Assessing coastal groundwater quality and its suitability for agricultural and drinking use

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Abstract

Agricultural activities with their intensive utilization of agri chemicals, pose a significant potential for negative impact on the quality of underlying groundwater. The present study was conducted to assess seasonal variation of groundwater quality and its suitability for agricultural use in the coastal area of Mazandaran province, Northern Iran. The suitability of ground water for drinking was also assessed based on Schoeller's diagram. In three times of a water year (i.e. in spring, summer and winter), different characteristics of groundwater quality were determined in about 30 observation wells representing shallow aquifers and covering all the study area. The groundwater salinity was high in most cases while its alkalinity was fairly stable in different times.
Keywords: Agricultural sector- Wilcox method, Groundwater quality, Schoeller's diagram.

Introduction

Groundwater is usually defined as water contained in an aquifer matrix located beneath the surface in the saturated zone, as opposed to free surface water bodies like streams, reservoirs, or lakes (Siebert et al., 2010). Agricultural activities, with their intensive utilization of agrichemicals, pose a significant potential for negative impact on the quality of underlying ground waters over broad areas of the Mazandaran province in northern Iran. The magnitude of the problem and primary factors controlling the occurrence of groundwater contamination in agricultural setting are still poorly understood (Betcher etal., 1996).

Regularly monitoring of the groundwater quality for various purposes or to prevent contamination is very useful. A lot of researches were conducted on analyzing groundwater quality and its temporal changes. Forrest et al. (2006) surveyed nutrients and major ions in shallow groundwater of Alberta's Agricultural areas by sixteen water quality parameters which were measured in water samples from 76 wells with low and high agricultural activity in their surrounding areas. This study showed that there was a significant relationship between agricultural activities with local data and nitrate concentration. Karandish and Shahnazari (2013) applied Geostatistical methods to estimate Mazandaran coastal ground water quality and demonstrated that the groundwater in the study area is slightly basic and the values of EC exceeded the permeable limit in more than 40% of the study area. Also there was sodium hazard and high concentration of TDS in the north-east part.

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Due to rice cultivation in coastal areas, Mazandarn province requires huge quantity of water for irrigation. This requirement is mostly met through groundwater, extracted from the shallow aquifers. However, over the years overexploitation of groundwater from these aquifers has resulted into a significant reduction in the groundwater level. The declining trends of groundwater level, both long term and short term, has negative impact on groundwater quality of the study area. Investigation of the seasonal variation of groundwater quality during a water year was considered as a major objective of this research.

Material and methods

Study area

The study area (Figure 1), covers large area of agricultural land in Alborz Integrated Land and Water Management Project (AILWMP) area. Considering this area was due to intensive agricultural activities especially citrus and paddy fields. Following wheat, rice is the second principal dietary item of Iranian (Darzi-Naftchali and Shahnazari, 2014). Iran's major rice producing region, within Gilan and Mazandaran provinces of the country, is located between the Alborz Mountains and the Caspian Sea. This humid region accounts for about 75% of the total amount of rice produced in the country, because of heavy rainfall that typically facilitates paddy cultivation and suitable soils (FAO, 2003).

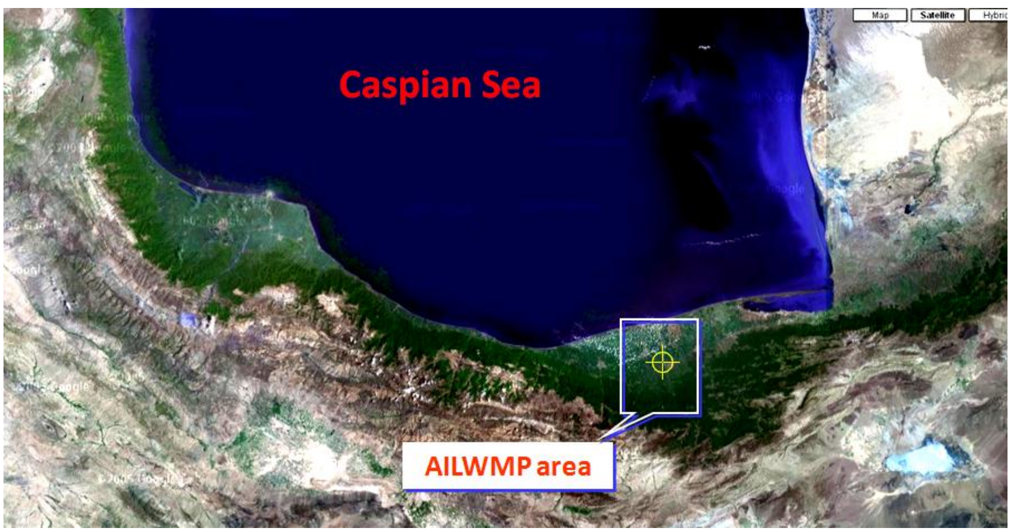

Figure 1.Study area in the coastal area of the Caspian Sea

Data collection

It is important to prepare a good sampling plan. The sampling plan should be prepared in consultation with stakeholders and field and laboratory technicians (Sundaram et al, 2009). The main data for this study was provided through information collected from AILWMP. Data includes three sets of samples representing spring, summer and winter conditions, collected in 2010 from more than 30 operating wells across the study area used for irrigation and drinking. Samples were analyzed for electrical conductivity (EC), acidity (PH), total dissolved solid (TDS), carbonate concentration (CO_3^{-2}), chloride concentration (Cl^-), sulphate concentration (SO_4^{2-}), calcium concentration (Ca^{2+}), magnesium concentration (Mg^{2+}), Sodium concentration

(Na^+), potassium concentration (K^+), total hardness (TH), water depth (WD), temperature (T) and total rainfall (TR).

Water quality indices

To assess irrigation water quality, the parameters such as sodium percentage (Na %) and sodium adsorption ratio (SAR) was calculated based on the chemical variables of water samples through eqs 1 and 2, respectively, as follows:

$$\mathrm{Na\%} = \frac{\mathrm{Na}^+}{\mathrm{Na}^+ + \mathrm{Ca}^{+2} + \mathrm{Mg}^{+2} + \mathrm{K}^+} \times 100\% \qquad (1)$$

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

Where all the ionic concentrations are expressed in mille equivalents per liter (meq L^{-1}). Based on the calculations and water quality analysis, the groundwater suitability for irrigation was determined by Wilcox' diagram (Wilcox, 1995). Also, by using Schoeller's diagram (Schoeller, 1967), the suitability of groundwater for drinking was analyzed.

Results and discussion

As mentioned earlier, water quality data were from three times of a water year namely winter, spring and summer. Since large of Mazandaran coastal area devoted to rice cultivation, the water quality program was considered to be consistent with rice cultivation practices. In this regard, the winter, spring and summer sampling was consistent with pre planting, transplanting and postharvest periods of rice growing season, respectively. For each sampling time, the average of pH, EC and SAR was determined and the results are presented in Figures 2 to 4, respectively. Groundwater of the study area was mildly alkaline in winter and spring with average pH of 7.51, while it was approximately neutral in summer with average pH of 7.06.

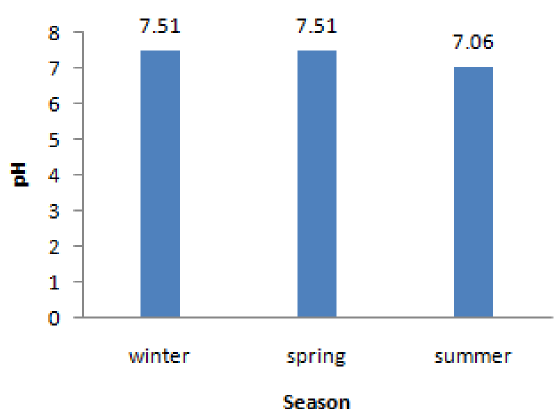

Figure 2. Average pH of groundwater samples in different times.

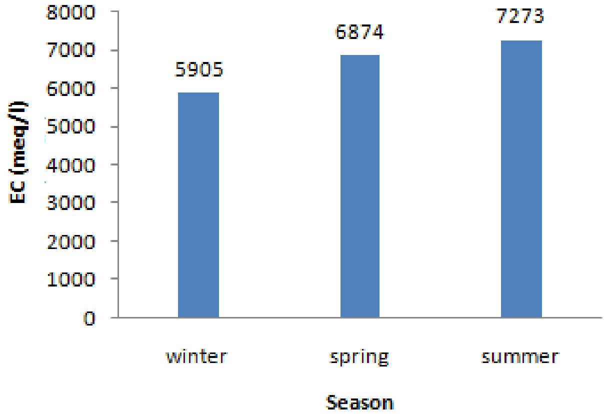

Figure 3. Average EC of groundwater samples in different times.

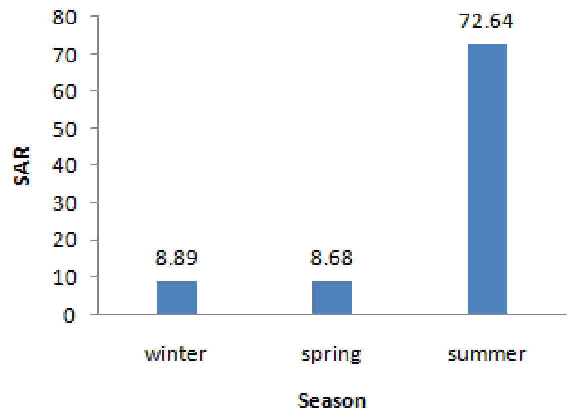

Figure 4. Average SAR of groundwater samples in different times.

Comparison of EC and SAR of three measurements show that the risk of salinity and sodium was increased at the end of the growing season as a result of application of salt containing irrigation water together with declining in groundwater level. Irrigation water quality can have a profound impact on crop production. All irrigation water contains dissolved mineral salts, but the concentration and composition of the dissolved salts vary depending on the source of the irrigation water (Grattan, 2002). In the study area, Abbandans (ancient water resources) and shallow aquifers are traditionally used to irrigate paddy fields. However, supplemental irrigation may be needed at the end of the rice growing season. Generally, farmers tend to use shallow groundwater for supplemental irrigation which results in more declining in groundwater level and increase in its salinity. Groundwater sodification in summer is related to the intrusion of residuals of fertilizers and pesticides into groundwater during growing season. Plants respond to osmotic and ion toxicity effects with a gradually declining yield as water quality deteriorates. This enables the farmer either to accept this loss or to determine whether the marginal return to the cost incurred in avoiding salinity or toxicity problems is worthwhile. Because of the wide range of species tolerance to salinity and toxicity the type of crop being grown has a large bearing on these decisions (George, 1983).

One of the common methods to determine the combination hazard of both salinity and sodicity is Wilcox' s diagram. The quality classification of groundwater of the study area is shown on Wilcox' s diagram for different times (Figure 4). Also, the percentage of groundwater samples related to different classes of Wilcox' s diagram is presented in Table 1. The level of salinity hazard in the study area was almost high and very high while alkalinity hazard was low and medium.

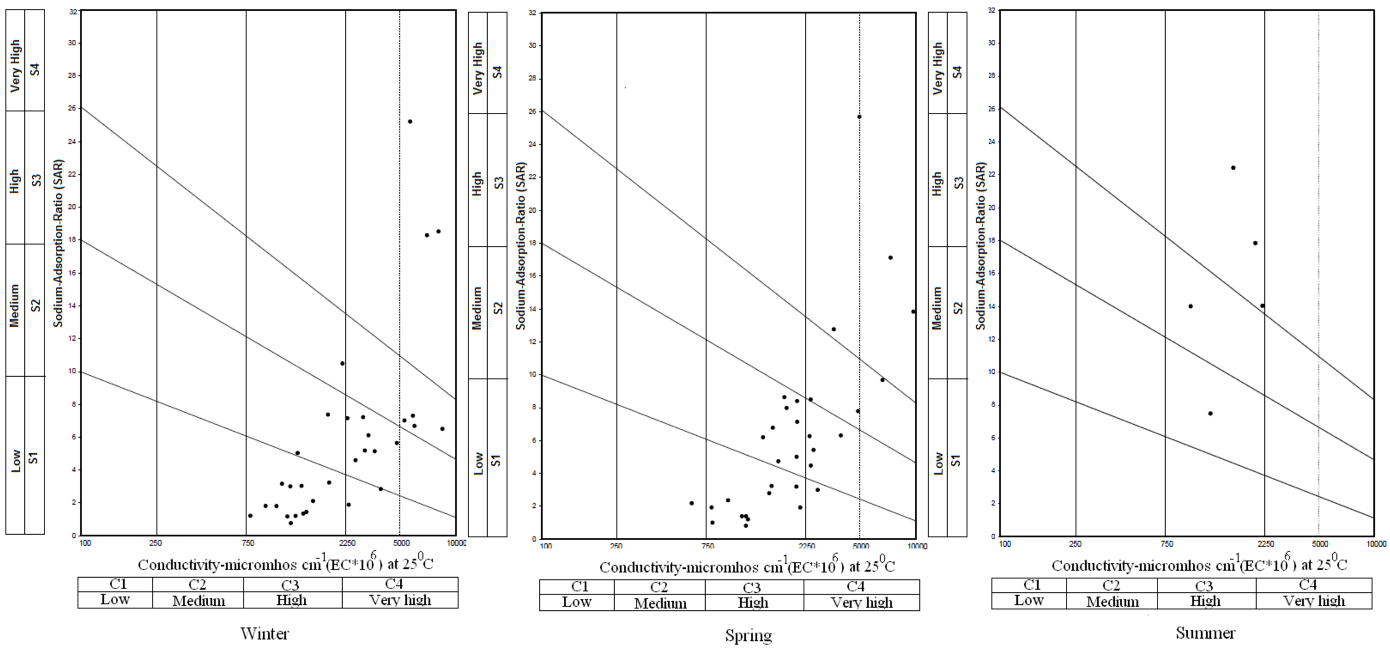

Figure 4. Quality classification of groundwater of the study area (data were out of Wilcox' s diagram are not shown)

Table 1. Percentage of groundwater samples related to different classes of Wilcox' s diagram.

Winter 2010				Spring 2010				Summer 2010			
C1				C1				C1			
S4	S3	S2	S1	S4	S3	S2	S1	S4	S3	S2	S1
0	0	0	0	0	0	0	0	0	0	0	0
C2				C2				C2			
S4	S3	S2	S1	S4	S3	S2	S1	S4	S3	S2	S1
0	0	0	0	0	0	0	2.7	0	0	0	0
C3				C3				C3			
S4	S3	S2	S1	S4	S3	S2	S1	S4	S3	S2	S1
0	0	5.41	35.14	0	0	13.51	24.33	15	5	5	0
C4				C4				C4			
S4	S3	S2	S1	S4	S3	S2	S1	S4	S3	S2	S1

21.62	13.51	18.92	5.41	24.33	8.11	18.92	8.11	75	0	0	0

Groundwater alkalinity was fairly constant in winter and spring with more than 50% of samples attributed to C4-S1, C4-S2, C4-S3 and C4-S4 classes. In summer, the level of alkalinity in 75% of samples attributed to C4-S4 class. Groundwater suitability for drinking was evaluated by Schoeller's diagram and the results tabulated in Tables 2- 4.

Table 2. Percentage of winter groundwater samples related to each class of Schoeller's diagram

Classification	So4	Cl	Na	pH
Good	64.86	24.32	21.62	54.05
Acceptable	24.32	16.22	18.92	29.73
Medium	10.81	18.92	27.03	16.22
Unsuitable	0	8.11	10.81	0
Quite unpleasant	0	16.22	8.11	0
Non-potable	0	16.22	13.51	0

Table 3. Percentage of spring groundwater samples related to each class of Schoeller's diagram

Classification	So4	Cl	Na	pH
Good	56.76	21.62	21.62	8.11
Acceptable	35.14	13.51	10.81	24.32
Medium	8.11	24.32	35.14	45.95
Unsuitable	0	13.51	13.51	16.22
Quite unpleasant	0	10.81	8.11	5.41
Non-potable	0	16.22	10.81	0

Table 4. Percentage of summer groundwater samples related to each class of Schoeller's diagram

Classification	So4	Cl	Na	pH
Good	55	10	10	10
Acceptable	40	10	15	20
Medium	0	20	15	30
Unsuitable	5	10	25	25
Quite unpleasant	0	25	15	5
Non-potable	0	25	20	10

The drinking suitability of groundwater was considerably affected in summer so that, more water samples had worse quality for drinking. With regard to that paddy rice is primary crop in the study area, inadequate water and fertilizer management during rice season has considerable influence on groundwater quality. In addition, overexploitation of groundwater during rice growing season caused more negative impacts on water quality. Lashkaripour and Ghafoori (2011) studied and examined the groundwater decline and its effect on the quality of groundwater in aquifer of Torbat Jam plain (Northeast Iran) for a period of 19 years. The results showed that groundwater in the major portions of the study area had high concentrations of major cations and anions due to the continuous decline of groundwater level.

Chaudhuri and Srinivasulu (2014) studied long term (1960–2010) trends in groundwater contamination and salinization in the Ogallala aquifer in Texas. They showed that movement of groundwater from underlying formations was largely resulted from lowering of hydraulic heads in the Ogallala aquifer due to prolonged groundwater withdrawal for irrigated agriculture.

Conclusion

Investigation of groundwater quality in a coastal area of Mazandaran province in winter, spring and summer suggesting high risk of salinity and alkalinity of groundwater from agricultural use viewpoint. Change in water quality, particularly at the end of rice growing season (a commonly crop cultivated in the study area), is attributed to the impact of agricultural activities such as the indiscriminate use of fertilizers and pesticides and leaching of their residuals into shallow aquifers. Therefore, improved agricultural practices and efficient management of nutrients and pesticides are necessary to minimize the negative impacts on the environment and consequently to achieve sustainable agriculture in the study area.

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