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Spatial Variability of Groundwater Quality and its Relationship with Pistachio Yield in Anar Region, Iran

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Abstract: This study was conducted to examine the spatial variability of some groundwater quality factors and to determine their relationship with pistachio yield in pistachio growing areas of Anar, Iran. One hundred and fifty seven water samples from the wells of the studied area were determined for electrical conductivity (EC), Na^+, Ca^{2+}, Mg^{2+}, SO_4^{2-}, HCO_3^-, Cl^-, total hardness and Sodium Adsorption Ratio (SAR). Groundwater levels of the wells were also recorded. Results showed high positive correlation among EC, Na^+, Cl^-, Mg^{2+}, Ca^{2+}, and total hardness and high negative correlation between water-table level and other variables. Most of the area had EC>8 dS m^{-1} and SAR≥13 (meq $L^{-1})^{0.5}$. Kriging maps of the variables except water-table level are highly corresponded. Water-table level had a reverse pattern in comparison with other factors. The lowest quality of groundwater was found in the eastern, southern and the northern parts of the area where its negative effects on pistachio yield have been reported. Modern irrigation techniques and saving high quality waters in order to mix them with poor quality waters in the area is necessary for sustainable pistachio production and also preventing the reduction of water-table level in the area.

Key words: Electrical conductivity, Kriging maps, sodium adsorption ratio, groundwater

INTRODUCTION

Pistachio is one of the most important exportable products in Iran. Groundwater is the main source of water for domestic, agricultural and industrial uses in this country (Hosseinifard *et al*., 2006). One of the most severe problems in arid and semi-arid regions is high concentration of salts in soils and water resources. The expansion of irrigation systems into such areas and the inefficient use of groundwater in such systems may lead to the salinization of groundwater. Consequently, water quality and its management have received much attention in developing countries.

Water quality plays an important role in the management of irrigation and leaching fraction (Fereres *et al*., 2003). A detailed investigation of the spatial distribution of the groundwater will provide an insight in the current agro-ecological conditions and future sustainability of crop productivity. Spatial variability of water properties can be used for water quality assessment, modeling source pollutants in soils, and site-specific crop management (Corwin and Lesch, 2005).

From an agricultural perspective, the principal variables to be evaluated in the classification of water quality are (a) the concentration of dissolved solids and salts, (b) the relative presence of Na^+, (c) the CO_3^{2-} and HCO_3^- content, and (d) the concentration of other specific ions, such as chloride and boron. The main problem with a high sodium concentration is its effects on chemical and physical properties of soils. It contributes directly to the total salinity and toxicity of sensitive crops and has negative effect on the structure of the soil that reduces its capacity to conduct water and air through its profile (Castellanos *et al*., 2002). This, in turn, decreases soil fertility, because in addition to affecting aeration, it also increases pH and reduces the availability of Fe and Zn. High sodium concentration also has an antagonistic competition with K uptake and causes cell injury (Grattan and Grieve, 1998).

During recent years, changes in the quality of groundwater have been reported for different areas of the world, like southeastern Spain, South Texas, and Northern Chihuahua (Castellanos *et al*., 2002). The chemical composition of groundwater is controlled by many factors that include composition of precipitation, geological structure and mineralogy of the watersheds and aquifers, and geological processes within the aquifer (Andre *et al*., 2005).

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Very little research has been conducted with the aim of assessing the chemical components of groundwater in Iran (Jalali, 2005). Anar area in the arid Kerman Province, central Iran is facing a serious deficiency in quantity and quality of groundwater resources due to an increasing demand associated with pistachio orchards development. Although pistachio as a tolerant tree has been reported (Sepaskhah *et al*., 1985; Sanden *et al*., 2006), high salinity decreases its yield significantly (Sepaskhah and Maftoun, 1988; Sanden *et al*., 2006). High salinity and clay content of the soils decrease the quantity and quality of pistachio in Anar area. Despite the importance of groundwater in pistachio orchards, no information is available about the groundwater quality and its effect on pistachio yield in this area. Also, although reduction of water-table has been occurred in the study area, no investigation was conducted about the status of groundwater in this region. The main objectives of this study were to examine the spatial variability of some groundwater quality factors and to determine their relationship with pistachio yield in order to understand better the reduction of pistachio yield in Anar orchards, Kerman Province, Iran.

MATERIALS AND METHODS

The area under investigation has a size of approximately 2100 km^2. It is located between 30° 32′ and 31° 07′ N and 54° 41′ and 54° 57′ E in Anar area, Kerman Province, central Iran. The area has an annual rainfall of 100 mm and evaporation of 3500 mm with an altitude of 1500 m above the sea level. Pistachio is the main crop in this area and the age of pistachio trees is about 30 years. One hundred and seventy five wells were randomly selected and surveyed to analyze their groundwater quality so that cover all pistachio growing areas. The wells were pumped at least 24 h before the samples were obtained. In order to avoid contamination, clean 500 mL plastic containers were used to collect the water samples from the wells. The variables included in the analysis were: Electrical Conductivity (EC) was determined by conductivity cell (Kent EIL 5003), pH was estimated with pH-meter (Corning 220), Na^+ was measured by flame photometer (Corning 410), Ca^{2+} and Mg^{2+} were determined by titration with EDTA, Cl^- determined using titration with $AgNO_3$ and SO_4^{2-} was determined by spectrophotometric turbidimetry (Rowell, 1994). All determinations were made within 48 h after collection. Sodium adsorption ratio (SAR) for the samples was calculated using the equation as suggested by Suarez (1981). The depth of water table was also measured using a tapeline with a cylinder that flaps when it touches the water surface in the well. The reported mean of pistachio yield between years 2002 to 2006 in different parts of the area was used to compare with the results. In addition, EC and SAR values of groundwater for some of wells (n = 73) in the study area separately compared with pistachio yield in the orchards (n = 146) irrigated with these wells. Yield of individual orchards was determined by weighing the whole orchard yield divided by its area and reported in kg ha^{-1}.

Table 1: Parameters of variograms for selected variables

Variables	Nugget	Sill-Nugget	Range (m)
EC (dS m^{-1})	15.80	29.20	11559
Log Na^+ (meq L^{-1})	0.03	0.07	13260
Mg^{2+} (meq L^{-1})	159.60	247.00	12580
Ca^{2+} (meq L^{-1})	145.00	182.70	7479
Cl^- (meq L^{-1})	1974.00	3192.00	10880
Log SAR (meq L^{-1})$^{0.5}$	0.02	0.03	14960
Total hardness (mg L^{-1})	1.33×10^6	2.14×10^6	9520
Log water surface (m)	0.03	0.03	8840

Descriptive and geostatistical methods were used to analyze the dataset. Log- transformation was used to normalize non-normally distributed data. Variograms calculation and modeling were done using variowin 2.2 software. Variogram is a quantitative measure of how the variance between sampled points is reduced as separation distance decrease (Mulla and McBratney, 2000).

The parameters of variograms (Table 1) were used to produce kriging maps in Surfer 8 software. Kriging is a general term describing a geostatistical approach for interpolation at un-sampled locations (Mulla and McBratney, 2000).

RESULTS AND DISCUSSION

Results suggest that EC and SAR values are two restricted factors in the area (Table 2). A reasonable critical level of EC is 8 dS m^{-1} for pistachio seedling (Sepaskhah and Maftoun, 1988; Sanden *et al*., 2006). Most of the study area had EC>8 dS m^{-1} and SAR>13 (meq L^{-1})$^{0.5}$ (Fig. 1). Chemical analysis of the groundwater shows that the mean concentration of the cations is of the order $Na^+ > Ca^{2+} > Mg^{2+}$, while that for anions is $Cl^- > SO_4^{2-} > HCO_3^-$.

High positive correlation among EC, Na^+, Cl^-, Mg^{2+}, Ca^{2+} and total hardness has been observed (Table 3). The Na-Cl relationship has often been used to identify the mechanisms for acquiring salinity and saline intrusions in semi-arid regions (Magaritz *et al*., 1981; Dixon and Chiswell, 1992). A parallel enrichment in both ions indicates dissolution of chloride salts or concentration processes by evaporation (Jalali, 2005). This can indicate that NaCl is one of the main soluble salts in groundwater of the area. XRD analysis has also shown that NaCl is the main soluble salt in saline soils of central Iran (Salehi and Rafieiolhossaini, 2004). A positive correlation has been

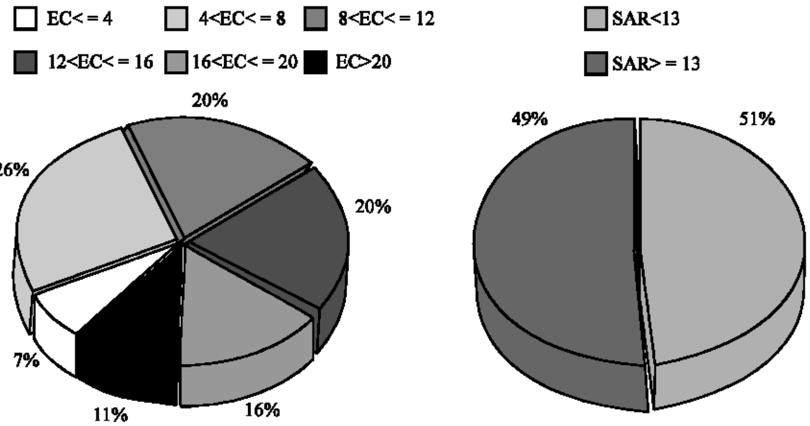

Fig. 1: The proportion of EC (dS m^{-1}) and SAR ($(meq\ L^{-1})^{0.5}$) values in groundwater

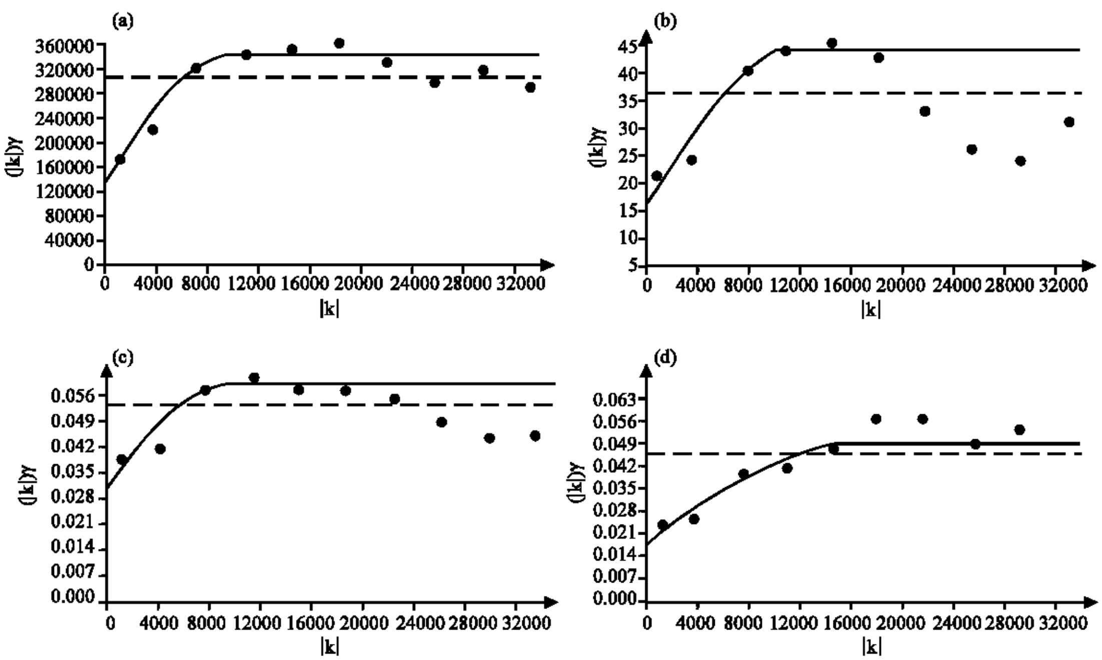

Fig. 2: Variograms of selected variables of groundwater in Anar area, (a) total hardness (mg L^{-1}), (b) EC (dS m^{-1}), (c) log water surface (m) and (d) log SAR (meq $L^{-1})^{0.5}$

Table 2: Some statistical descriptions of groundwater in Anar area

Variables	Min	Max	Mean
EC (dS m^{-1})	1.30	28.30	12.30
Na^+ (meq L^{-1})	8.50	209.00	74.20
Mg^{2+} (meq L^{-1})	1.70	72.00	29.00
Ca^{2+} (meq L^{-1})	1.50	80.00	30.00
Ca:Mg	0.23	8.50	1.30
Cl^- (meq L^{-1})	1.00	300.00	115.00
SO_4^{2-}(meq L^{-1})	1.80	72.30	14.75

reported between the pairs of ions: Cl^- and Mg^{2+} (r = 0.71), Cl^- and Na^+ (r = 0.76), HCO_3^- and Na^+ (r = 0.56), SO_4^{2-} and Mg^{2+} (r = 0.76), SO_4^{2-} and Na^+ (r = 0.69) in Hamadan region (Jalali, 2006). Considering high mobility of Cl^- in the soils, its toxicity can be occurred in plants. High sodium concentration and its negative effects on chemical and physical properties of soils and also its competition with K uptake can decrease soil fertility and in turn, pistachio yield in the area.

High water hardness and low Ca:Mg ratio are other limitations in groundwater of the area (Table 2). Waters with more than 150 ppm hardness cause a carbonate precipitate problem (Frank and Delynn, 1996). In this case, the Ca:Mg ratio should be 3 to 5. If there is more calcium than this ratio, it can block the ability of the plant to take up magnesium, causing a magnesium deficiency.

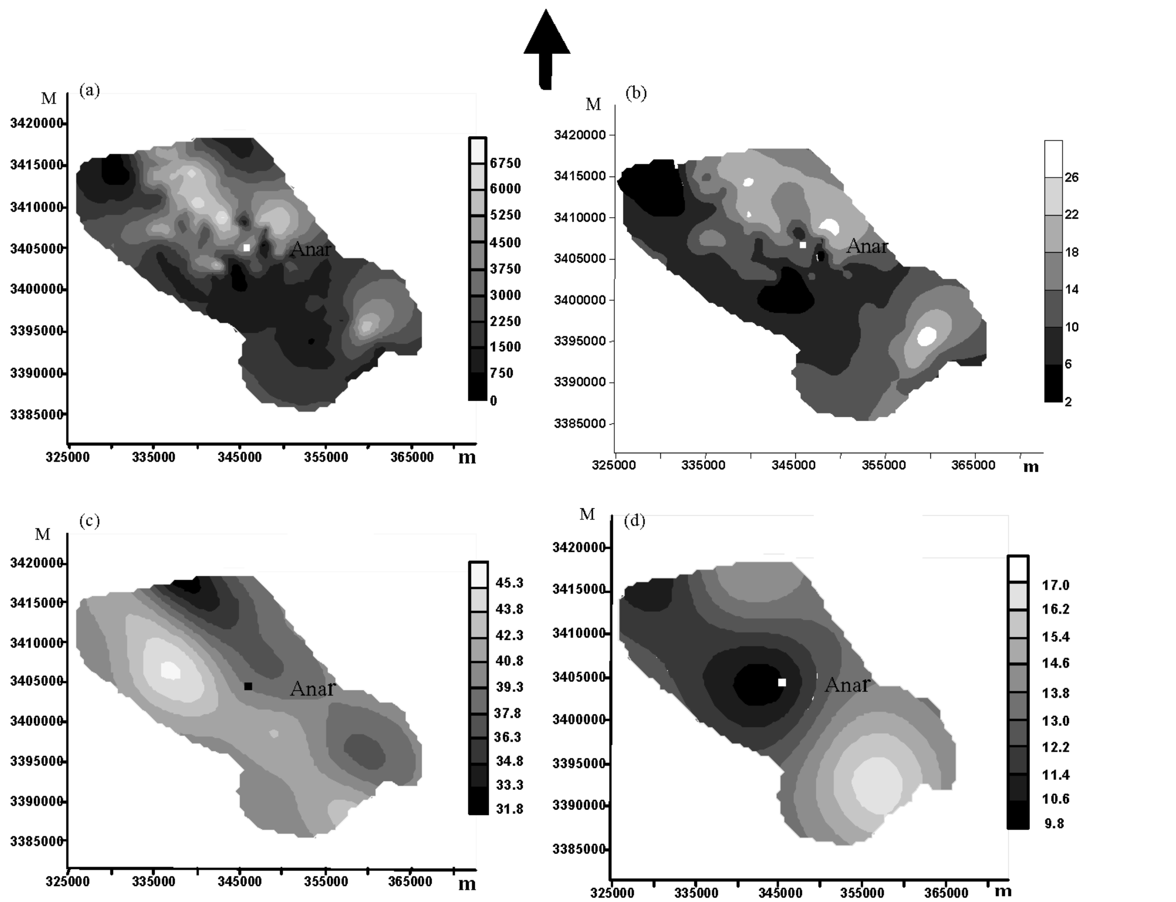

Fig. 3: Kriging maps of selected variables of groundwater in Anar area (a) total hardness (mg L^{-1}), (b) EC (dS m^{-1}), (c) water surface (m) and (d) SAR (meq $L^{-1})^{0.5}$

Table 3: Correlation coefficients of selected variables in Anar area

Variables	EC	Ca^{2+}	Mg^{2+}	Na^{+}	Cl^{-}	SAR	Total Hardness	Water Surface
EC (dS m^{-1})	1.00	0.87**	0.76**	0.90**	0.99**	0.50**	0.85**	-0.33**
Ca^{2+} (meq L^{-1})		1.00	0.83**	0.63**	0.85**	0.28**	0.95**	-0.24**
Mg^{2+} (meq L^{-1})			1.00	0.50**	0.76**	0.07	0.96**	-0.27**
Na^{+} (meq L^{-1})				1.00	0.88**	0.60**	0.58**	-0.35**
Cl^{-} (meq L^{-1})					1.00	0.48**	0.85**	-0.31**
SAR (meq $L^{-1})^{0.5}$						1.00	0.17*	-0.13
Total hardness (mg L^{-1})							1.00	-0.27**
Water surface (m)								1.00

**Correlation is significant at the 0.01 level (2-tailed). *Correlation is significant at the 0.05 level (2-tailed)

Conversely, if the ratio is less than 3, the high proportion of magnesium can block the uptake of calcium, causing a calcium deficiency (Schultheis, 2005).

Variograms of all variables were spherical and their ranges were almost equal (Fig. 2, Table 1). These ranges suggest that a sampling distance of 9 km is reasonable to study the most of the variables in the area. This can be a good indicator to decrease the samples for monitoring of these parameters in the future. Water-table level had a reverse pattern in comparison with other variables (Fig. 3).

A negative significant correlation was also observed between water-table level and other variables (Table 3). This means that groundwater in greater depths has better quality. As this area formed under alluvial deposits (Hosseinifard *et al*., 2005a), the quality of groundwater is probably related to the existence of layers with less soluble salts in greater depths. Pervious studies indicate that the bedrock geology and weathering of surface rock are the main influence on water chemistry of stream water (Jenkins *et al*., 1995). However, water extraction from greater depths in this region not only indicates the reduction of piezometric level in such area with arid conditions but also increases the water extraction costs. This is inconsistent with the case of southeastern Spain, South Texas and northern Chihuahua (Castellanos *et al*., 2002). In these cases, water is systematically extracted from ever-greater depths and such waters may be older or may have circulated through rocks containing more highly soluble minerals (Carrillo-Rivera, 2000).

Generally, the lowest quality of groundwater was found in the eastern, southern and northern parts of the area (Fig. 3) where its negative effects on long-term pistachio yield have been reported (Table 4). To better understand the relationship between EC and SAR with pistachio yield, a direct linkage between water quality and pistachio yield would need to be established. This would require pistachio yield separately be obtained for a sufficient number of wells. For this purpose, we divide the area into three different regions (Table 5). The lowest pistachio yield belongs to the southern parts with high EC and SAR values of groundwater. In contrast, the highest pistachio yield belongs to the central and western parts with lower EC and SAR values. This table shows that EC values more than 8 dS m^{-1} could noticeably decrease the pistachio yield in the area. Analysis of variance showed significant differences ($\alpha = 0.01$) for mean values of EC, SAR and pistachio yield in three different regions. Least Significant Difference (LSD) analysis ($\alpha = 0.05$) showed that region 2 (center and west) had higher yield and lower EC and SAR values than two other regions (data not shown). Therefore, although pistachio as a tolerant product to high EC values has been reported by Picchioni and Miyamota (1990), our results indicate that the increasing EC will decrease the yield of pistachio trees like pistachio seedling considerably.

Overall correlation coefficients between EC and SAR of the wells with the pistachio yield were statistically significant at the 0.01 level ($r = -0.53$ and -0.64, respectively) showing negative effects of EC and SAR on the pistachio yield. These correlations were higher ($r = -0.67$ and -0.85, for EC and SAR, respectively) and significant ($p<0.01$) in the region 3 (east and north of the area). However, despite being negative, the correlations were not significant ($p<0.15$) in two other regions, suggesting that other soil and water factors may affect pistachio yield. Hosseinifard *et al.* (2005a ,b) reported that high salinity and high clay content of soils decreased the quantity and quality of pistachio in this area. It seems that soil texture plays an important role on pistachio yield so that negative effects of high EC values of groundwater could partly decrease in soils with less clay content. However, if proper management does not consider preventing the reduction of water-table levels, complicated problems may arise in the near future. Modern irrigation techniques are a good choice to decrease water consumption. However, due to the high concentration of hardness (Table 2), some problems with usual modern irrigation techniques may arise. Results show that hardness of groundwater in all parts of the study area is more than critical level (150 ppm) as can be seen in Fig. 3. Therefore, the water quality analysis can be quite useful in identifying potential maintenance problems. On the other hand, since pistachio tree does not tolerate excess water in the root zone, over-irrigation must be avoided. Studies showed that proper irrigation especially during summer months increased productivity of the pistachio nut tree (Fereres *et al*., 2003). A proper irrigation or irrigation scheduling must be based on quantitative knowledge of tree water requirement and relationships among soil, weather and plant characteristics. While planning an irrigation scheduling, we should consider growth stages and age of the tree. Therefore, water saving techniques in order to mix high quality waters with groundwater in the area is necessary for sustainable pistachio production. Systematic studies on groundwater and study the relationship between soil and water characteristics with pistachio yield and its quality are also recommended in order to identify better management of quantity and quality of available waters.

Table 4: The mean of pistachio yield between years 2002 to 2006 in different parts of the study area

Region	Yield (kg ha^{-1})
North	1200
East	760
Center and West	2300
South	1300

Table 5: The mean of EC, SAR and pistachio yield in three separated regions according to wells and orchards

Region	No. of wells	No. of orchards	Mean of EC (dS m^{-1})	Mean of SAR (meq $L^{-1})^{0.5}$	Mean of pistachio yield (kg ha^{-1})
South	23	46	15	21	848
Center and West	29	58	8	10	1848
North and East	21	42	19	16	1128

CONCLUSION

The results show that the groundwater used for irrigation in pistachio orchards has poor quality and its negative effect on pistachio yield was observed in the area. However, modern irrigation techniques and saving high quality waters in order to mix them with available poor quality waters in the area is necessary for preventing the reduction of water table and sustainable pistachio production in the area. Preparation of soil texture and salinity maps is highly recommended in order to understand better soil variability and proper management of pistachio. The monitoring studies of soil and water can give a better insight to find a good way for solving problems in pistachio growing areas of this province.

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