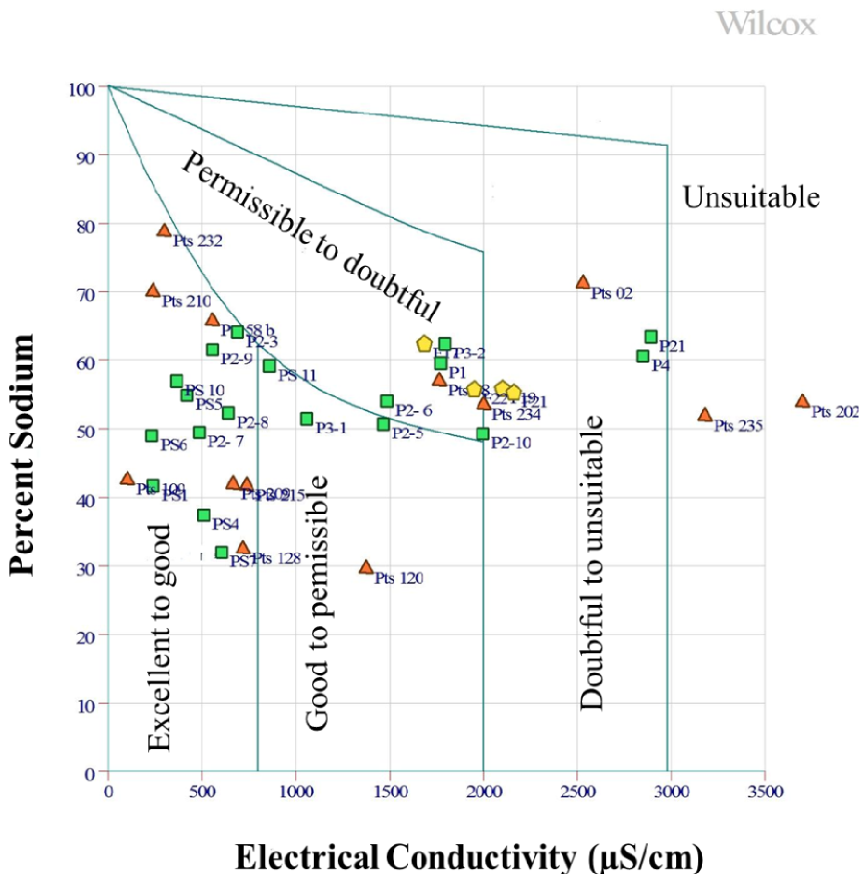

Fig. 2: Evaluation of groundwater for irrigation in Wilcox (1955) diagram

Table 6: Irrigation groundwater classification based on Sodium Absorption Ratio (SAR)

Water class	Range	Number of samples	Percentage of samples
Excellent	<10	36	100
Good	10-18	Nil	Nil
Doubtful	18-26	Nil	Nil
Unsuitable	>26	Nil	Nil

the ion exchange complex may become saturated with Na^+, which destroys soil structure because of dispersion of clay particles. As a result, the soil tends to become deflocculated and relatively impermeable. Such soils become very difficult to cultivate. High sodium adsorption ratio can influence the rate of water infiltration. Then, low SAR is always desirable (Kaur and Singh, 2011). Sodium also contributes directly to the total salinity of the water and may be toxic to sensitive crops such as fruit trees. The Sodium Adsorption Ratio (SAR) content in the study area varied between 0.66 and 5.75 with an average value of 2.44. The classification of groundwater samples based on SAR values are shown in Table 6.

Based on Sodium Adsorption Ratio (SAR), all groundwater samples are of excellent quality for irrigation in the study area since none of the samples exceeded the SAR value of 10. The analytical data plotted on the US salinity diagram (Richards, 1954) (Fig. 3) shows that 11% of groundwater samples fall in the field of C1S1, indicating low salinity hazard-low sodium water. This type of water can be used for irrigation on most crops in most soils with little likelihood that soil salinity will develop and with little danger of developing harmful levels of sodium; 13.9% of groundwater samples fall in the field of C2S1, indicating medium salinity hazard-low sodium water. This type of water is suitable for irrigation in almost all the soils with less danger of the development of Na^+ and salinity problems; 16.7% fall in the field of C2S2 indicating medium salinity hazard/medium sodium water, which can be used in coarse-grained soils or in organic soil with good permeability or if soil washed with a moderate amount of water (Burger and Čelková, 2003); 5.6% of groundwater samples fall in the field C2S3 indicating medium salinity hazard-high sodium water. Such water can be used in soil having good drainage and in soil where sufficient organic substance was added (Burger and Čelková, 2003). One sample (2.8%) falls in the field C3S2 indicating high salinity hazard-medium sodium water, which can used to

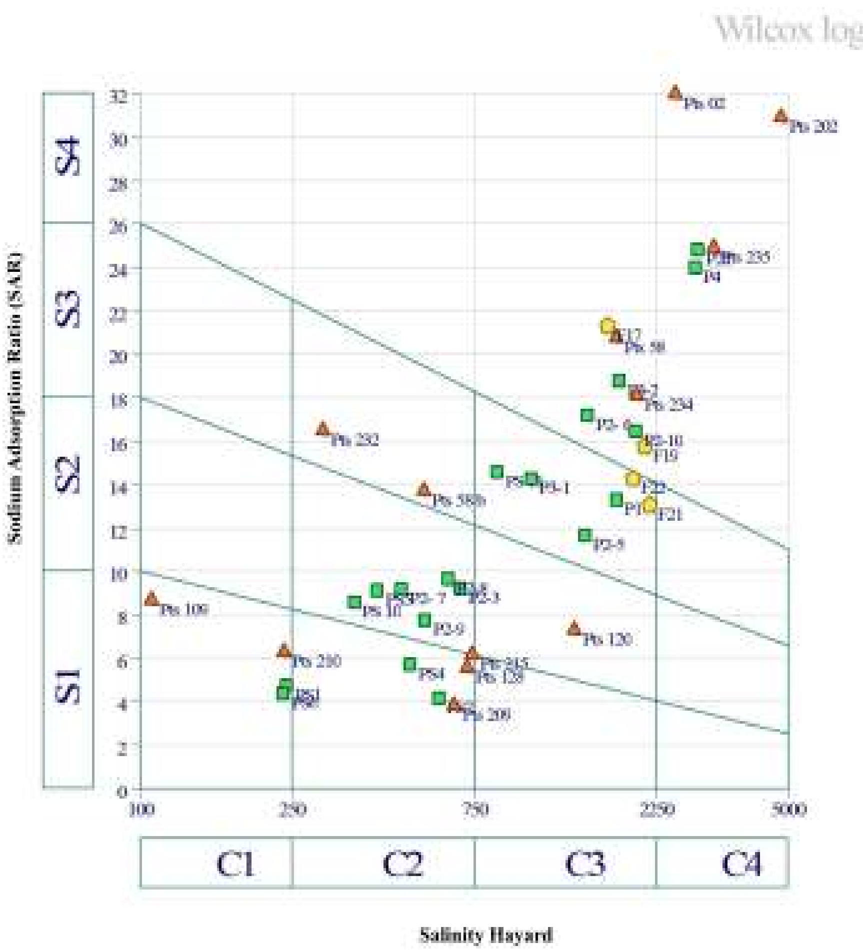

Fig. 3: US salinity laboratory classification of groundwater for irrigation

Table 7: Classification of irrigation water based on Residual Sodium Carbonate (RSC)

Water class	Range	Number of samples	Percentage of samples
Good	<1.25	34	94.4
Doubtful	1.25-2.50	2	5.6
Unsuitable	>2.50	Nil	Nil

irrigate salt tolerant and semi tolerant crops under favorable drainage condition. (16.7 and 19.4%) of groundwater samples fall in the field of C3S3 and C3S4 respectively indicating high salinity hazard-high to very high sodium water. These types of water are not suitable for irrigation but can be used under certain conditions and to irrigate crops with good salt tolerance. (13.9%) of the collected groundwater falls in the field C4S4 indicating very high salinity hazard-very high sodium water, which were not at all suitable for irrigation under ordinary conditions but it may be used occasionally under very special circumstances.

Residual Sodium Carbonate (RSC): The concentration of bicarbonate and carbonate can also influences the suitability of water for irrigation purpose. In fact, when water has high concentration of bicarbonate ions, there is a tendency for Ca^{2+} and Mg^{2+} to precipitate as carbonates. As a consequence, the relative proportion of sodium increases and gets fixed in the soil there by decreasing the soil permeability. Eaton (1950) proposed the concept of residual sodium carbonate to assess the sustainability of high carbonate waters for irrigation purpose. RSC is calculated using the following equation:

$$RSC = [HCO_3^- + CO_3^-] - [Ca^{2+} + Mg^{2+}]$$

where, all ionic concentrations are expressed in meq/L.

If the RSC of water exceeds 2.5 meq/L, water is unsuitable for irrigation purpose. Groundwater having RSC between 1.25 to 2.5 meq/L is marginally suitable for irrigation purpose whereas values of RSC lower than 1.25 or equal to 1.25 indicates that water is suitable for irrigation purpose. The computed RSC values of groundwater samples of the study area range from -23.72 to 1.90 with an average value of -4.18. Based on the computed values of RSC, the classification of groundwater for irrigation purpose indicates that 94.4% of groundwater in the study area is good for irrigation purpose whereas 5.6% of groundwater is doubtful (Table 7).

Ca^{2+}/Mg^{2+} ratio: Calcium (Ca^{2+}) and Magnesium (Mg^{2+}) do not behave equally in the soil system and high concentrations of Mg^{2+} are not preferred in water because of Mg^{2+} adsorption onto the soil cation exchange sites, causing soil aggregates to disperse and deteriorate soil structure particularly when waters are Na^+ dominated and highly saline (Jalali, 2011). If the Ca^{2+}/Mg^{2+} ratio of groundwater is near or less than one, the uptake and translocation of Ca^{2+} from soil water to the aboveground parts of the growing crop is diminished due to antagonistic effects of high Mg^{2+}. Furthermore the potential effect of Na^+ may be increased and adversely affect soil quality. The computed values of Ca^{2+}/Mg^{2+} ratio in the study area indicates that most of the groundwater samples have Ca^{2+}/Mg^{2+} ratio higher than one (only one sample have Ca^{2+}/Mg^{2+} ratio equal to one) and then groundwater can be classified as suitable for irrigation purpose (Table 4).

Kelley Ratio (KR): Sodium content measured against calcium and magnesium is known as Kelley's ratio, based on which irrigation water can be rated (Kelley, 1940). The kellez's ratio is calculated using the following equation:

$$KR = \frac{Na^+}{Ca^{2+} + Mg^{2+}}$$

where, all ionic concentrations are expressed in meq/L.

A Kelley's Ratio (KR) of more than one indicates an excess level of sodium in waters. Hence, waters with a Kelley's Ratio less than one are suitable for irrigation, while those with a ratio more than one are not suitable for irrigation. Based on Kelley's Ratio (KR) values, 80.6% of groundwater in the study area are less than one (1) indicating good quality of water for irrigation purpose while remaining 19.4% is more than 1 and indicate that water are unsuitable for irrigation purpose (Table 3).

CONCLUSION

Groundwater is an important source of drinking water and agricultural activities for many people around the world particularly in arid and semi-arid zones. The groundwaters in the study area are slightly acidic in nature. Based on the Total Dissolved Solids (TDS), 41.7 and 27.8% of the groundwater samples are respectively within the desirable and permissible limits of drinking water. On the other hand, according to the electrical conductivity 61% of groundwater samples are fit for drinking water purpose.

The comparison of the major ion data with the WHO standards indicates most of groundwater samples are fit for drinking water purpose. However, in few sampling sites the groundwater samples exceed the permissible limits of certain hydrochemical such as sodium, magnesium, calcium, potassium, chloride and sulphate.

In the study area, the most conspicuous change in chemistry of groundwater is the high enrichment of nitrate beyond permissible limits (>50 mg/L) of drinking water standards.

The higher concentrations of nitrate in urban areas, other than agricultural activity, may be due to improper sanitary conditions, leachate from animal wastes, sewage and solid waste dump. Based on the nitrate content of the study area, groundwater needs some degree of treatment before drinking and it needs to be protected from contamination so as to prevent adverse health effects on human beings.

Based on the irrigation quality parameters like %N, SAR, RSC, KR and Ca^{2+}/Mg^{2+} ratio it is found, respectively, that 91.7, 100, 94.4, 80.6 and 97.2%, respectively of the groundwater samples of the study area are suitable for irrigation purpose. Then, it was observed, based on %N, RSC, KR and Ca^{2+}/Mg^{2+} ratio, that the quality of groundwater is not suitable for irrigation purpose in some sampling sites.

Groundwater quality for irrigation purpose of the study area was also classified based on USSL groundwater classification method. The plot of data on the US Salinity Laboratory diagram reveals that the majority of groundwater samples in the study area are found in the following six water class: C1S1 (11%), C2S1 (13.9%), C2S2 (16.7%), C3S3 (16.7%), C3S4 (19.4%) and C4S4 (13.9%). Only one groundwater sample is found in C3S2 water class and two in the water class C2S3 (5.6%).

According to the Wilcox irrigation water classification, 47.2% of groundwater samples fall in the field of excellent to good category, 11.1% of groundwater samples fall in the field of good to permissible category, 19.4% fall in the field of permissible to doubtful, 16.7% fall in the field of doubtful to unsuitable category and 5.6% of groundwater samples fall in the field of unsuitable for irrigation. Irrigation with waters of doubtful to unsuitable category, generally gives low crop yield due to presence of excess sodium salts which reduces the intake of soil nutrients.

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