Assessment of groundwater quality for irrigation purpose in Amol Plain, Iran

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Abstract

Groundwater is a valuable source of water for agricultural activities in the arid and semi-arid area. Nearly, 80% of Amol Plain in north of Iran are covered by irrigated land such as rice fields and citrus groves. Groundwater samples were collected from 27 wells during rainy season and 30 wells during dry season of 2009. Sodium percentage (Na %), Sodium Adsorption Ratio (SAR), Residual Sodium Carbonate (RSC) and water hardness were used as indicators for evaluating the suitability of water for irrigation purpose. Kriging was used as the advanced interpolation technique for predicting spatial distribution of groundwater quality for agriculture activities in the study area. Analysis showed that 76% water sample in dry season and 74% in rainy season were classified as very hard water. Based on RSC, 40% and 49% water samples in dry and rainy seasons respectively are not suitable for to be used for irrigation. Based on interpolation map, west and central sections of Amol Plain, the water quality is suitable for agricultural activities. The values of RSC, water hardness, and SAR and sodium percentage increase gradually from west to east and north-east where groundwater has been influenced by dissolution of carbonate rocks and intrusion of Caspian Sea water. It is concluded that hardness was a major problem for agricultural activities in the eastern section of study area.

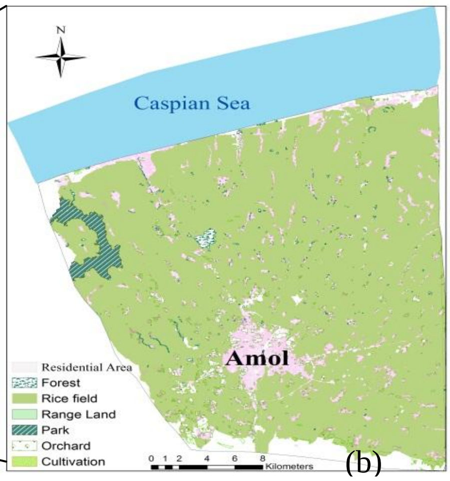
Keywords: Interpolation. Kriging. Irrigation. Water quality. Amol plain.

1. Introduction

Water shortages have become a serious problem in the arid and semi-arid region in the world (Jalili et al. 2011). Agriculture is mainly limited by the availability of desirable irrigation water. Suitable irrigation water plays a significant role in soil physical and chemical characteristic and fertility. In the Amol Plain, a part of Mazandaran province, north of Iran, groundwater is a major source for agricultural activities especially for rice fields which covered nearly 80% of land use. The quality of groundwater reflects inputs from the atmosphere, soil and bed-rocks weathering and other pollutant sources such as domestic, agricultural and industrial wastes and mining activities (Mitra et al. 2007). For assessing the suitability of groundwater for irrigation purpose, groundwater chemical composition should be considered (Khodapanah et al. 2009). Since, groundwater uses for different purpose, different criteria of water quality such as standard methods for reporting and compering results should be used for water analysis (Babiker et al. 2007). Groundwater often consists of major ions such as Cl^-, Na^+, Ca^{2+}, Mg^{2+}, HCO_3^-, K^+ and SO_4^{2-}, which directly influence on classifying and assessing water quality (Sadashivaiah et al. 2008). Features that usually required to assess the suitability of groundwater quality for irrigation include sodium percent (Na %), Sodium Adsorption Ratio (SAR), Residual Sodium Carbonate (RSC) and Total Hardness (TH) (Carmelita Nishanthiny et al. 2010). Identification of groundwater appropriate zones for irrigation purposes has been previously undertaken by using interpolation methods (Ashraf et al. 2011). Geostatistical technique can be applied to obtain a continuous surface through the interpolation using a set of sample points (Sajil Kumar et al. 2011). Numerous researches have evaluated groundwater quality for irrigation purposes by considering chemical composition (Sadashivaiah et al. 2008; Carmelita Nishanthiny et al. 2010; Vasanthavigar et al. 2010; Kaur and Singh 2011; Khodapanah et al. 2009). Ashraf et al (2011) applied GIS software to specify suitable zone for agriculture in the Damghan region of Iran. The objective of present study was to assess groundwater chemical composition and its suitability for irrigation purpose in the Amol Plain.

2. Study area

Amol Plain is located in the Mazandaran province in Iran (Fig 1-a). It is extended between Caspian Sea in the north, Alborz Mountain in the south, Babol city in the east and Alish River in the west. The weather is influenced by moderate, semitropical climate with an average temperature of 25 °C in summer and about 6 °C in winter (Shahbazi and Esmaeli-Sar 2009). The annual rainfall is 870 mm, with maximum quantity around 400 mm in October, November and December. The main activities carried out in this area are agriculture (rice field) and crop irrigation activities, which cover near 80% of land uses (Fig 1-b). Irrigation agriculture highly depends to groundwater resources in the study area. Based on the census of 2006, the population of the study area was 343474 of which 54% resided in urban and 46% in village (CIRI 2006). Amol Plain developed on alluvial fan for Haraz River which passes through Amol city.



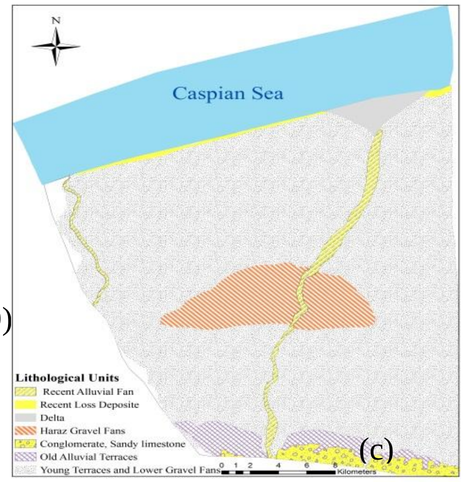


Fig. 1 Schematic map of (a) Iran, (b) Land use map of Amol Plain, (c) Lithological map of Amol Plain (Fakharian 2010)

3. Material and methods

A total of 57 samples of groundwater in the study area were collected from 30 wells in the dry (May and June 2009) and 27 wells in the wet seasons (October and November 2009). The samples were collected after 10 minute to avoid screen contamination and remove groundwater stored in the wells (Belkhiri et al. 2010), then stored in polyethylene bottle at 4°C until there were sent to the laboratory. Unstable parameters such as temperature, pH, Electrical Conductivity (EC) and Total Dissolved Solid (TDS) were measured in site. The major ions such as Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^{-}, Cl^{-} and SO_4^{2-} were analyzed by following the standard method of APHA (2005).

3.1 Suitability for irrigation purpose

The suitability of groundwater for irrigation uses depends upon the mineral constituent (Khodapanah et al. 2009). Excessive amount of mineral can effect on the growth of plant and agricultural soil physical and chemistry, which reducing the productivity (Khodapanah et al. 2009). The general indicators to assess the suitability of groundwater for irrigation purpose include; sodium percentage (Na %), Sodium Adsorption Ratio (SAR), Residual Sodium Carbonate (RSC) and Total Hardness (TH).

3.2 Geostatistic technique

Interpolation maps could be created by using geostatistical technique when the measured points at different locations are given. These techniques produce a set of statistical tools for prediction surface, error and uncertainty of surface (Uyan and Cay 2010). As the first step, after normalization of data, semivariogram should be used between measured points to describe the variability of data with respect to spatial distribution. Uyan and Cay (2010) noted that spherical, exponential and Gaussian are the most widely used variogram models. The suitable model for fitness on experimental variogram is chosen by cross validation. Based on cross validation, the best model is determined by Root Mean Square Standardized (RMSS). The closest RMSS value to one will be chosen. Kriging is considered as an optimal geostatistical approach for interpolation at unsampled location where sample points close to each other is more alike than that are far from each other. The model and the parameters of the groundwater quality for irrigation purpose are given in table1. In this study, ordinary kriging method by using suitable variograms is used to prepare spatial distribution maps in the studied area.

Variogram	**Dry Season**					**Wet Season**				
Parameter	**Spherical**	**Exponential**	**Gaussian**	**Tetrasphericа**	**Circular**	**Spherical**	**Exponential**	**Gaussian**	**Tetrasphericа**	**Circular**
TH	1.051	**1.048**	1.051	1.049	1.051	1.106	**1.044**	1.111	1.108	1.103
Na %	1.082	1.094	**1.075**	1.085	1.077	1.025	**1.019**	1.027	1.023	1.025
SAR	1.117	1.129	**1.111**	1.119	1.114	1.059	**1.053**	1.064	1.057	1.06
RSC	1.029	1.041	**1.026**	1.029	1.031	0.976	**0.975**	0.976	0.976	0.976

Table 1 Selection of the most suitable model for evaluation on experimental variogram base on RMSE. (Bold numbers indicate selected vriograms)

4. Result and discussion

Based on the results, pH was found to range from 6.6 to7.9 in the dry season and 6.5 to 7.5 in the wet season, which were within FAO permissible limits (6.5- 8.4) (Table 2). The values of EC ranged from 632.3 to 1387 µs/cm and from 632.0 to 1417.0 µs/cm in the dry and wet seasons, respectively which indicated that EC concentration was lower than FAO (1994) standard limit of 3000 mg/l. Also, the TDS mean concentration was 713.9 mg/l in the dry season and increased slightly to 728.3 mg/l in the wet season, which were lower than FAO (1994) irrigation water quality standard (2000 mg/l). During dry season to wet season, potassium concentration changed from 14.5 to 18.77 mg/l which were extremely lower than FAO permissible limit (78 mg/l).

Parameter	unit	Descriptive Statistics Dry Season				Descriptive Statistics Wet Season				Standard (FAO 1994)
		Minimum	Maximum	Mean	Std. Deviation	Minimum	Maximum	Mean	Std. Deviation	
pH		6.6	7.9	6.96	.299	6.5	7.5	6.89	.233	6.5- 8.4
EC	μs/cm	632.3	1,387.0	952.73	192.207	632.3	1,417.0	975.07	205.593	3000
TDS	Mg/l	415.0	1,024.0	713.96	164.583	414.2	1,056.0	728.34	167.987	2000
K^+	Mg/l	2.9	90.0	14.53	18.392	1.0	65.0	18.77	15.249	78
Mg^{2+}	Mg/l	7.0	60.0	36.47	9.317	19.0	60.0	34.11	9.732	60
Ca^{2+}	Mg/l	28.0	170.0	87.30	32.775	42.0	180.0	86.15	34.872	400
CO_3^{2-}	Mg/l	0.0	160.0	74.67	49.252	0.0	80.0	28.15	27.461	30
HCO_3^-	Mg/l	190.0	1,000.0	416.00	179.407	200.0	1,130.0	549.63	210.132	600
SO_4^{2-}	Mg/l	1.0	142.0	86.43	34.947	0.0	132.0	90.15	36.612	900
Cl^-	Mg/l	29.0	275.0	125.53	59.230	5.0	375.0	139.33	92.039	1000
Na^+	Mg/l	13.2	132.6	33.36	25.703	10.2	140.6	35.96	28.520	900

Table 2 basic statistics of field parameters and analytical data for groundwater sample

Magnesium is found to range from 7 to 60 mg/l in the dry season and from 19 to 60 mg/l in the wet season. The maximum concentration showed values near permissible limit of 60 mg/l by FAO (1994). The Mg/Ca mean ratio for groundwater ranged from 0.773 in the dry season and 0.76 in the wet season. Vengosh and Rosenthal (1994), indicated that Mg/Ca ionic ratio is normally in the range of 0.5 – 0.7 in waters that affected by limestone rocks. It seems that groundwater in the Amol plain has affected by weathering and dissolution of limestone and dolomite rocks from highlands in the southern side. Mean values of Ca^{2+} varied from 87.3 to 86.1 in the dry and wet season respectively. Maximum concentration of bicarbonate was 1000 mg/l in the dry season and increased slowly to 1130 mg/l in the wet season which represented values higher than permissible limit of 600 mg/l by FAO (1994) irrigation ware standards. High values of bicarbonate concentration may be indicating the interaction of water with dolomite and limestone that could change groundwater type to alkaline in some part of Amol Plain. The mean concentration of sulfate changed from 86.4 to 90.1 mg/l in the dry and wet seasons, respectively. The values were extremely lower than FAO (1994) irrigation water standard of 900 mg/l. In both seasons, the mean concentrations of sodium and chloride were lower than permissible limits. The values quality standards for Na^+ and Cl^- are 900 mg/l and 1000 mg/l (FAO 1994) respectively. The maximum concentration of sodium and chloride were 33.3 mg/l and 35.9 mg/l in the dry season and 125.5 mg/l and 139.3 mg/l in the wet season.

4.1 Assessment groundwater for irrigation purpose

Sodium percentage (Na %)

The sodium in irrigation water is represented as percent sodium which is significant in classifying irrigation water. Excess sodium in groundwater produces the undesirable effects on soil structure, permeability and aeration which affect plant growth (Khodapanah et al. 2009). Sodium percentage was calculated by using following formulate (Todd 1980):

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

Where all ionic concentrations are represented in meq/l

The Na^+ % values ranged from 8% to 50.9% in the dry season and 9.4% to 56.8% in the wet season (Table 3). About 76.6% and 66.6% of the samples were found to be suitable to be used for irrigation uses during dry and wet seasons (Table 3). Spatial distribution maps (Fig

2-b and 3-b) show that Na % increase gradually from southern to northern of Amol Plain, where groundwater might be influenced by Caspian Sea saline water.

Parameter	Range	Classification	Percentage of Sample	
			Dry	Wet
TH	< 75	soft	0	0
	75-150	moderate hard	0	0
	150- 300	hard	23.3	26
	> 300	very hard	76.6	74
Na %	< 20	excellent	76.6	66.6
	20-40	good	16.6	26
	40-60	permissible	6.6	7.4
	60-80	doubtful	0	0
	>80	unsuitable	0	0
SAR	<10	excellent	100	100
	18_26	good	0	0
	18-26	doubtful	0	0
	>26	unsuitable	0	0
RSC	<1.25	good	43	37
	1.25-2.5	doubtful	16.6	14.8
	>2.5	unsuitable	40	48.1

Table 3 Groundwater quality based on TH, Na%, SAR and RSC in the dry and wet seasons

Total hardness

Total hardness of groundwater is caused by dissolved Ca^{2+} and Mg^{2+} in water expressed as $CaCO_3$. Water hardness is divided to temporary and permanent hardness. Temporary hardness is happened when calcium carbonate present in water, it is removed by boiling water. Permanent hardness is evidence of Ca^{2+} and Mg^{2+} presence in water and it is removed by ion exchange process (Vasanthavigar et al. 2010) . WHO (2008) found an evidence of excessive water hardness consumption may increase heart diseases. High hardness may also scale the pots, boilers and irrigation pipes. Total hardness in mg/l is calculated by using following formula (Todd 1980):

$$TH = 2.497\ Ca^{2+} + 4.115\ Mg^{2+} \quad (2)$$

Groundwater total hardness varies between 176.1 to 646 mg/l in the dry season and 195.4 to 593.5 mg/l in the wet season. Around 23.3% and 26% of samples was classified as hard water type and 76.6% and 74% was classified as very hard water type in the dry and we seasons, respectively (Table 3). A total hardness is found to increase slightly from west side of Haraz alluvial fan to the north-east and east side of Amol Plain (Fig 2-a and 3-a).

Sodium Adsorption Ratio (SAR)

Sodium hazard in relation to calcium and magnesium concentration is expressed in terms of sodium adsorption ratio. High sodium concentration (SAR) leads to development of an alkaline soil (Khodapanah et al. 2009), which becomes hard and compact when dry and impervious to water penetration. Therefore, it causes damage to the soil physical structure and undesirable to plant growth. SAR was calculating by the following equation (Hem 1991):

$$SAR = \frac{Na^{+}}{\sqrt{\frac{(Ca^{2+} + Mg^{2+})}{2}}} \quad (3)$$

Where all ionic concentrations are represented in meq/l.

The SAR results show the variation from 0.31 to 2.98 meq/l in the dry season and 0.25 to 3.55 meq/l in the wet season. These indicating 100% of samples during both study season are suitable for irrigation. Base on spatial distribution map (Fig 2-d and 3-d), the SAR values show gradually increased from Haraz plain (south and central part) to coastal area (northern side) where coastal aquifer is suspected to be contaminated by sea water intrusion.

Residual Sodium Carbonate

Bicarbonate hazard is usually represented in terms of RSC, which shows the tendency for calcium and magnesium to participation as the water in the soil becomes more concentrated (Carmelita Nishanthiny et al. 2010). Therefore, the relative proportion of sodium in the water is increased in the form of sodium bicarbonate (Sadashivaiah et al. 2008), RSC is calculated by the formula given below (Janardhana 2007):

$$RSC = (HCO_3^- + CO_3^{2-}) + (Ca^{2+} + Mg^{2+}) \quad (4)$$

Where all ionic concentrations are expressed in meq/l.

RSC ranges from 3.22 to 9.77 meq/l and 2.98 to 13.61 meq/l during dry and wet seasons respectively (Table 3). It is concluded that nearly 43% and 37% of sampling wells have good condition for irrigation activities in dry and wet seasons based on RSC. Approximately more than 40% samples in dry season and 48% samples in wet season are unsuitable for irrigation purpose. Based on fig 2-c and 3-c, groundwater near Haraz alluvial fan showed good condition for irrigation and RSC value increase with distance from the Haraz fan to surrounding plains. The sources of high RSC in the studied area is due to the recharge area (Alborz highlands) contain of limestone and sandy limestone.

5. Conclusion

The suitability of water for irrigation is evaluated base on RSC, SAR, Na% and TH. Most of the samples are in the suitable range for irrigation purpose base on SAR and Na% results in the Amol Plain. The values increase slightly to the north, where coastal aquifer may be affected by Caspian Sea water. More than half of samples hardness and RSC exceeded the concentration suggested by (FAO 1994). Thus, it showed the significant role of carbonates rock in the recharge area to groundwater quality in the plain. Application of kriging method has been applied to identify the suitable zones of groundwater quality for irrigation purpose. From spatial distribution maps, it was observed that the central regions of Amol Plain are most suitable zones for agricultural activities. Based on the results, seasonal variations were found to have no significant influence on the suitability of groundwater for irrigation uses in the study area.

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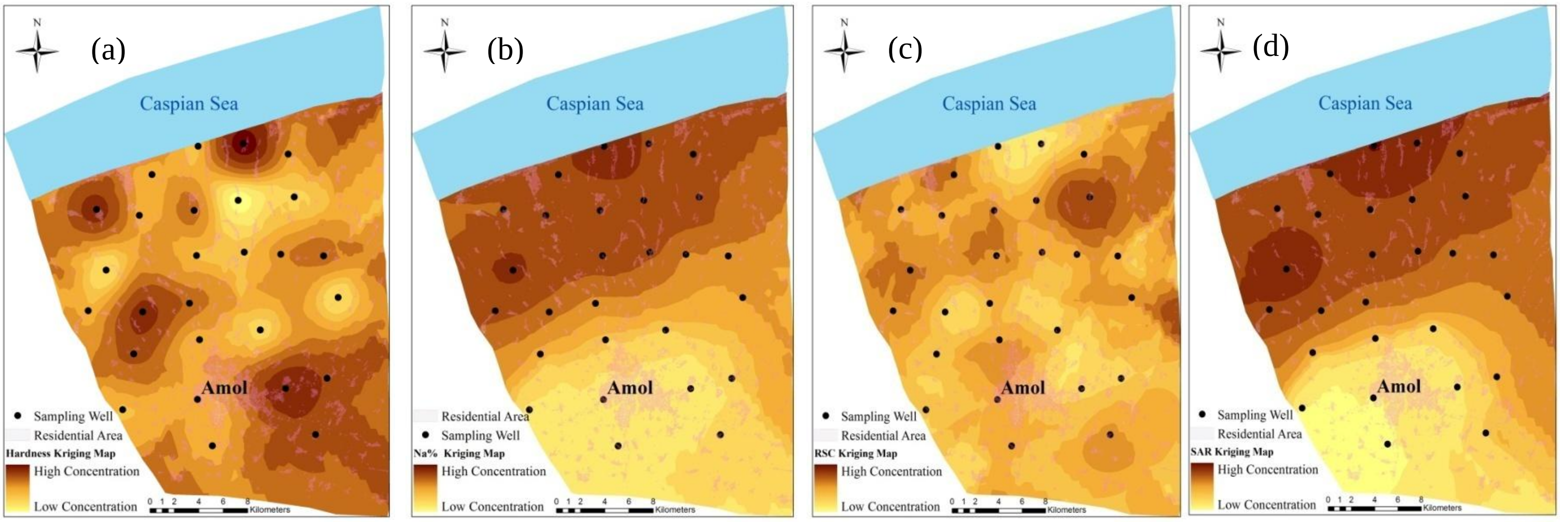

Fig. 2 Spatial distribution map of, TH (a), Na % (b), RSC (c) and SAR (d) in wet season of Amol Plain

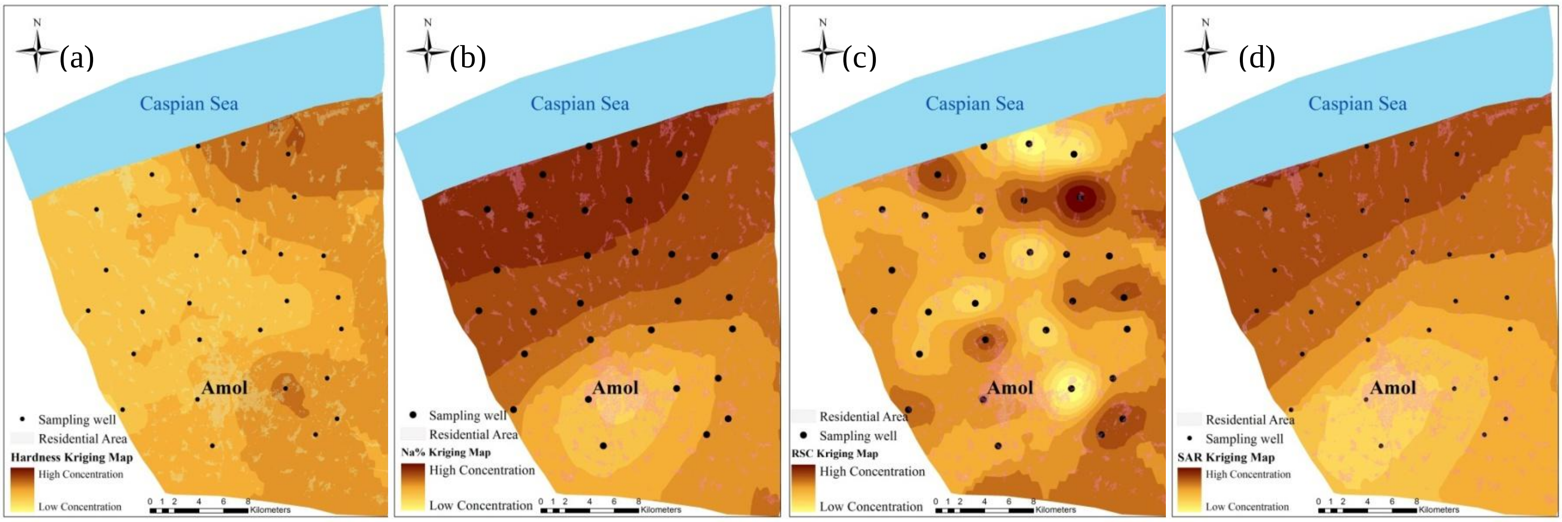

Fig. 3 spatial distribution map of, TH (a), Na % (b), RSC (c) and SAR (d) in dry season of Amol Plain

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