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An Indirect Estimation of Soil Quality Changes Resulting from Groundwater Use in Sistan and Baluchistan

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Abstract: Soil salinity and its exacerbation resulting from water quality effects decrease product quality and cause specific ion toxicity in plants. The present study examined the Sodium Adsorption Ratio (SAR) and Sodium Soluble Percentage (SSP) indicators of groundwater resources to indirect evaluate the water quality effects on the soil of Sistan and Baluchestan, Iran. For this purpose, 655 samples were collected during 9 years from groundwater wells with agricultural land use in fixed sitesofthe province. After measuring the parameters of sodium, calcium, magnesium, potassium, chloride, sulfate, phosphate and electrical conductivity of the samples, the SAR and the SSP were determined using Microsoft Excel Software and then their distribution throughout the province was detected by GIS_{V10} Software. The results showed that the quality of 98% of groundwater resources with agricultural land use in the province based on the SSP and the SAR, respectively was dubious to unsustainable and unusable. No doubt, indiscriminate use of these water resources exacerbates soil degradation in the region, especially in the cities of Iranshahr, Saravan and Khash and will change seriously biodiversity of crop plants in these regions in the future.

Key words: Groundwater, sodium adsorption ratio, sodium soluble percentage, soil quality, salinity, Sistan and Baluchistan

INTRODUCTION

Water is the most important factor in agricultural development throughout the world. Worldwide, agriculture accounts for 70% of all water consumption (Dastorani *et al*., 2010; Pitman and Lauchli, 2002). Groundwater resources are the main sources of water supply for agriculture in arid climate regions including a

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major part of Iran (Hosseinifard and Aminiyan, 2015). According to the chemical nature of the water, this valuable substance is not found in nature in its pure form and always dissolves low to high levels of salts, suspended matters and various gases (Mehrdadi *et al*., 2009). This unique feature makes the water have different qualities in various regions based on the retention time of the aquifer, climatic conditions and type of geological formations, so that the chemical properties of natural waters can be understood as a reflection and function of mineralogy, kinetic energy of solution and flow patterns (Biglari *et al*., 2016a-e).

Pollution leakage, penetration of pollutants resulting from human industrial activities, mixing saline waters into the groundwater (Marsh and Lees, 2003) water passing through the soil saline bed, high evaporation, using agricultural fertilizers, effects of return flow and continuous irrigation expose heavily the agricultural soils to pollution from the effects of water use and exacerbate soil salinity gradually in most areas due to the transfer of salt from the water into the soil (Hur *et al*., 1985; Absalan *et al*., 2011). Currently, over 40% of irrigated lands in Iran are at risk of secondary salinization (Hur *et al*., 1985). The soil salinity can lead to undesirable effects, such as increased plant water requirement (Absalan *et al*., 2011) reduced soil hydraulic conductivity, destruction of soil pore size and arrangement, low soil moisture and fertility (Bauder and Brock, 2001) specific ion toxicity, variation of soil osmotic potential, disruption of the nutritional balance, failure to absorption of nutrients from the soil by plants, adverse effects on the enzyme activity and nucleic acid and protein synthesis in plants (Khoyerdi *et al*., 2016) reduced germination and cell development of leaves, decrease in leaf growth, effect of leaf surface salinity and total dry matter on plant relative growth as well aslow net CO_2 assimilation rate (Romheld and Kirkby, 2010; Ravikovitch and Yoles, 1971) resulting in changes in the variety of crops or product quality in the region.Palm trees grow in well-drained soils and proper ventilated soil is a key measure of growth. The palm trees are somewhat resistant to soil salinity but excessive salinity affects intensely the amount of products and its quality (Afshar, 2011). Rapid population growth, developed agriculture and providing water supplies for the region reveal the intensity of the pressure on water resources and severe water crisis in the country (Pitman and Lauchli, 2002). Excessive use of underground water resources leads to increase access to water depth, thus increasing the dissolved minerals especially sodium ions. Increased evaporation due to global warming, intensification of desertification processes and adverse effects resulting from in appropriate use of water resources especially the transmission of salt into the soil led to doubt the quality and quantity of crops, in addition to the loss of water as a precious asset (Absalan *et al*., 2011). By studying the quality of water resources, capability and utilization rate of water are determined for agricultural purposes (Klove *et al*., 2014). Chemical composition of irrigation water can be useful to predict the effects of excess salts from irrigation water affecting the chemical and physical properties of soil and plants (Suarez, 1981; Israeli *et al*., 1986). The water dissolves anions and cations by passing from soil vertical substrate, brings them to the surface of irrigated farms and causes changes in the chemical and physical properties of soil in the region and even in adjacent areas due to the horizontal movement of groundwater from one place to another (Biglari *et al*., 2016a-e). The famous agricultural indicators such as Sodium Adsorption Ratio (SAR) and Sodium Soluble Percentage (SSP) are strategies for monitoring the severity of soil salinity caused by the effects of water use (Burn e*t al*., 2015; Shaffer *et al*., 2012). Therefore, given the trace amounts of atmospheric precipitations, the inappropriate spatial and temporal distribution, hot and dry climate, dry winds of 120 day increased solute concentrations in groundwater caused by the recent drought in Sistan and Baluchestan province (Bazrafshan *et al*., 2012). The importance of maintaining or improving the quality and quantity of commercial and strategic crops of region especially palm, the current study was conducted with the aim of indirect estimation of soil quality changes resulting from groundwater use in Sistan and Baluchestan.

Study area description: Sistan and Baluchestan Province is located in the Southeast of Iran. The province is the largest in Iran with an area of 181,785 km^2, Sistan in the North and Baluchestan in the South. This region according to the geographical location of arid and semi-arid in some cities is affected by multiple atmospheric flows like the Indian subcontinent wind flows and consequently the Indian Ocean monsoon rains and high-pressure moderate latitudes. Intense heat is the most important climatic phenomena. The province has long hot summers with a maximum temperature of 50°C and short winters with a minimum temperature of approximately -7°C and every couple of years up to -18°C as well as it is classified climatically on the border between desert and semi-desert climate. The average atmospheric precipitation is between 70-130 mm/year and the average evaporation level is about 4000 mm/year (four times the average salinity). In the Southern and coastal areas of the province up to a radius of about 150 km from the Gulf of Oman, the day and night temperature varies between

10 and 25°C in Winter (Biglari *et al*., 2016). This feature combined with relative humidity of 50-95% during the year has provided enormous capacity for the production of tropical products and non-seasonal vegetables. Highlands of Sistan and Baluchestan Province belong to the second and third geological eras often with limestone and gypsum. Wheat is the dominant crop in farms as well as onions, barley, rice, vegetables and other kitchen garden plants are cultivated in some areas of the province. The major trees in the region are palm groves with an agricultural history of 2000 year old. Currently, there are 70 different species of date with cultivation areas of 49.255 ha and annual output of about 215,000 tons of products which as the second province of date producer has a clear share in preserving the rank of Iran as one of the four world's major exporter of date.

MATERIALS AND METHODS

In order to perform the present descriptive-analytical study, 655 samples over a period of 9 year since spring 2008 were collected from wells with agricultural purposes scattered throughout the Sistan and Baluchestan province from possible fixed sites (Fig. 1) with regard to regional security issues and according to the researcher's previous study and standard methods (Sajadi *et al*., 2015; Mirzabeygi *et al*., 2016). Then, the parameters including sodium, calcium, magnesium, potassium, chloride, sulfate, phosphate and electrical conductivity were determined using the method set forth in reference books. Finally, data were analyzed using the Microsoft Excel 2016 Software. The indicators of Sodium Adsorption Ratio (SAR) and Sodium Soluble Percentage (SSP) were calculated according to the following equations and their distribution was plotted at the provincial level by the GIS_{V10} Software:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}} \quad (1)$$

$$SSP = \frac{Na^{+}}{Ca^{++} + Mg^{++} + Na^{+}} \quad (2)$$

In Eq. 1 and 2, the ion concentrations of calcium, magnesium and sodium are based on meq/L. The SAR index values are interpreted as follows: <3, water resources can be used to irrigate crops without limitation; between 3 and 6, water resources must be used cautiously for sensitive products; between 6 and 9, water resources are unusable for agricultural products and lime should be added to them for stabilization if necessary and >9, water resources are highly unsustainable and harmful (Salama *et al*., 1999). The SSP index values are interpreted as follows: <20, water resources with high quality water for agricultural purposes; between 20 and 40, water

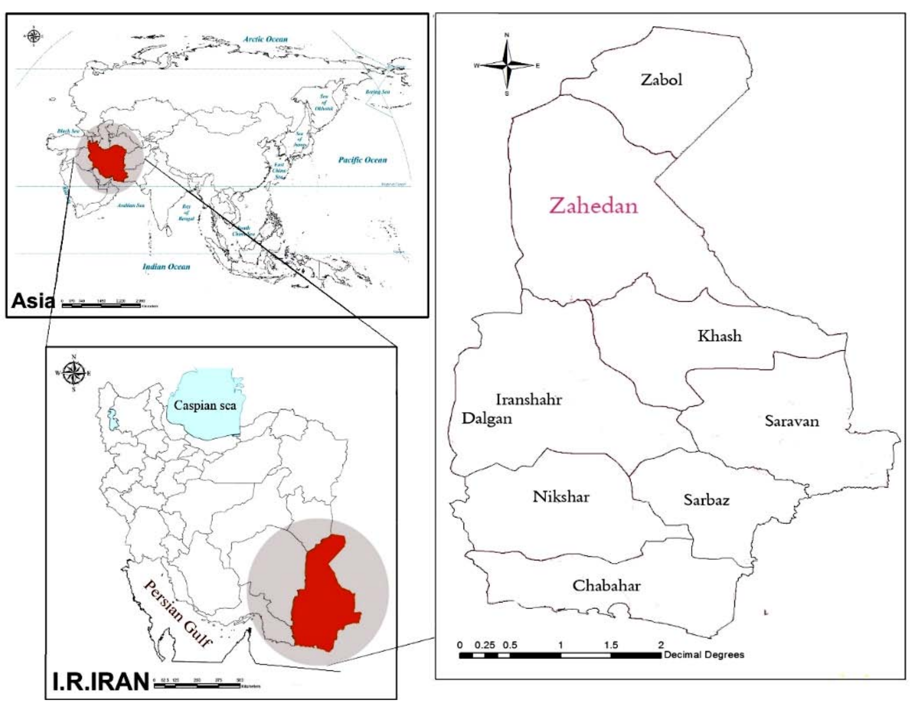

Fig. 1: Sistan and Baluchistan location

resources with good quality, between 40 and 60, water resources with acceptable quality, between 60 and 80, water resources dubious quality and >80, water resources with bad quality (Khoyerdi *et al.*, 2016).

RESULTS AND DISCUSSION

In this study, the changes in the chemical quality of groundwater resources in Sistan and Baluchestan province were monitored during 9 years. Because of the multitude of experiments and variables measured and the impossibility of presenting them all, only the main and expressible results have been shown in Fig 3-5. Figure 2 indicates the values of Sodium Adsorption Ratio (SAR) based on the mean data of the resources in each city.In accordance with the Fig. 2. The SAR values of groundwater for different cities were in various ranges, including 7.68-10.29 with an average of 8.74±0.91 in Zahedan (unusable for sensitive agricultural products and highly damaging to crops) 2.54-5.34 with an average of 4.39±1 in Khash (at the level of caution for sensitive products) 6.19-8.62 with an average of 7.12±0.87 in Konarak-Chabahar (unusable for sensitive products) 2.66-4.47 with an average of 3.21±0.58 in Sarbaz (in the border without limitation on use cautiously) 3.08-5 with an average of 3.94±0.59 in Nikshahr (usable with caution for sensitive products) 5.33 -8.87 with an average of 6.80±1.03 in Saravan (unusable for sensitive products) 3.60-6.48 with an average of 5±1 in Zabol-Zehak (usable with caution for sensitive products) 7-10.66 with an average of 8.57±1.09 in Iranshahr (unusable for sensitive crops such as beans, rice, corn, alfalfa, sunflower and onion). Since, the most index values of samples were frequently at the level of usable with caution and unsustainable so continuesuse of the water resources can change the soil texture and the resulting product will be in low quality. Certainly, the diversity of crops in the regions especially sensitive and semi-sensitive products will be altered and limited in the future.

Figure 3 shows the changes of SSP values of ground water for different cities of Sistan and Baluchestan province from 2008-2016 in various ranges including 58.22-69.43 with an average of 63.40±3.23 in Zahedan (dubious) 43.33-54.11 with an average of 49.55±4.02 in Khash (acceptable) 52.78-62.76 with an average of 57.61±3.28 in Konarak-Chabahar (on the border between acceptable and dubious) 40.18-49.89 with an average of 45.54±2.75 in Sarbaz (acceptable) 47.11-57.15 with an average of 53.26±3.53 in Nikshahr (acceptable) 57.22 to 68.55 with an average of 62.55±3.93 in Saravan (dubious) 47.30-63.20 with an average of 55.34±6.26 in Zabol-Zehak (on the border between acceptable and dubious) and 62.81-73.82 with an average of 68.73±3.44 in Iranshahr (dubious).

Figure 4 indicate distribution of concentration of anions including sulfate, chloride, phosphate and bicarbonate and cations of sodium, magnesium, calcium and potassium obtained from the average 9 years point to pointdata in the sampling sites. The highest concentrations of cations and anions (ppm) in the resources of groundwater (Fig. 4) were related to calcium (22.40 and 40.40, respectively) in Zahedan and Saravan, potassium (34) in Dalgan county in Iranshahr, chloride (1231) in Zahedan, bicarbonate (719) in Karvandar rural district in Khash, magnesium (122 and 136, respectively) in Zahedan and Chabahar, phosphate (between 0.148 and 1.48) in northern counties of Khash, Saravan, Iranshahr and Zahedan as well as southern counties of Zabol, sulfate (1458) in Zahedan and sodium (1139) in Zahan. The electrical conductivity was 6517 $\mu S\ cm^{-1}$.

Figure 5a shows the distribution of SSP index and Fig. 5b specifies the distribution of SAR index in the areas of Sistan and Baluchestan Province that were plotted based on the average 9 years point to point data. Evaluation of Fig. 5a and b demonstrated that the major groundwater resources of Sistan and Baluchestan Province are in the range of very unsustainable and damaging quality. In addition, we can say that in near future, the soil texture and subsequent agricultural capacity will alter in the regions as well as 98% of the groundwater resources in the province has potential negative changes and exacerbation. Figure 5 also revealed that groundwater resources in the northern region of the province (Sistan) are at the acceptable level of SSP for agricultural purposes and at the usable with caution level of SAR for sensitive products. Some studies have reported that the soil surface features partly in all parts of Sistan can be seen as salty and joint (Fig. 2) and varied based on intermittent layers of soft and light sand and clay soil mixed with uneven sandin depth (Afrakhteh, 2006). Therefore, it is expected that flowing water is initially very salty and the degree of salinity decreases slightly by passing through the lower substrate layers of soil according to the process of replacement and filtration. This is clearly visible in the index values obtained (Fig. 5).

As can be seen in Fig. 5 and 6 the SAR and the SSP of groundwater resources in areas of Hamoun Lake (Sistan) have changed toward the areas of Baluchestan, respectively, from the usable with caution level to unusable and unsustainable levels and from the acceptable level to the dubious level. This seems to be related to the fact that the soil texture is heavy and hard around the Hamoun Lake and that hard and heavy soil becomes soft away from the lake (Afshar, 2011). Poor

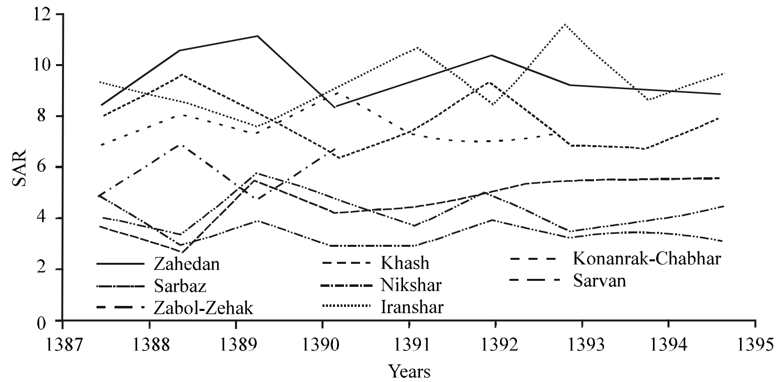

Fig. 2: The statue of SAR index in Sistan and Baluchistan during different years

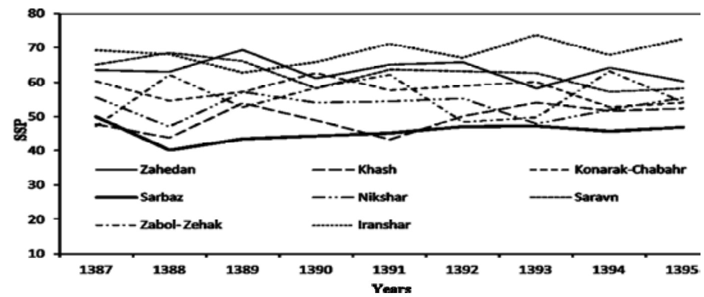

Fig. 3: The statue of SSP index in Sistan and Baluchistan during different years

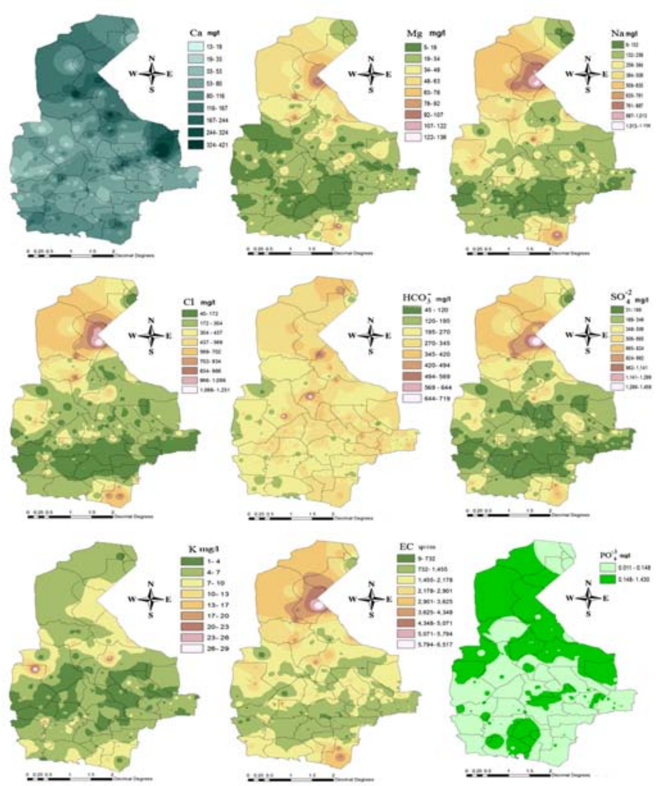

Fig. 4: The scatter of anions and cations in Sistan and Baluchistan ground water resources

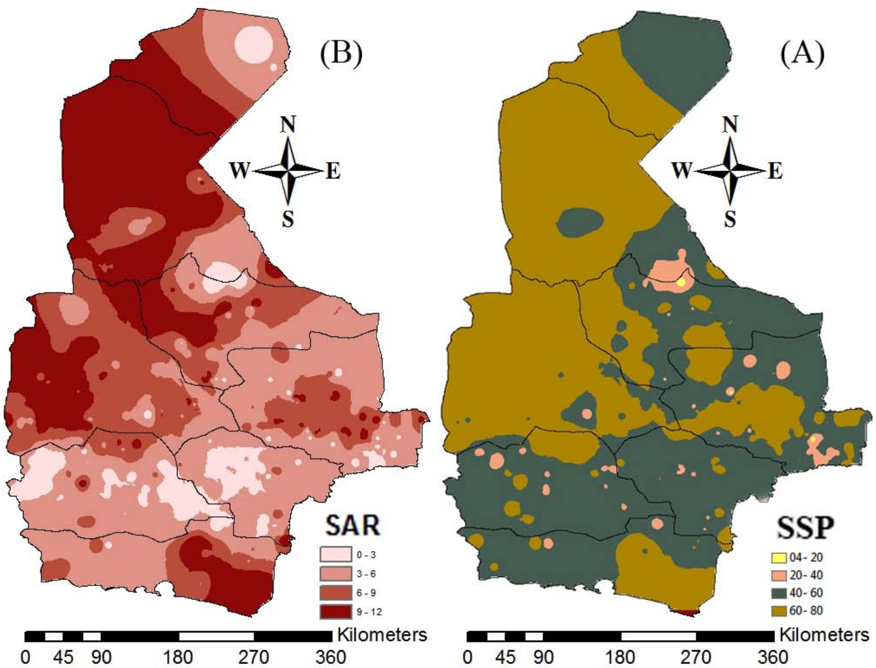

Fig. 5: a) The Scatter of SSP index and b) the scatter of SAR index

groundwater quality in parts of the cities of Iranshahr, Chabahar, Saravan and Sarbaz according to the context of fine alluvial soil and a dense layer of organic matter on the surface (Fig. 2) suggest transitional flow of groundwater from the other area or high-salt bedrock in the lower layers. According to the results of the two SAR and SSP indexes, the continuous use of groundwater resources in these areas for irrigation of farm fields seems to accelerate the deterioration of soil texture in the region, in addition to the effects of wind erosion and high temperature, thereby reducing current soil fertility capacity covering major agricultural industry in the province (Afshar, 2011). In some desert areas, especially in Zahedan, Khash and Saravan, the structure of surface soils and even lower layers is as desert and sierozem with high salinity. In addition to the poor quality of the soil in these regions, the groundwater quality in these areas focuses on the prohibition on the use. Some previous studies reported that the soils in most areas of Sistan and Baluchestan province are rich in potassium and variable in nitrogen so that the concentration of potassium (potash) in most parts of the territory is more than enough about 900-1210 kg ha^{-1} (Afshar, 2011). Figure 5 shows the average concentration of potassium ions in groundwater resources with maximum concentration of 29 ppm in Dalgan county. The potassiumions partially reduce the impact of soil salinity but due to the low concentration of these ions in water, it cannot be compared with quality effects of mean sodium concentration of 9 years (at least 30 ppm) on soil (Khoyerdi *et al*., 2016). Several studies suggest that the passive absorption of potassium is reduced due to the high concentration of sodium in saline soils and its dominant competition with potassium ions (Romheld and Kirkby, 2010; Malash *et al*., 2008). Because salinity of irrigation water leads to increased accumulation of salt in soil, thus proper irrigation management and implementation of leaching can reduce the soil salinity during the cropping season (Boyd and Tucker, 1992; Mohammadi *et al*., 2015; Moradi *et al*., 2016; Sajjadi *et al*., 2016). Considering that the quality of groundwater resources used in irrigation is close to become inappropriate, unsustainable and highly damaging, so dealing with issues surrounding the economy obtained from agriculture or eternal destruction of soil texture is important and urgent in the study regions.

CONCLUSION

In this study, the two Sodium Adsorption Ratio (SAR) and Sodium Soluble Percentage (SSP) indicators were investigated in the groundwater resources of Sistan and Baluchestan province, Iran. The results showed that 98% of groundwater resources of Sistan and Baluchestan province are dubious and unusable for irrigation purposes based on SSP and SAR, respectively. Since, poor organic matters, insufficient soil quality, inadequate precipitations and sometimes floods are obvious characteristics of Sistan and Baluchestan province, so irrigation with the current groundwater resources seems to be nothing except lack of agricultural extension, degradation of soil texture and consequently the changes in the type of products and reducing their quality. Certainly in the near future due to changes in soil quality, biodiversity of crop plants will be altered in Sistan and Baluchestan province, especially in the cities of Iranshahr, Saravan and Khash.

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