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Assessment of groundwater quality for irrigational use: A case study from the coastal tracts of Sindhudurg district, Maharashtra

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In the present study a total of 36 water samples were acquired from open dug wells, bore wells and hand pumps during the pre-monsoon period in and around Kankavli-Malvan-Vijaydurg, northern part of Sindhudurg district of coastal Maharashtra, to examine the suitability of water quality for agricultural purpose. Irrigation quality parameters namely sodium absorption ratio (SAR), residual sodium carbonate (RSC), soluble sodium percentage (SSP), magnesium adsorption ratio (MAR), Kelly's ratio (KR), permeability index (PI), percent sodium (%Na) and Chloroalkaline indices (CA) have been calculated along with the corresponding electrical conductivity (EC), total dissolved solids (TDS) and total hardness (TH). The US salinity diagram reveals low to high salinity and low sodium water and thus suitable for irrigation in almost all types of soil, while only one water sample (EC>9000 µS/cm) is unsuitable for irrigation. According to Wilcox classification, all water samples, excepting three, fall under excellent to good class and are acceptable for irrigation purpose. The three samples (well numbers 7, 15 and 32), which are in propinquity to Arabian Sea, divulge high EC values (> 750 µS/cm) and is categorized under the permissible to unsuitable range. It is further observed that based on SSP, MAR, KR and RSC and PI, more than 80% of the water samples are suitable for irrigation. The Chloroalkaline indices of the groundwater in this region signify that normal ion exchange is slightly more than the reverse ion exchange process.

[**Key words:** Groundwater, irrigation parameters, Sindhudhurg district, Maharashtra]

Introduction

The coastal zones are under constant development with mounting and conflicting demands on the natural resources, and often they are subject to irreversible degradation. The critical factors which mainly affect the groundwater in these areas are coastal erosion, flooding due to tidal waves or rising sea level, contamination of the aquifers through intrusion of seawater etc[1]. Also there is a strong incidence of human activities mainly linked to agricultural practices, dumping of sewage and industrial wastes[2].

Excessive use of fertilizers for irrigation usually results in accumulation of nutrients in groundwater thereby contaminating it[3]. Hence suitable monitoring and protection actions should be implemented for the preservation of this precious resource.

Numerous researchers have appraised the quality of groundwater both for domestic and agricultural use with the aid of several hydrochemical parameters to evaluate the seawater invasion process, which in turn can manage the water quality in coastal areas[4-6]. It has further been reported that the major sources of most major and minor elements has been attributed due to various processes like saline water mixing, anthropogenic contamination, and water–rock interaction, which is reflected by very wide ranges of hydrochemical parameters, such as TDS, Cl^-, SO_4^{2-}, Mg^{2+}, and Na^+ exceeding the limit of drinking water standard[7]. These can in turn have a major effect on human being due to either deficiency or excessive intake[8].

Groundwater chemistry plays a very important role for the study of its quality in the costal aquifers[9] and thus assessing seawater ingress through an aquifer in coastal belts is a periodic analysis of groundwater chemistry[10]. The 720 km long coastal belt of Maharashtra, India, is witnessing rapid strides in developmental activities and therefore the available groundwater resources are under constant threat. Groundwater is the main source for domestic, industrial and agricultural uses, and the coastal belt being a tourist place, the consumption of water is immense, and thus vulnerable to human impacts apart from natural phenomena. It is therefore pertinent to monitor the water quality in order to ascertain its fitness for both drinking and irrigation purposes.

Several researchers have studied the water quality in the coastal districts of Maharashtra[11-14]. The water quality essentially for drinking and irrigational purposes from Guhagar area, located along the Konkan coast of Ratnagiri district, Maharashtra[15] state indicated a striking difference in physicochemical characteristics of groundwater obtained from different aquifers and different seasons. The summer groundwater samples from coastal aquifers are unsuitable for drinking water purpose, while a slight improvement in quality was observed from the samples collected during winter season. However, the inland aquifers revealed suitability of drinking water both during summer and winter seasons. These authors further reported that though the water samples are unsuitable for agriculture, these can be used for salt tolerant crops growing on permeable formation such as beach rock, which has adequate drainage. The samples from inland aquifers indicated their suitability for any kind of plantation.

The water samples were studied to assess sea water ingress and the quality of water around Ratnagiri coast[16] which revealed that most of the water samples from the coastal part are contaminated from the waste water discharge from sewage and industries.

Various hydrological parameters and water quality of the Ulhas river estuary along the Vasai coastal area of Thane district indicated high concentrations of phosphate, nitrate and sulphate[17]. The high concentration of phosphate may have put forth the danger of eutrophication in water bodies in this area, while high nitrate values may cause hypoxia in tissue, and impair the respiratory metabolism.

The fusion of electrical resistivity and geochemical result[10] in the southern part of Sindhudurg district reflects that all the cations and anions are well below the permissible limit excepting at a few locations. The electrical conductivity and total dissolved solids scales are also found within the acceptable limits. Moreover, the total hardness of water samples at most of the areas is found to be higher in nature. Water quality index of the study area shows that more than 50% of groundwater comes under the range of excellent to good quality. Gibb's diagrams indicate that the groundwater is mainly controlled by the rock water interactions, while parameters analysed for the irrigation suitability of water and are found to be in good to moderate in most cases except at Mobar and Shiroda. Most of the water samples from the study area have been found to be fit for drinking and irrigation[10]. This study was of immense help to understand the intensity of contamination of drinking water quality in the southern part of the district. However, the water quality of the coastal aquifers in northern part of Sindhudurg district is yet to be established for various purposes.

The present study thus focuses on the northern part of Sindhudurg district encompassing Kankavli, Malvan, Vijayadurg and surrounding coastal regions with an aim to evaluate the quality of surface and groundwater to determine the suitability of water for agricultural purposes.

Materials and Methods

The study area is located in the northern part of Sindhudhrg district of Maharastra, which consists of major westerly flowing rivers such as Gad River, Achra River, Piyali River and Kharada River (Fig. 1). Geologically the study area exposes rocks ranging in age from Archaean to Recent period. Dharwarian metasediments (Archaean), Kaladgi formation (Precambrian), Deccan Trap lava flows (Upper Cretaceous to Lower Eocene age), Laterite (Pleistocene) and Alluvial deposits (Recent to Sub-Recent) are the probable water bearing formations observed in Sindhudurg district[18-19]. However, Kaladgi formation is sparse and does not form potential aquifer in the district. The Alluviums also has limited areal extent found mainly along the coast. Laterites has more porosity than the Deccan trap basalt, thereby forming potential zones. The primary porosity is negligent in the Deccan trap basalts, and therefore secondary porosity due to jointing and fracturing plays an important role in groundwater circulation[20]. About 70% of the study area is covered with lateritic formation. The region reveals unusual

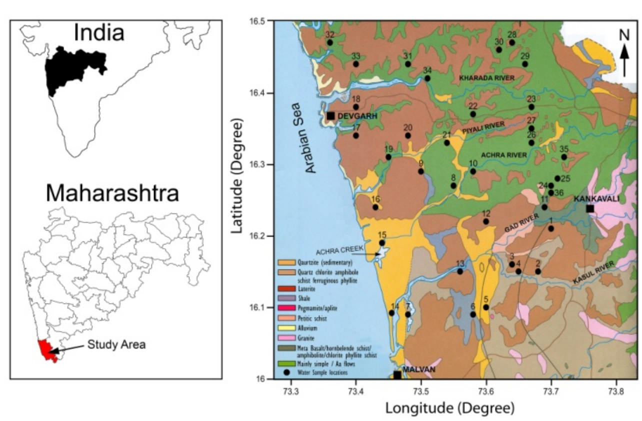

Fig. 1 — Location map of the study area. Also shown are the water sample points

physiographic system with undulating landscape throughout the area, except for the coastal plains. The area further exhibits a dendritic drainage pattern. Groundwater level in the study area varies from 2 m to 20 m below ground level (bgl)[10]. Groundwater occurs in unconfined aquifers in the phreatic zone up to a depth of about 15 m bgl in the weathered zone, cracks and joints in the massive unit and weathered/fractured vesicular units[18]. In addition, several lineaments oriented towards NNW-SSE and NE-SW is reported, which are partially responsible for controlling the physical setting of the coastal area and groundwater flow[21].

The combined impact of the Sahyadri Mountain and proximity of the Arabian Sea is well reflected on the climate of the Konkan coastal plain, where the temperature ranges from 26-32°C. Owing to the proximity of the sea, the Konkan plain on the whole is very humid (75-80%). The relative humidity even during winter and summer seasons seldom goes below 55% and therefore is classified as humid and tropical region[18].

A total of 36 water samples were collected from tube wells, hand pumps and open dug wells during May 2016 (pre-monsoon period) in the study area. The sampling locations (Fig. 1) were distributed evenly as much as possible in order to cover the entire study area. These samples are collected in pre-cleaned 1000 ml polyethylene bottles with necessary precautions and carefully sealed. All the samples were analyzed based on standard methods suggested by American Public Health Association[22]. The physicochemical attributes like pH, electrical conductivity (EC), total hardness (TH), Total Dissolved Solids (TDS) and major cations and anions were measured in the laboratory. Major cations (Ca^{+2}, Mg^{+2}, Na^+, and K^+) were determined using ICP- Mass Spectrometer. Total hardness and bicarbonate was analyzed by volumetric method. Chloride was determined by volumetric titration.

All concentrations were expressed in milligrams per litre (mg/l), except the pH and EC. The physico-chemical parameters of groundwater samples were compared with the permissible limits suggested by BIS and WHO standards[7,23], while the classification of water quality for irrigation are made as per the UCCC standard limits[24].

The fitness of the water for irrigation purposes in the study area were evaluated by calculating different vital irrigation quality parameters like sodium absorption ratio (SAR), Percent sodium (%Na), soluble sodium percentage (SSP), Magnesium adsorption ratio (MAR), Kelley's ratio (KR), residual sodium carbonate (RSC), Permeability index (PI), and chloroalkaline indices (CA).

Results and Discussion

The suitability of water for irrigation depends mainly on water quality, type of soils and the cropping pattern. Excessive amount of chemical constituents in water not only decreases plant growth and agro-based production but also the overall economy. Soluble salts in the form of cations (Na^+, Ca^{2+}, Mg^{2+} and K^+) and anions (Cl^-, F^-, CO_3^{2-}, HCO_3^-, and NO_3^-) are always present in irrigation water.

If not protected well in time, the impact of using such polluted water may result into the diminution of plant growth, agricultural production and economy[8]. Hence, identifying and addressing the irrigational water quality-related issues are crucial to investigate. In the present study area, the suitability of groundwater resources for irrigation has been evaluated based on various hydrochemical aspects and their salinity and sodicity hazards.

The analytical results with their range, mean and standard deviation for some physico-chemical parameters along with irrigation indices of groundwater samples from the study area are presented in Table 1.

Table 1 — Statistical summary of groundwater quality parameters

Water Quality Parameters	Max	Min	Mean	Std. deviation
pH	8.66	6.19	7.15	0.48
EC (μS/cm)	9420	170	686.45	1534.17
TDS (mg/l)	4667	77	335.86	764.29
TH (mg/l)	2038.71	78.56	310.36	362.42
Ca^{+2}(mg/l)	640	21	85.17	109.69
Mg^{+2}(mg/l)	107	2.1	23.73	26.17
Na^+ (mg/l)	108	5	34.53	23.94
K^+ (mg/l)	70	0	2.83	11.56
CO_3^{-2} (mg/l)	64	3	29.08	15.8
HCO_3^- (mg/l)	203.61	29	91.35	45.5
SO_4^{-2} (mg/l)	248	76.84	143.59	49.92
Cl^- (mg/l)	249	15	52.08	42.53
SAR (meq/l)	3.29	0.17	0.97	0.63
%Na	65.62	6.69	24.23	13.99
SSP	65.03	6.69	23.8	14.11
MAR (meq/l)	67.43	10.17	31.92	14.15
KR	1.86	0.07	0.37	0.35
RSC (meq/l)	1.57	-39.25	-4.22	7.32
PI	90.04	12.91	47.39	21.44
CA-1	0.72	-3.23	-0.25	0.87
CA-2	0.33	-0.39	-0.03	0.18

The irrigational indices are calculated as follows:

The concentrations of EC or TDS usually reflect the salinity hazard in groundwater. In the present case, based on TDS, all the groundwater samples are apt for irrigation (TDS < 1500 mg/l) except at one well (well number 32) where the TDS value recorded is 4667 mg/l, which exceeds the permissible limit. It is also observed that well number 32 is characterized by very high EC value (9420 µS/cm). It is pertinent to mention that this well is within a distance of 1 km from the coast.

Excess of Na^+ concentration in irrigation water is a major apprehension as it worsens the quality of soil due to reduced permeability[25]. The indices sodium adsorption ratio (SAR), %Na and soluble sodium percent (SSP) are evaluated to understand the degree of sodium hazard.

Sodium absorption ratio (SAR) expresses the sodium content of the crop, which is an important parameter for determining the suitability of groundwater for irrigation. This index is the ratio between sodium to calcium and magnesium ions in water and asserts the effect of these ions on soil structure due to dispersion of clay particles and permeability, which creates difficulty in cultivation[26-27]. The SAR values were evaluated by the following expression[28],

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

where sodium, calcium and magnesium concentrations are expressed in meq/l. In the present study area, SAR values ranges between 0.177-3.29 with a mean value of 0.98, suggesting very low sodium hazard (Table 1). According to the classification of[29], all the water samples fall in excellent category (<10) (Table 2)[30], and thus fit for irrigational purpose.

By using SAR and EC values, the classification of water for irrigation is determined graphically by plotting these values on the United States salinity diagram (USSL)[31] (Fig. 2). Most of the water samples fall in the C1-S1 (low salinity-low sodium water) and C2-S1 (medium salinity-low sodium water) classes and are excellent to good for irrigation. Two water samples fall in C3-S1 category (high salinity and low sodium water). In general it is seen that the study area reveals low to high salinity and low alkalinity water, which is suitable for irrigation in almost all types of soil. One water sample with EC value > 9000 µS/cm (not shown in Fig. 2) is unsuitable for irrigation in any type of soil.

Sodium percent is a parameter used to evaluate its fitness for irrigational purposes and therefore is a vital component in classifying irrigation water. This is due to the fact that reaction of sodium with soil reduces its permeability. The percent sodium (%Na) is calculated by using the following

$$\%Na = \frac{Na^+ + K^+ * 100}{Ca^{2+}+Mg^{2+}+Na^+ + K^+}$$

where all the cations are expressed in meq/l.

According to[32] standards, the maximum permissible limit for %Na is 60% for irrigational waters (Table 2). In the present case, 47% of groundwater samples are found to be excellent while 50% are of good to permissible for irrigation. Only 3% of groundwater samples fall in doubtful/ unsuitable category.

Further Wilcox diagram[33] based on %Na and EC values advocate less than 60% were classified as good for irrigation. The Wilcox diagram is shown in Figure (3), which reflects that in the present study area all water samples, except three, fall under excellent to good category suggesting its permissibility for irrigation purpose. The three samples (well numbers 7, 15 and 32) fall under the permissible to unsuitable range. This is mainly due to the high EC concentration (> 750 µS/cm) in these water samples. It is pertinent to mention here that these three wells are in the vicinity of the Arabian Sea.

Soluble Sodium Percentage (SSP) is used to evaluate sodium hazard. It is reported that water with a SSP value greater than 50% (Table 2) produce

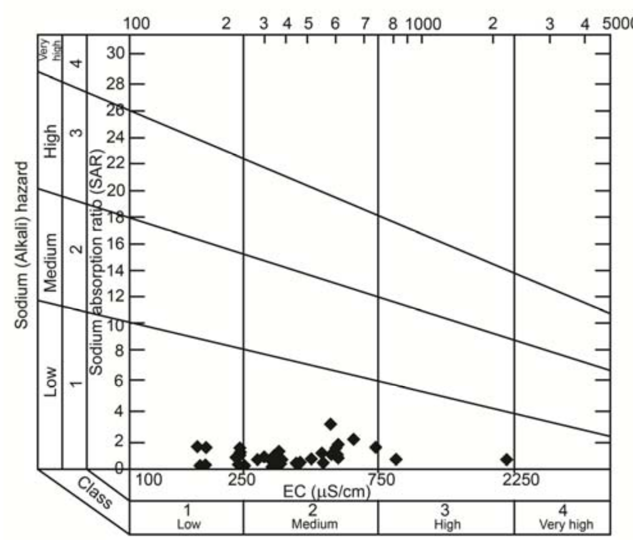

Fig. 2 — Classification of groundwater samples based on USSL diagram

Table 2 — Classification of waters based on irrigational water quality parameters

Parameter	Range	Classification	Sample numbers	% of samples
TH as $CaCO_3$ (mg/l)[30]	<75	Soft	2,8-10,13,16,19-21,26-28,30,33,36	44
	75–150	Moderately hard	1,3-6, 11,17,18,22,25,29,34,35	36.1
	150–300	Hard	15,23,24,31	11
	> 300	Very hard	7,14,32	8.3
EC (µS/cm)	0–250	Low(Excellent quality)	2,8-10,13,16,21,27,29,30,33-36	38.8
	251–750	Medium(Good quality)	1,3-6,11,12,17-20,22-26,28,31	50
	751–2250	High(Permissible quality)	7,15	5.5
	2251–6000	Very High	–	-
	6,001–10,000	Extensively High	–	-
	10,001–20,000	Brines weakly conc.	14,32	5.5
	20,001–50,000	Brines moderately conc.	–	–
	50,001–100,000	Brines highly conc.	–	–
	> 100,000	Brines extremely high conc.	–	–
TDS (mg/l)	<1,000	Fresh	1-6,8-13,15-31,33-36	94.5
	1,000–3,000	Slightly saline	--	-
	3,000–10,000	Moderately saline	14,32	5.5
	10,000–35,000	High saline	--	-
SAR [26,29]	< 10	Excellent (S1)	1-36	100
	10–18	Good (S2)	--	-
	19–26	Doubtful/Fair poor (S3)	--	-
	>26	Unsuitable (S4 and S5)	--	-
Percent Sodium[33]	<20	Excellent	1-36	100
	20–40	Good	--	-
	40–60	Permissible	--	-
	60–80	Doubtful	--	-
	>80	Unsuitable	--	-
RSC[29]	<1.25	Good	1-16,18-36	97.3
	1.25–2.50	Doubtful	17	2.7
	>2.50	Unsuitable	--	-
KR [25]	<1	Suitable	36	100
	>1	Unsuitable	--	-
MAR [35]	<50	Suitable	36	100
	>50	Unsuitable	--	-
SSP	<200	Suitable	36	100
	>200	Unsuitable	--	-
PI	<80	Good	36	100
	80-100	Moderate	--	-
	100-120	Poor	--	-

sodium accumulations resulting in disintegration of the soil's physical properties[34]. This is because sodium forms saline soil which is unsuitable for the growth of plants and can make disruption on internal drainage patterns in soil due to the absorption of sodium ions by clay particles. SSP was calculated by the following equation[26],

$$SSP=\frac{Na^{+}*100}{Ca^{2+}+Mg^{2+}+Na^{+}}$$

The cations concentrations are expressed in meq/l.SSP values ranges from 6.69 to 65 in the study area (Table 1) suggesting that about 94% of water samples are suitable for irrigation purpose and the rest 6% are unsuitable.

The Ca^{2+} and Mg^{2+} ions are scale-forming factors, which maintain a state of equilibrium in most groundwater[28]. In equilibrium, Mg^{2+} in water affects the soil by making it salty (alkaline) and results in decrease of crop yield. Magnesium adsorption ratio (MAR) is calculated using the formula [35] as,

$$MAR=\frac{Mg^{2+}}{(Ca^{2+}+Mg^{2+})}\times 100$$

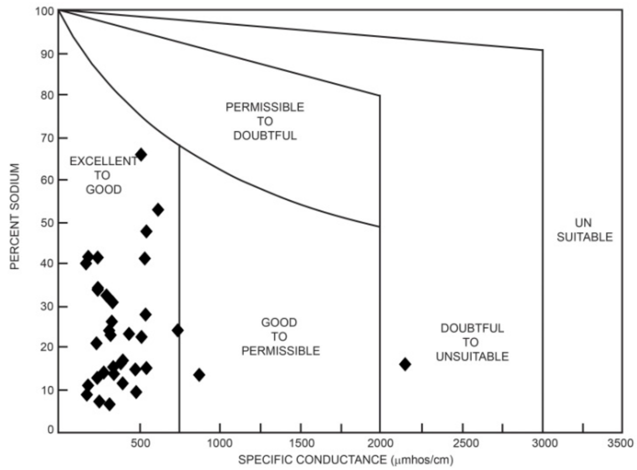

Fig. 3 — Suitability of groundwater for irrigation based on EC and percent sodium

The magnesium and calcium concentrations are expressed in meq/l.

In the study area the values of MAR (Table 1) range between 10.1-67.4 with an average of 31.9. Seven water samples (19%) revealed MAR >50 and hence falls below the permissible limit, thus unsuitable for irrigation, while remaining 29 samples (81%) are suitable (<50 MAR) for irrigation (Table 2).

Kelly's ratio (KR) is an important parameter for determining irrigation water quality, which is used to measure the sodium concentration against calcium and magnesium[36]. High amount of sodium concentration in water usually modifies the soil properties and soil permeability, which is an indication of alkali hazard[37]. Also the soil gets diffused due to smaller amount of calcium in water thereby reducing the infiltration rate[38]. The following equation represents the Kelly's ratio,

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

If KR<1, it is considered to be fit for irrigation, while if KR>1, it suggests excess of sodium in water and thus unfit for irrigation (Table 2). The sodium, magnesium and calcium concentrations are expressed in meq/l. In the present study area 94% of groundwater samples are fit for irrigation and only 6% of samples have KR values greater than unity.

Residual sodium carbonate (RSC) is used to assess the excess carbonate and bicarbonate in water over the concentrations of calcium and magnesium, which is unsuitable for irrigation[29, 39]. This parameter can be calculated by the following equation,

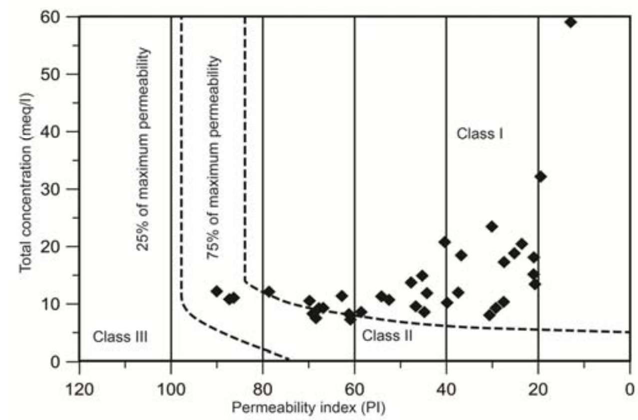

Fig. 4 — Suitability of groundwater for irrigation based on Permeability Index

$$RSC=(CO_3^{+2}+HCO_3^{-})-(Ca^{+2}+Mg^{+2})$$

The cations and anions are expressed in meq/l. The RSC values shown in Table 2, reflects that 35 water samples have RSC values less than 1.25 and therefore suitable for irrigation. Negative values of RSC (Table 1) suggest that the concentration of calcium and magnesium are high and sodium build-up in soil is unlikely if irrigated with this water[40]. In the present case, one water sample reveal positive RSC values (>1.25) which may reduce permeability of soils and tends to enhance the sodium concentration in soils.

Permeability index (PI) represents the soil permeability which is affected by long term use of water containing salts like sodium, calcium, magnesium and bicarbonate for irrigation. This index[41] for determining groundwater suitability for irrigation is given as,

$$PI=\frac{Na^{+}+\sqrt{HCO_3^{-}}}{Ca^{2+}+Mg^{2+}+Na^{+}}\times 100$$

where the concentrations are in meq/l. The PI is classified into three classes wherein Class I and II of water have 75% and more permeability and thus suitable for irrigation. The Class III type of water with 25% maximum permeability is unsuitable for irrigation purpose.

The PI of study area varies from 12.9-90 with an average of 47.4. In the study area, all the samples fall in Class 1 and Class 2 category (Fig. 4), indicating that the water type is good for irrigation with 75% or more of maximum permeability.

In order to comprehend the chemical reactions involved in an aquifer environment, the Schoeller indices[42] (also known as chloroalkaline indices) was evaluated for cations (CA-1) and anions (CA-2), both during the residence and movement period of groundwater. The chloroalkaline indices are computed by following equations.

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

where the concentrations are expressed in meq/l.

$$CA\ 2=\frac{[Cl^{-}-(Na^{+}+K^{+})]}{SO_4^{-2}+HCO_3^{-}+CO_3^{-2}+NO_3^{-}}$$

where the concentrations are expressed in meq/l.

These two indices are negative when there is an exchange between calcium or magnesium in groundwater with sodium or potassium. In the case of reverse ion exchange, both the indices will be positive. In the event of negative CAs, the water may soften due to exchange process between ions, and vice versa.

The results reveal that 52% (19 wells) of water in the study area is having negative chloroalkaline indices, while 48% (17 wells) display positive CA values. This observation suggests that normal ion exchange is slightly more than the reverse ion exchange process. It may be advocated that the positive values signify the absence of base-exchange and thus is a cation anion exchange reaction. The negative values suggest base-exchange between sodium and potassium in water with calcium and magnesium primarily due to the weathering of basalts[43].

Conclusion

The analysis reveals that most of the samples fall within the permissible limits prescribed by WHO and BIS, barring a few, where, the TDS and EC are beyond the acceptable limit. This is due to the saline water ingress in these wells. The irrigation quality parameters calculated suggest that very low sodium hazard is evident at all stations through SAR values and thus is excellent for irrigation use. The US salinity diagram shows low to high salinity and low sodium water and hence suitable for irrigation in almost all types of soil. Only one water sample with EC value in excess of 9000 µS/cm is unsuitable for irrigation. Based on the Wilcox diagram classification, all water samples, except three, fall under excellent to good category and are permissible for irrigation purpose. The three samples (well numbers 7, 15 and 32) fall under the permissible to unsuitable range, primarily due to high EC values (> 750 µS/cm) at these sampling points, which are in proximity to Arabian Sea. More than 80% of the water samples are suitable f or irrigation based on SSP, MAR, KR and RSC and PI. The CA I and II of the groundwater in this region indicate that normal ion exchange is slightly more than the reverse ion exchange process. Generally it is observed that most of the groundwater samples from the study area are suitable for agricultural purposes.

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