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Effect of Drought on Qualitative and Quantitative Parameters of Zahedan Plain Aquifer

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ABSTRACT The effect of drought indices on hydrostatic variations and qualitative parameters of the Zahedan Plain's aquifer was investigated. For this purpose, 12-year statistics from observational and piezometry wells in the plain, the drought index of percentage normal (PN), standardized precipitation index (SPI), and 30-year precipitation statistics of Zahedan station were used. Results revealed that the PN index had a greater variety than SPI. The aquifer hydrograph showed a rise of 1.37 m in water level from the year 2002-2003 to 2013-2014. Considering the drought conditions in the plain, this rise in the water level can be attributed to the reduced water extraction from the aquifer, because the water requirement of Zahedan city was supplied from other sources, viz. Chah-nimehs. Also, there was a significant correlation between the parameters of anion, TDS, and Na^+ with SPI. However, PN index did not have any significant relationship with the quality parameters. There was a significant correlation between water level balance and SPI only at the level of 1%.

Key words: *Acquirer's unit hydrograph, Drought indices, Ground water quality, Zahedan plain*

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1 INTRODUCTION

Evaluation of ground water resources and their stability in arid and semi- arid regions are of great importance, as they are usually the sole water supplying source for drinking and agricultural purposes (Nosrati and Eeckhaut, 2011). Precipitation permeates into soil and upon reaching impermeable layers, it develops ground water reserves. In recent years, drought has resulted in a considerable decrease in surface waters, while use of ground waters has increased, which has led to both dramatic decrease in the level of ground water acquirers and changes in their quality (Afzali and Shahedi, 2014).

Despite the fact that ground water resources are exploited in different areas, a strong relationshipbetweenthe indicator SPI and ground water levels exist in many cases, which wasused to relate the efficiency of ground water levels in Australia with its major drought pattern (Khan *et al.* 2008). Ahmadvash *et al.* (2013) examined the effects of recent droughts on ground water resources in Azarshahr Plain. Theyfound increase in ground water level by 0.59 m from June 2002 to June 2010, and

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Also increased electrical conductivity, chloride and sodium concentrations due to the intrusion of the salty water from Urmia Lake. Watmough and Juckers (2014) examined the effects of simulated drought and found the level of aquifer decreased, but the effective water chemical factors increased. In general, the majority of studies reveal a descending ground water hydrostatic level and effective qualitative factors in the long term drought. Najafzadeh *et al.* (2015) found that the water level and quality factors of theground waterhad dropped in much of the Mah-Velayat Plain as the result of drought. Application of standardized precipitation index (SPI) in Kashan (Aleboali *et al.*, 2016) and Shahre-Babak plains (Jahanshahi *et al.*, 2016) showed a significant relationship between the ground water level and drought.

The experience of drought in recent years in Sistan-Baluchistanand the importance of the ground water resources in this province highlight the significance of examination of drought in this region. In this research, theSPI indexwas used to assess the impact of droughtonthe ground water level and qualitative parameters in Zahedan Plain aquifer.

The findings of this research can help planners and managers in making decisions in line with variations in climatic elements.

2 MATERIALS AND METHODS

2.1 Study region

Zahedan Plain is situated in Sistan-Baluchistan Province (60˚ 39' -60˚ 56’ E and 29˚23' - 29˚ 35' N). Considering the distribution of wells, one major aquifer with an area around 210 km^2 in alluvial sediments was considered for this study (Figure 1). The average height of mountain and plain this region is 1686 and 1454 meters, respectively. The direction of the ground water in the aquifer is from west to east and in the southern region is northwards, eventually leaving the aquifer from the northeast (Regional Water Bureau, 2011).

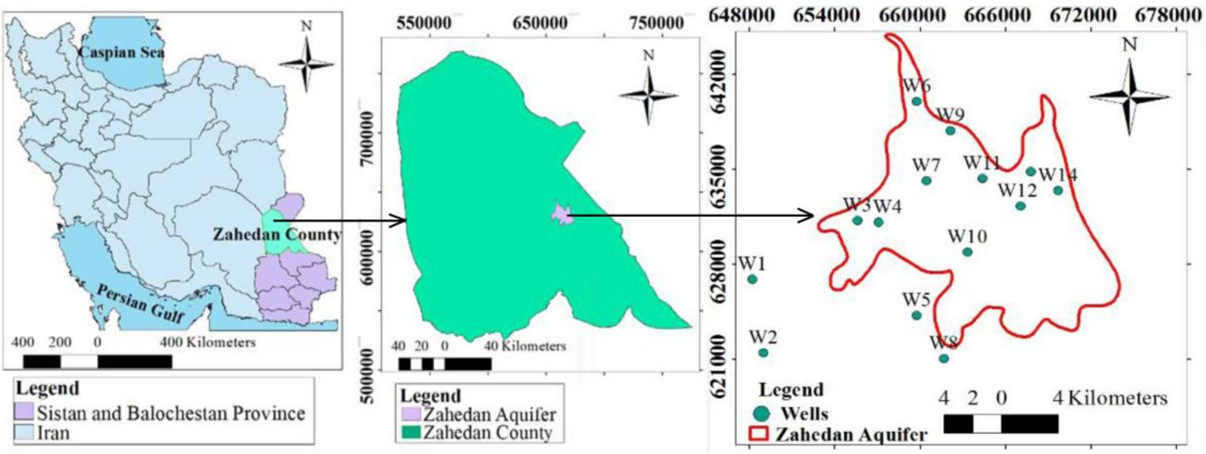

Figure 1 Location of the study area in Sistan-Baluchestan Province (top) and distribution of wells (bottom)

2.2 Index of Percentage of Normal Precipitation (PN)

Being always positive and limited to zero from the bottom, PN index is has no theoretical limitation from the top. Its main concept is division of real precipitation by normal precipitation. It is calculated this index, Equation (1), has been used (Nahvinia *et al.*, 2008).

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$$PN = (\frac{P}{P0}) \times 100 \qquad (1)$$

Where P is monthly precipitation or the period of interest (mm), P_0 the average long-term precipitation during this statistical period. Considering the different values of PN, various drought intensities are recognizable (Table 1).

Table 1 Classification of drought intensities

Drought Classification	Value
Normal	80-120
Slight drought	70-80
Moderate drought	55-70
Severe drought	40-55
Extreme drought	Less than 40%

2.3 Standardized precipitation index (SPI)

In this method, the duration of drought period is determined by the beginning and termination of negative figures of SPI, with the cumulative values of SPI representing the magnitude and intensity of drought period (McKee *et al.*, 1993). To calculate this method, Equation (2) is used.

$$SPI = \frac{(P - P0)}{SD} \qquad (2)$$

Where SPI is standardized precipitation index, P monthly or annual precipitation (mm), P_0 the average monthly or annual precipitation (mm), SD standard deviation within the period of interest. Following the calculation of the SPI for each period, using Table 2, the years in which drought has occurred in the region were determined (McKee *et al.*, 1993).

Table 2 Values of classified standardized precipitation index (McKee *et al.*, 1993)

Drought Classification	Value
Extremely wet	+2
Very wet	1/5 up to1/99
Moderately wet	1 up to1/49
Near normal	-0/99 up to 0/99
Moderately dry	-1/49 up to-1
Severely dry	-1/99 up to -1/5
Extremely dry	Less than -2

2.4 Plotting unit hydrograph of the aquifer

The unit hydrograph on the level of the balance of ground waters was plotted in order to observe the trend of changes in the ground water level of the region over time. After organizing the statistics, first to generalize the measured values to the region's level, Theissen function was used in the Arc Map 9.3 software. Next, the aquifer's water balance hydrograph was plotted in Excel with the aim of achieving an overview of the trend of changes in the ground water level. The aquifer unit hydrograph was obtained by Equation (3) (Akbari*et al.*, 2009).

$$h_p(y,m) = \lambda_1 * h_{w1}(y,m) + \lambda_2 * h_{w2}(y,m) + \\ ... + \lambda_n * \mathrm{h}_{\mathrm{wn}}(y,m) \qquad (3)$$

Where hp (y,m) is the aquifer balance in the year y and month m. λ_1 ،λ_2 ،... ،λ_n the weight of observational wells of w_1, w_2,...,w_n. h_{w1} (y,m) the balance of observational well of w1 in the year y and month m. h_{wn} (y,m) the balance of observational well of w_n in the year y and month m.

2.5 Qualitative zoning of the aquifer

Geographical location and water qualitative data for each well were fed to GS^+ software to determine suitable semivariogram. The results were transferred to the ArcGIS 9.3 software, whereby based on Kriging method, the zoning maps of the qualitative status of ground water in the plain of interest were prepared (Ahmed, 2002; Arsalan, 2012; Taghizadeh Mehrjerdi, 2008).

In selecting the best model of fitted semivariogram, the indices should reach their optimal value. Greater value of R^2 and the lower value of residual sum of squares (RSS) represent the greater accuracy of the fitted model (Jahanshahi *et al.*, 2014; Sarhadi, 2015).

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2.6 Water quality in terms of agriculture

Wilcox diagram, based on electrical conductivity and sodium absorption rate, was used for this purpose (Wilcox, 1955), in which the sodium absorption rate is calculated by Equation (4).

$$SAR = \frac{Na}{\sqrt{\frac{Ca+Mg}{2}}} \quad (4)$$

Where Na, Ca and Mg denote the amounts of sodium, calcium, and magnesium ions, respectively, in terms of m Eq l^{-1} in the water sample.

2.7 Water quality in terms of drinking

The Schoeller diagram was used for this purpose (Schoeller, 1962), in which only typical anions and cations along with mineral properties of water are considered.

2.8 Determining the type of water

The type of ground water was determined using Piper's diagram (Goovaerts, 1997), in which water is classified according to its cation (viz., calcic, sodic, etc.) and anion constituents (viz., bicarbonated, sulfated, etc.).

3 RESULTS

3.1 Standardized precipitation index (SPI)

The results indicated that the region tolerated very dry conditions in 2002 and 2003, except for Mar. and in 2004 except for the months of Jan., Feb. and Mar. The conditions were relatively normal and no sign of drought was observed in 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, and 2013. Moreover, in Mar. 2005, 2007, and 2010, the conditions were mild and humid.

3.2 Percent of normal index (PN)

A weak precipitation occurred in Jan. 2003, Apr. 2005, Mar. 2009, and Nov. 2010. A moderate drought happened in Feb. 2005, Jan. 2005, 2006, and 2008, Dec. 2007, and Nov. 2013. Moreover, severe droughts occurred in Apr. 2003, Jan. 2002 and 2012, and Feb. 2003 and 2008. In the other month of the year, incidents of extremely severe droughts were observed.

3.3 Changes in the hydrostatic level of Zahedan plain's aquifer

The unit hydrographs of the plain indicated increased level of the ground water by 1.37 m. within 12 years of the investigated period (Figure 2).

3.4 Quantitative parameters of ground water

Using the GS^+ software, the conventional Kriging method was chosen for the estimation of 14 quantitative parameters in 2002-2003 and 2012-2013.

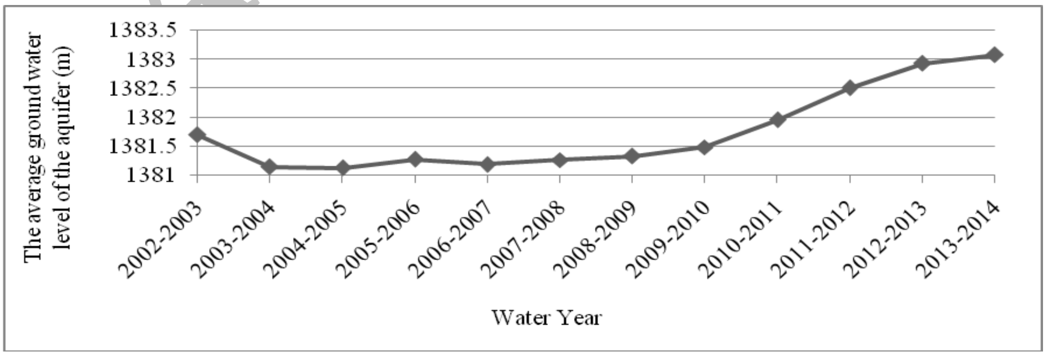

Figure 2 Unit hydrograph of the Zahedan aquifer in the period 2002-2014

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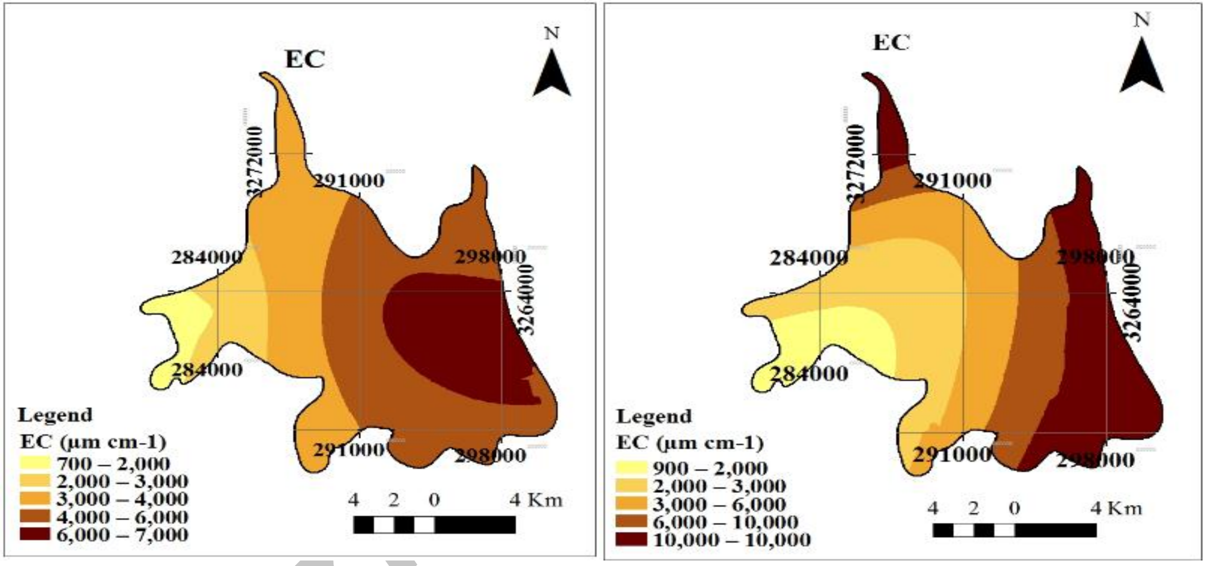
The Gaussian model for parameters of K^+, SO_4^{2-}, SAR, and the sum of cations in both periods was chosen as the best model for evaluation, while the spherical model for parameters of Na^+, Mg^{2+}, Ca^{2+}, Cl^-, and TDS was recognized as the best model. For the parameters of HCO_3^-, pH, and EC and the sum of anions in 2002-2003 the spherical model and in 2012-2013 the Gaussian model provided higher estimation accuracy.

3.5 Zoning of the chemical parameters of ground water quality

Considering the large number of maps prepared for different years, the first period (2002-2003) was chosen as the sample of dry year, while the second period (2012-2013) was selected as the normal year sample for presenting zoning maps.

3.5.1 Electrical conductivity (EC)

Figure 3 demonstrates zoning maps of electrical conductivity for the periods of 2002-2003 and 2012-2013. EC in 2012-2013 had increased in the northeast, eastern, and southeastern parts of the aquifer.



Water year 2002-2003

Water year 2012-2013

Figure 3 Changes in EC of the Zahedan aquifer in the dry and normal periods

3.5.2 Total dissolved solids (TDS)

Comparing the two maps, TDSlevels had increased in the northern, northeastern, and eastern parts of the aquifer during the period2012-2013 (Figure 4).

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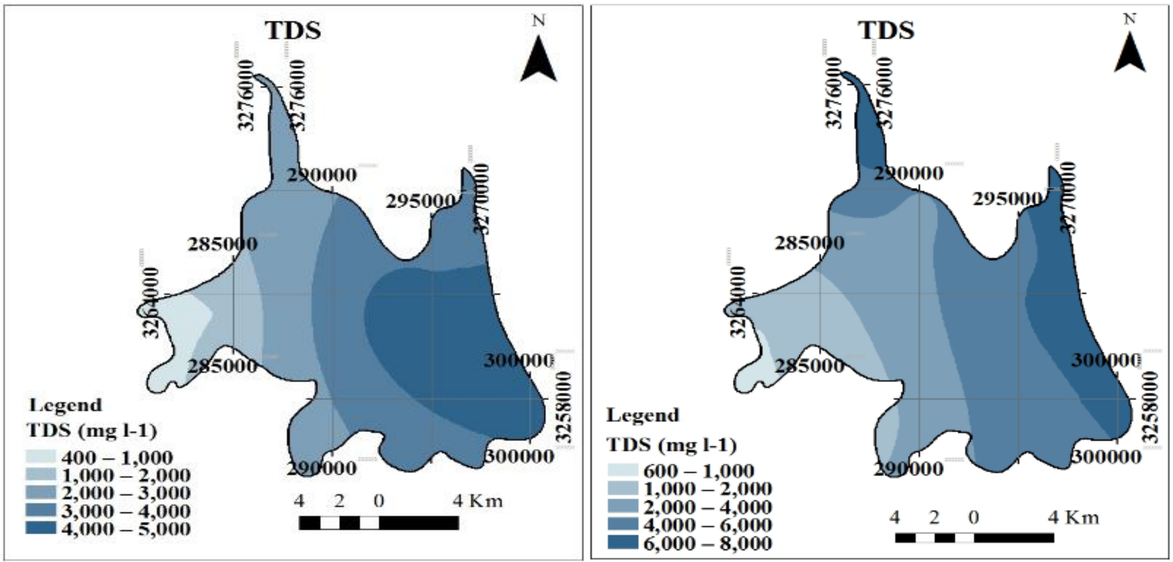

Water year 2002-2003 Water year 2012-2013

Figure 4 Changes in total dissolved solids of the Zahedan aquifer in the dry and normal periods

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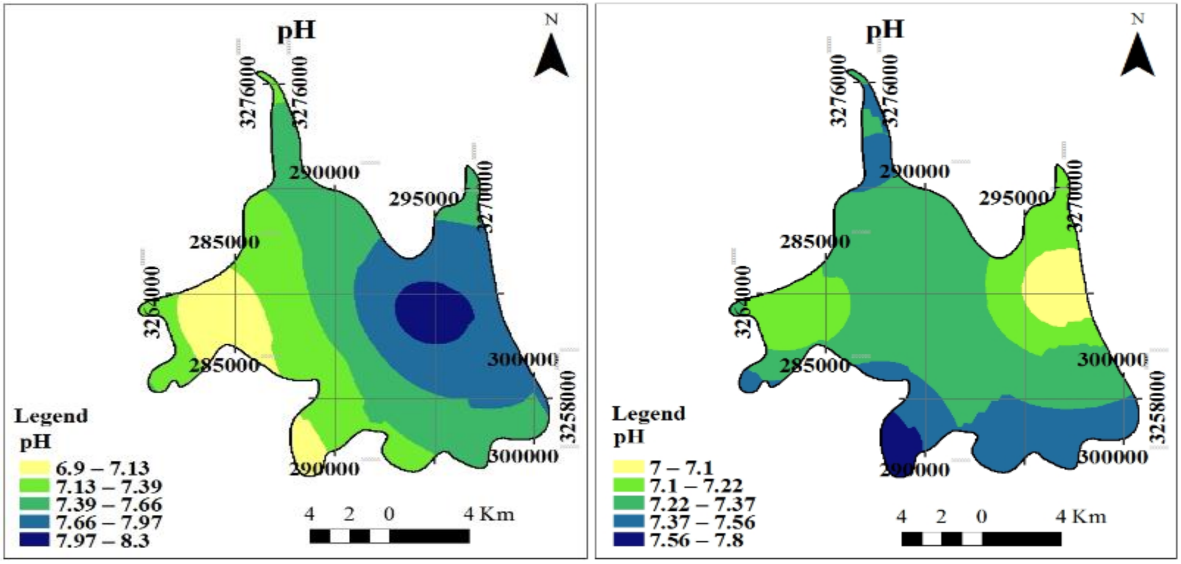
3.5.3 Acidity (pH)

The ground water pH had become more alkaline during the period 2002-2003 in the central and southern parts of the Zahedan Plain's aquifer (Figure 5).



Water Year 2002-2003 Water Year 2012-2013

Figure 5 Changes in acidity of the Zahedan aquifer in the dry and normalperiods

3.5.4 The sum of actions

The sum of cations in the normal period (1391-1392) had increased in the northeastern, western, and southern parts of the aquifer (Figure 6).

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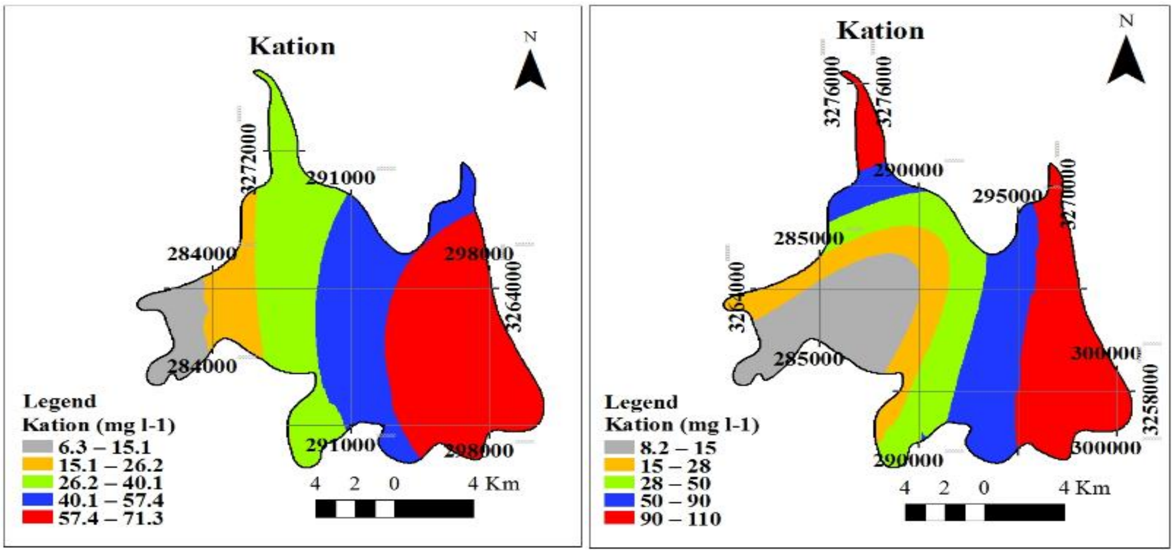
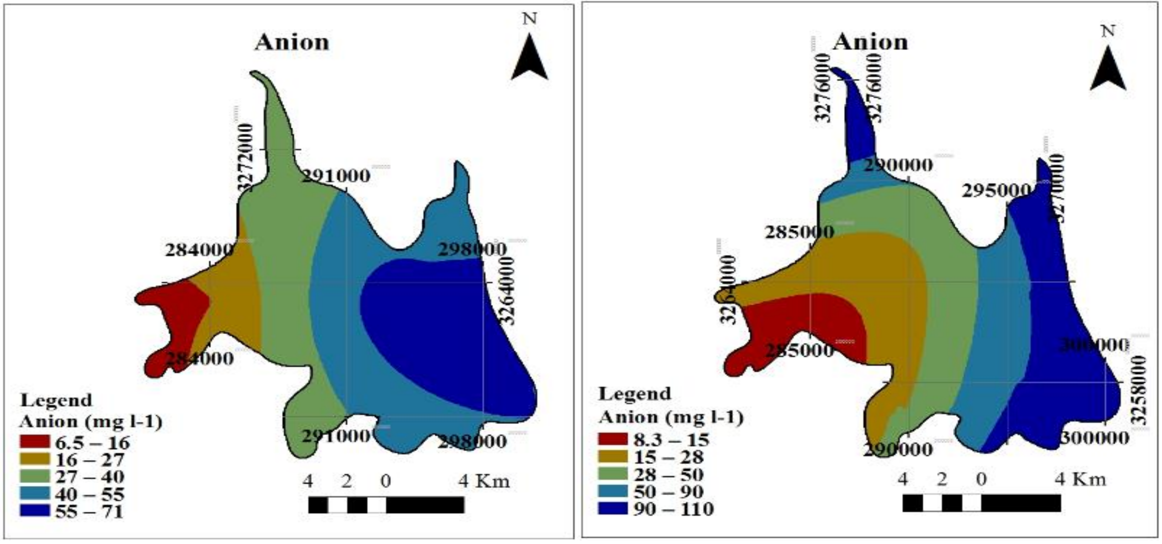


Water Year 2002-2003 Water Year 2012-2013

Figure 6 Changes in total cations of the Zahedan aquifer in the dry and normalperiods

3.5.5 The sum of anions

Thesum of anions in the normal period (1391-1392) had increased in the northern, eastern, and the southern parts of the aquifer, while it had declined in the northeastern, western, southern, and central parts (Figure 6).



Water Year 2002-2003 Water Year 2012-2013

Figure 7 Changes in total anions of the Zahedan aquifer in the dry and normalperiods

3.6 Classification of groundwater for consumption

3.6.1 Water quality in terms of drinking

Using Schoeller diagram, all the wells were chemically classified for drinking within both normal and dry periods (Figures 8 and 9), which showed that the quality of potable water in Zahedan Plain hadnot changed significantly within the dry and normal periods, thus suitable for drinking.

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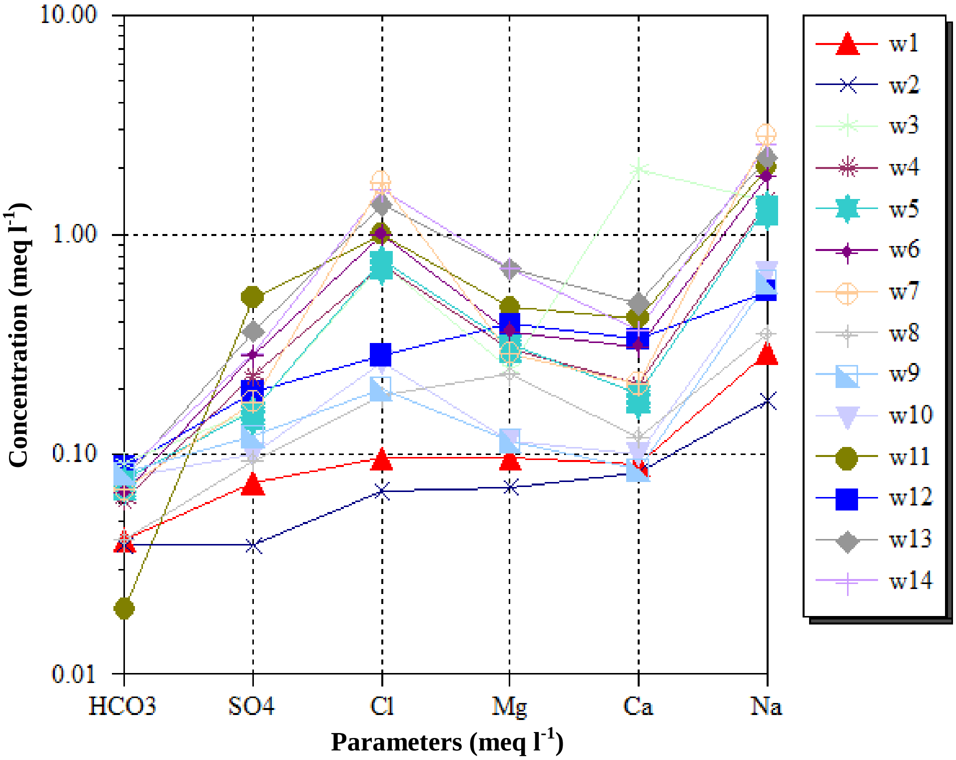

Figure 8 Classification of the Zahedan plain wells for drinking in the dry period

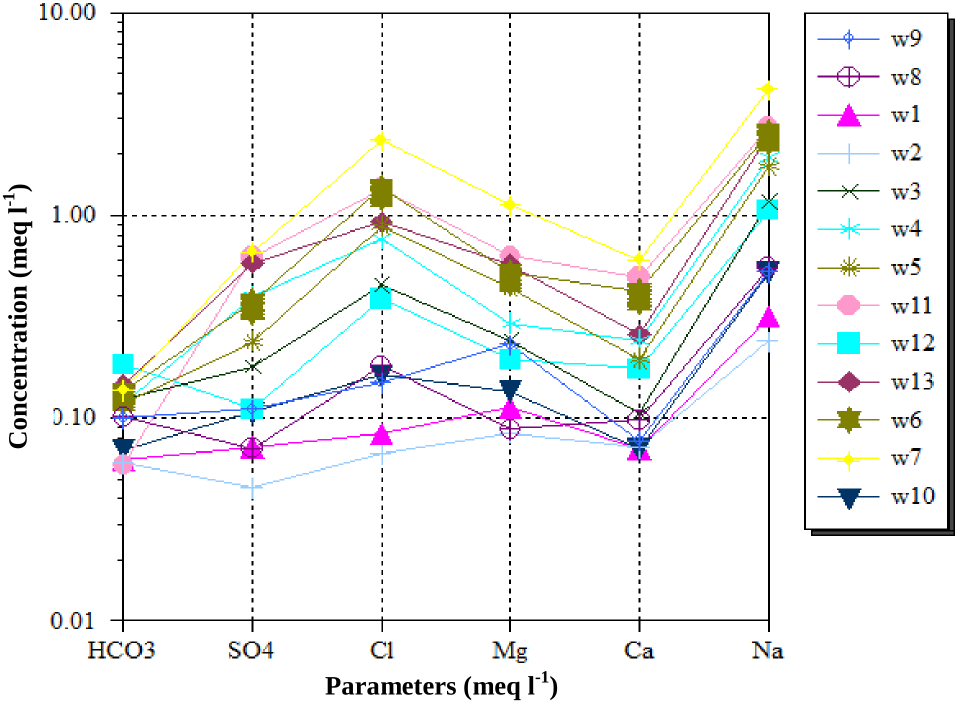

Figure 9 Classification of the Zahedan plain wells for drinking in the normal period

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3.6.2 Quality in Terms of Agriculture

Wilcox classification for agricultural use indicated that the ground water quality of the Zahedan Plain within the dry and normal periods varied between the limits of C_3S_1 and C_4S_1 (Figures 10 and 11). This suggests that drought had not had significantlyaffected the quality of the water for agricultural purposes.

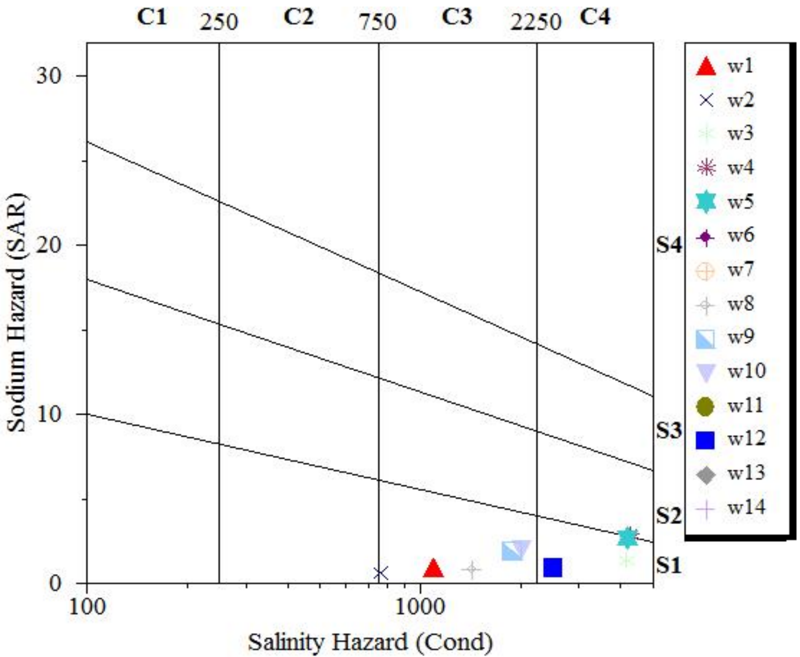

Figure 10 Classification of the Zahedan plain wells in the dry period for agricultural use

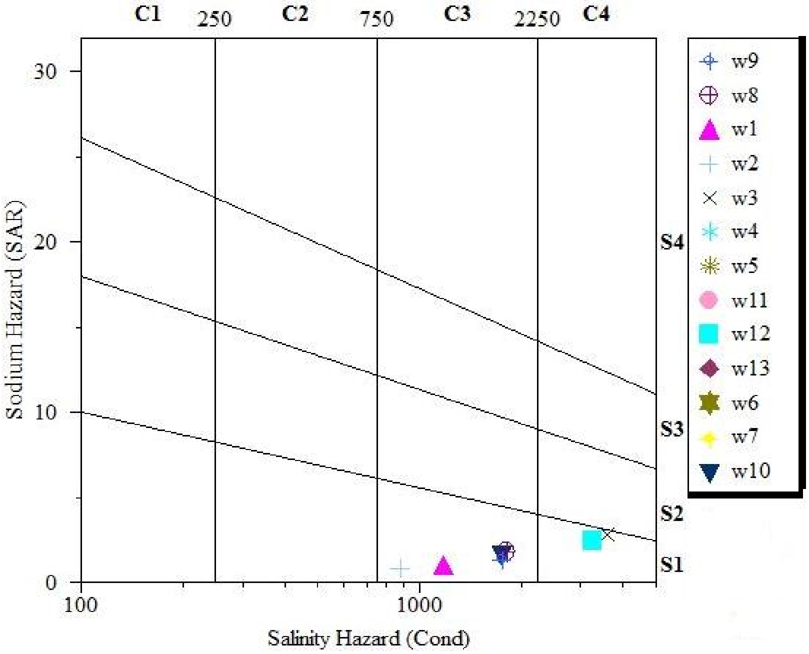

Figure 11 Classification of the Zahedan plain wells in the normal period for agricultural use

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3.6.3 The Piper Diagram

Based on the Piper Diagram, the ground waters of the Zahedan Plain within the dry period had three types of sodic chlorine, calcic chlorine, and sodic sulfate (Figure 12), while two types of sodic chlorine and sodic bicarbonate were recognized within the normal period (Figure 13).

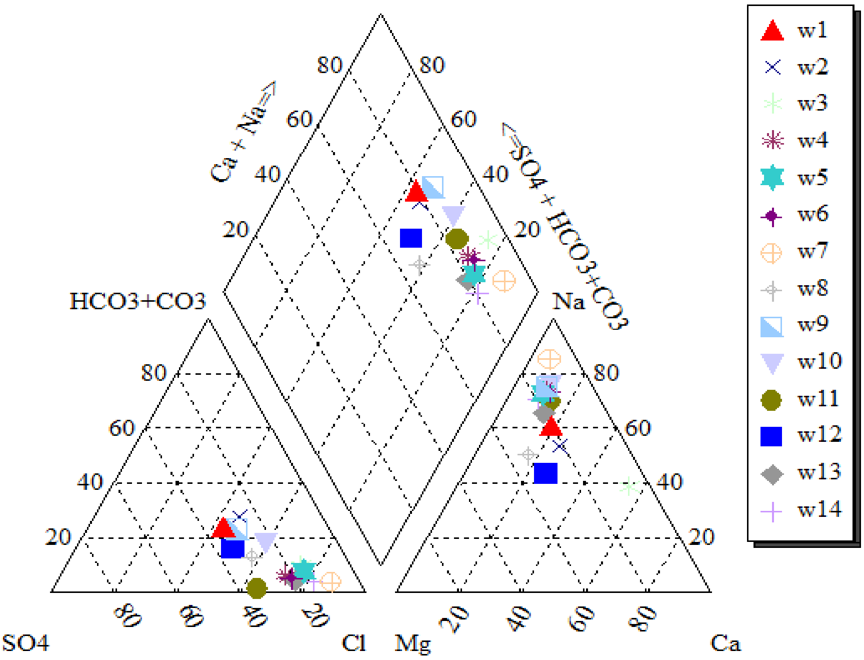

Figure12 Piper diagram of theZahedan plain wells in the dry period

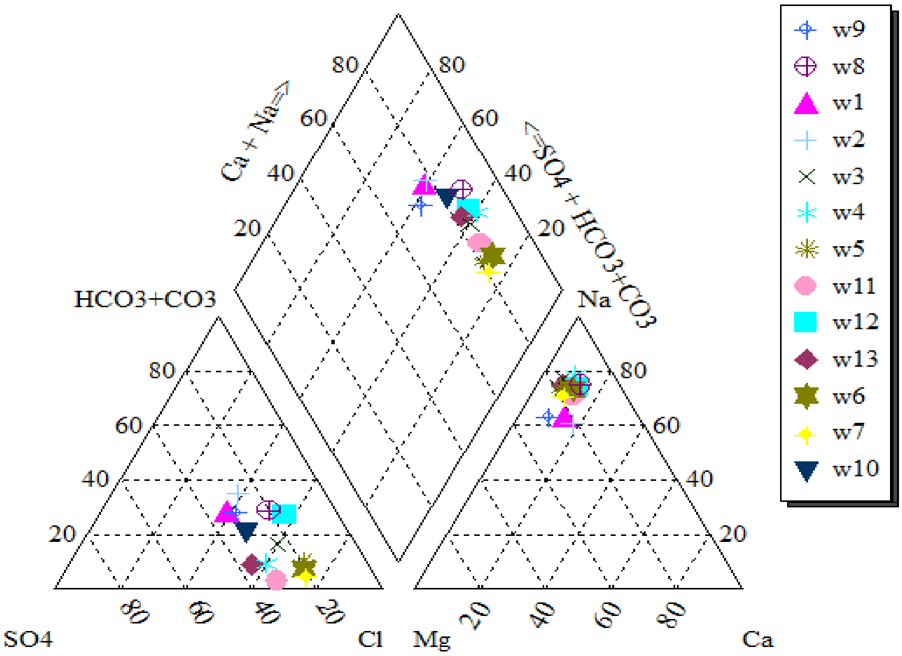

Figure 13 Piper diagram of the Zahedan plain wells in the normal period

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3.7 Correlation between the quality parameters and the balance of ground water levelwith drought indices

Table 3 lists the correlationbetween the water quality parameters and drought indices of SPI and PN. A significant correlationbetween the sum of anions and TDS with SPI was observed at 5% level. There was also a significant correlationbetween Na^+ and SPI at 1% level. However, there was no significant correlationbetween the quality parameters and PN. A significant correlationat 1% level between the water balance and only SPI at the level of 1% was found.

Table 3 Correlations between quality and ground water level in Zahedan plain with drought indices SPI and PN

		EC	TDS	pH	CL^-	Ca^{2+}	Mg^{2+}	K^+	Na^{2+}	Cation	SO_4^{2-}	HCO_3^-	Anion	ground water level (m)
SPI 24	Pearson Correlation	.421	.637*	-.143	.451	.501	.574	.412	.741**	.599	.453	.144	.637*	-.869**
	Sig. (2-tailed)	.197	.035	.674	.164	.117	.065	.208	.009	.051	.162	.672	.035	.001
PN	Pearson Correlation	-.119	-.006	.122	-.268	.141	.192	-.217	-.210	-.126	-.087	.322	-.155	-.043
	Sig. (2-tailed)	.727	.987	.720	.425	.679	.572	.521	.536	.711	.800	.334	.649	.901

****** The parameters significantly correlated with the level of 1%

4 DISCUSSION AND CONCLUSION

In many studies, only SPI has been used for investigation of ground water, but in this research the effect of PN index on theground water resources was also taken into consideration along with SPI. The results of the drought index of PN indicated that this index provided a greater variety than SPI. However, for drought studies and its impact on the ground water resources, it does not have the necessary efficiency. The results of the ground water level and unit hydrograph of the aquifer indicateda 1.37 m elevation in the phreatic zone in Zahedan aquifer from the periods of 2002-2003 to 2013-2014 (Fig. 2), which is in contrast with studies in otherregions (e.g. Watmough and Juckers, 2014; Najafzadeh *et al*., 2015). Considering the drought conditions, this increase in the ground water level is because that the water requirements of citizensin Zahedan city (over 600 thousand people requiring water about 25 million cubic meters in the year) has been supplied fromanother source called Chah-Nimehs (fed by the Hirmand River), whichin turn decreased exploitation of water from the wells across the aquifer. Moreover, lack of waste water collection system in Zahedan City andseepageof the disposed water throughthe plain's aquiferhas alsocontributed to increased level of the ground water (Sarhadi, 2015; Regional Water Company, 2011). Currently, 95% of the urban population in Zahedan is under coverage of water distribution system.

The findings of this section of the research are in harmony with the results obtained by Ahmadvash *et al*. (2013) considering elevated ground water level.There was a correlationbetween water level and the SPIdrought index at 1% level. Investigation of the trend of changes in EC, dry residual, and the sum of cations and anions of this aquifer (Figs. 3 to 7) demonstrated that the extent of these parameters were minimal in the west of the aquifer. It then dramatically grows at the direction of ground water movement towards east and north, which can be attributed to the presence of evaporative and quality-lowering sediments in the aquifer.The results of correlation of the water quality parameters

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withSPI indicated that there was a significant correlationat 1% level between Na^+ and SPI, but no significant difference was observed between the quality parameters and PN(Table 3).Regarding correlation between theground water level and the quality parameters with SPI drought index, the findings of this research are in correspondencewith those obtained by Aleboali *et al.* (2016), Jahanshahi *et al.* (2016) and Khan *et al.* (2008). Determination of the consumability of the ground waters of Zahedan Plain using Schoeller and Wilcox diagrams showed that drought had nosignificant effectson the class of ground water quality for drinking and agricultural purposes.Finally, considering the significance of water transfer project from SistanChah-nimehs to Zahedan, it is suggested that the environmental and socio- economic effects of this project should be investigated on water and soil resources in the area of origin (Sistan) and destination (Zahedan). Since farmers and other exploiters highly rely on the ground water resources for their requirements, permeation of salty waters towards the plain and its consequencesshould be considered and the necessary measuresto preserve the plain's water resources should be investigated.

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اثر خشکسالی بر پارامترهای کمّی و کیفی آبخوان دشت زاهدان

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چکیده با استفاده از شاخص‌های خشکسالی درصد نرمال بارش (PN) و بارش استاندارد (SPI)، تاثیر خشکسالی بر تغییرات سطح ایستابی و پارامترهای کیفی آبخوان دشت زاهدان بررسی شد. برای بررسی تغییرات کیفیت و سطح ایستابی آبخوان از آمار ۱۲ ساله چاه‌های مشاهده‌ای و پیزومتری در دشت و برای بررسی شاخص‌های خشکسالی PN و SPI، از آمار ۳۰ ساله بارندگی ایستگاه زاهدان استفاده شد. نتایج بیانگر تنوع بیش‌تر شاخص PN نسبت به شاخص SPI بود. هیدروگراف معرف آبخوان نیز بیانگر افزایش ۱/۳۷ متری سطح ایستابی از سال آبی ۲۰۰۲-۲۰۰۳ تا ۲۰۱۳-۲۰۱۴ بود که با شرایط خشکسالی می‌تواند به علت کاهش برداشت از آبخوان در پی انتقال آب از چاه‌نیمه‌های سیستان به زاهدان باشد. همبستگی معنی‌داری بین شاخص SPI و پارامترهای کیفی آب همچون Anion، TDS و Na^+ با SPI مشاهده شد، اما شاخص PN با هیچ‌کدام از پارامترهای کیفیت همبستگی معنی‌داری نداشت. در مورد تراز سطح آب نیز فقط با شاخص SPI همبستگی معنی‌داری در سطح ۱ درصد مشاهده گردید.

کلمات کلیدی: دشت زاهدان، شاخص‌های خشکسالی، کیفیت آب زیرزمینی، هیدروگراف واحد آبخوان

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