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Assessment of Chahnimeh Water Quality through the Water Quality Index (WQI)

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Abstract: Assessing quality of water resources and having accurate quality information are required for their management. The Chahnimeh reservoirs are the major source of drinking and agricultural water in southeast of Iran, and evaluation of their water quality is necessary. The water quality index (WQI) is the most important indicator expressing the qualitative condition of water in simple terms, without mathematical or statistical complexity. Therefore it was used in this descriptive, cross-sectional study of the first Chahnimeh reservoir based on sampling during the four seasons in 2016. Eight sampling stations were selected in the reservoir to determine six variables (nitrate, nitrite, dissolved oxygen, electrical conductivity, hardness, and pH). Despite spatial and temporal variations and fluctuations in these parameters, the results demonstrated that water quality in the reservoir is good. Moreover, the values for all measured parameters, apart from electrical conductivity, were within acceptable – i.e., recommended – ranges. Generally, considering the WQI values, water quality in the middle part of the lake was better than at its margins. Given the increasing importance of the Chahnimeh reservoirs, continuous evaluation and a water quality monitoring programme are required.

Key words: Water resource, water management, physico-chemical parameters, monitoring.

Introduction

Natural and artificial lakes are among the most important natural ecosystems, and require continuous water quality monitoring in relation to water resource management programmes. The prerequisite for sustainable development of water resources is to have reliable information on water quality and quantity, and the needs of different users (Abtahi et al., 2015).

Flowing waters exhibit different qualities because they are influenced by processes such as surface aeration, cellular respiration, mixing, flow velocity, etc. However, surface water storage may adversely affect quality. Construction and exploitation of large reservoirs increases water stagnation, resulting in differences in the quality of inflow and outflow waters (Mostafaei, 2014).

Reservoirs can act as accumulators of residuals transported by river water, prevent great changes in river water quality parameters, and improve water quality through correct management. On the other hand, suspended solids, dissolved solids; dissolved gases, microbial pollution, and temperature are all important factors that can reduce stored water quality (Al-Omran et al., 2015).

In other words, dams and reservoirs can cause major positive and/or negative changes in water quality. In addition, regional climate, and the type and intensity of exploitation of reservoirs and lakes behind dams directly influence these changes (Hou et al., 2016).

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In fact, natural processes and human activities affect physical, chemical, and biological features of water bodies, and can cause problems regarding water quality in lakes. Nowadays, the study and monitoring of water quality in reservoirs and lakes designed and used for storing river water, have attracted the interest of water experts worldwide, as they try to cope with and follow up on changes in water quality.

Use of the water quality index (WQI) is a simple method, free of mathematical and statistical complexities that explain water quality conditions in simple terms. WQI facilitates the monitoring of water quality changes over time, and indicates changes in quality in various regions of a country or around the world (Lobato et al., 2015). Furthermore, employing qualitative indicators allows the presentation of a large volume of information obtained from water quality sampling and measurement in the form of a single value with an interpreted qualitative meaning and definition (Sharma and Kansal, 2011).

Because of the importance of the subject, numerous studies have been made of rivers and reservoirs using WQI. For example, Alobaidy et al. (2010) used WQI to assess the quality in Dukan Lake, Iraq and showed that it had a declining trend (Alobaidy et al., 2010). In a study on the Aksu River, Şener et al. (2017) showed that water quality is poor and very poor in the north and south of the river basin, respectively and indicated that the most effective water quality parameters were COD and Mg in the determination of WQI for their study (Şener et al., 2017).

The Chahnimeh reservoirs are three large, natural depressions in the south of the Sistan Plain, in southeast Iran, and cover an area of 50 million m^2. The First Chahnimeh Reservoir, the main subject of this study, is the most important and largest, and extends from the Afghanistan border, parallel to the Hirmand River to about 6 km from Zahak city. The reservoir receives the excess water from the Hirmand River through a canal and stores it with the help of a 16 m high and 120 m long earth dam with the total surface area of 20 km^2 and volume of 210 million m^3.

The water enters the first reservoir through a canal of a length of 3.4 km. The speed of the water at the inlet of the reservoir is one metre per second, reaching a maximum of 130 to 160 cubic metres per second in the rainy times. Due to the special conditions designed for these reservoirs, the inlet and outlet of the Chahnime reservoirs are made only through the first reservoir. The connection of the reservoirs was carried out by a canal of 1.7 km between the reservoirs 1 and 2, and a channel of 1.1 km between reservoirs 1 and 3. The speed of the water at the main outlet of the first reservoir is 0.4 m per second.

It is the largest artificial lake located in the northern part of Sistan and Baluchestan Province.

Because of the reservoir's importance and the multiple uses of its water for the development of the southeast of Iran, it is important to assess water quality in the different parts of it and study the trend of changes throughout the year.

Qualitative indicators can be employed as a powerful management tool in making decisions on qualitative management of water resources. Given the simplicity of WQI and its results, WQI was chosen as a suitable tool to determine changes in water quality. The study's results can be employed to make water resource management decisions. This study is the first time that the WQI has been calculated using six parameters affecting water quality in this reservoir.

Materials and Methods

The reservoir is in the Sistan Plain between latitudes 60°20′ and 61°29′, in the lowest part of the Hirmand River Basin. It is recharged mainly by surface runoff from the Hirmand River and, depending on weather conditions, by precipitation.

This study was conducted from fall 2015 to fall 2016 and sampling was carried out in all seasons. Eight sampling stations were selected based on field visits and the research objectives, including one at the inlet of the First Chahnimeh Reservoir (Station 4), one at its outlet (Station 8), and six (Stations 1, 2, 3, 5, 6, and 7) in various parts of the reservoir. Figure 1 shows the locations of the Chahnimeh reservoirs (1, 2, 3, and 4) and Table 1 the sampling station characteristics.

Between 14 and 18 every month based on the weather conditions of the area, and depending on the average depth of the reservoir (estimated at about six metres), at each station from the depths of 0.5 and 3 metres from the water level and the 0.5 metre adjoining the bed the sampling were performed, and the physical and chemical parameters (nitrate, nitrite, dissolved oxygen, electrical conductivity, hardness, and pH) were measured and their seasonal means were obtained. The sample containers (1 litre) were placed on ice in darkness and transferred to the laboratory, and the parameters were measured based on standard methods (APHA, 2005). Nitrate and nitrite ions were measured through colorimetric method using a spectrophotometer (LUV–100A, Agilent, USA), dissolved oxygen through

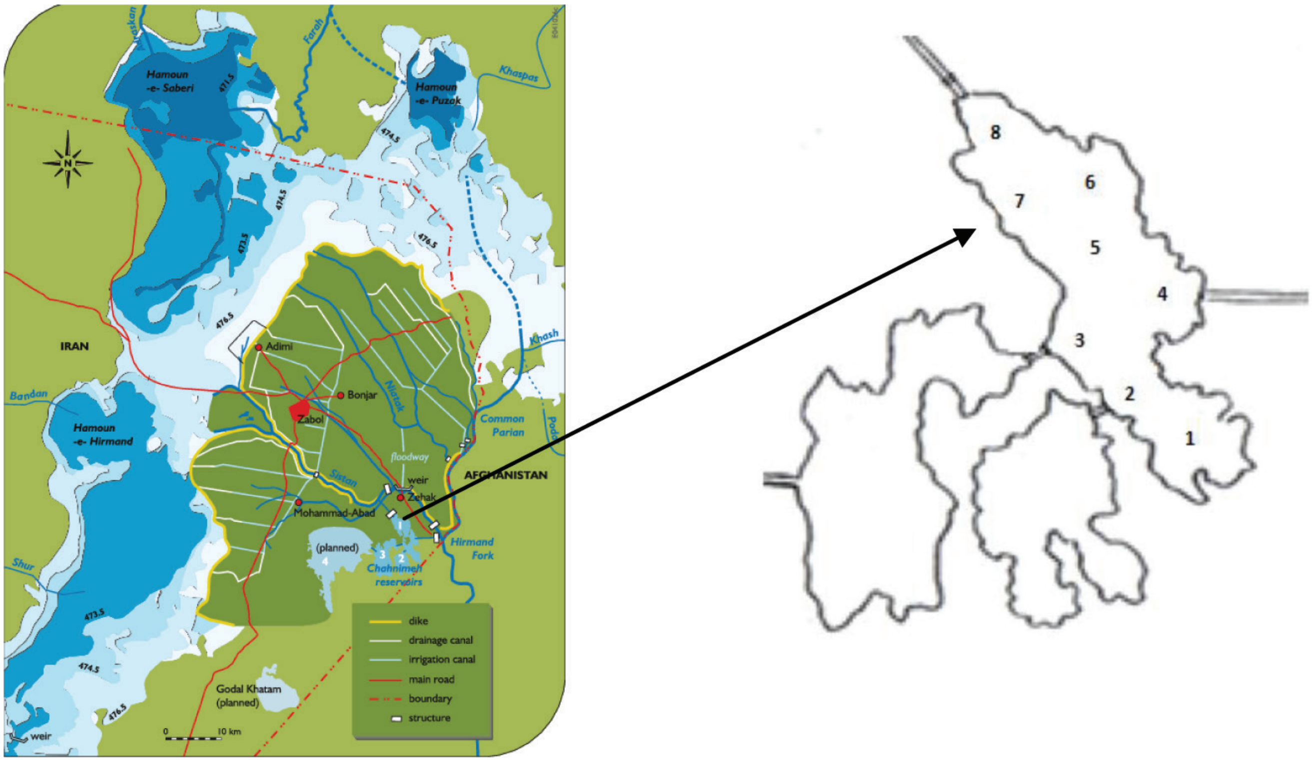

Figure 1: Location of the Chahnimeh reservoirs and sampling stations.

Table 1: Characteristics of the sampling stations in the First Chahnimeh Reservoir

Station	*Location*	*UTM Coordinates*		*Altitude*	*Reasons for Selection*
		Y	*X*		
1	The First Reservoir on the Afghanistan borderline (water depth: 4 m)	30°27′51″	61°42′20″	468	Study of water quality in the southeastern most part of the Reservoir
2	Inlet canal from the First Reservoir to the Second Reservoir (water depth: 4 m)	30°48′16″	61°43′09″	468	Study of water quality in the canal connecting the First and Second Reservoirs
3	Inlet canal from the First Reservoir to the Third Reservoir (water depth: 4 m)	30°46′43″	61°42′00″	466	Study of water quality in the canal connecting the First and Third Reservoirs
4	Inlet canal from the Sistan River to the First Reservoir (water depth: 3 m)	30°44′58″	61°41′43″	467	Determination of water quality in the canal through which water enters the First Reservoir
5	The Lake zone in the deep section of the Reservoir (water depth: 15 m)	30°46′38″	61°41′10″	464	Study of water quality in the middle and deep part of the Reservoir
6	On the margin of Research Centres at Zabol University (water depth: 8 m)	30°44′55″	61°40′24″	465	Determination of water quality and study of possible effects of the Research Centres on it
7	Northwestern margin of the First Reservoir (water depth: 8 m)	30°48′04″	61°39′20″	465	Study of water quality in the northeastern margin of the Reservoir
8	Outlet canal from the First Reservoir to the Sistan River (water depth: 7 m)	30°46′45″	61°42′20″	465	Study of water quality at the outlet of the Reservoir

the Winkler method, and hardness through titration. A pH meter (PHS-550-Lohand, China) and an EC meter (Hanna HI99301) were employed to measure pH and EC (APHA, 2005). Data were analyzed in SPSS, and normality of the data was investigated employing the Kolmogorov-Smirnov test. Differences between the data were evaluated using one-way ANOVA. The means were compared with Duncan's test. WQI was calculated using the six parameters of nitrate, nitrite, dissolved oxygen, EC, hardness, and pH, and the final values of WQI were obtained through the following relations (Eq. 1):

$$RW = AW/\Sigma AW \quad (1)$$

where *RW* (relative weight) is the weight ratio of each measured factor (Table 2) and *AW* (assigned weight) the weight allocated to each factor based on previous research and experts' suggestions (Table 3).

$$Q_i = (C_i/S_i) \times 100 \quad (2)$$

$$Q_i = (C_i - V_i/S_i - V_i) \times 100 \quad (3)$$

In the relations above, Q_i is the qualitative value, C_i the value of each measured parameter, S_i the reported value of the parameter in the International Standards for drinking water (Table 2), and V_i the desired values for the parameters of interest (7 for pH and 14.6 mg/L for dissolved oxygen and the zero value for the rest of the parameters) (Eqs 2 and 3).

$$SI_i = RW \times Q_i \quad (4)$$

where SI_i is the WQI sub-indicator obtained for each parameter (Eq. 4). Finally, WQI was determined by summing up the SI_i values. In fact, WQI was calculated at the stations for different seasons of the year with the help of the SI_i sub-indicators (and by summing them up).Water quality in the First Chahnimeh Reservoir was determined by comparing the obtained values with Table 4 (which presents the qualitative classification of water).

Table 3. Weight ratios of water quality parameters (WHO, 2011)

Parameters	*Drinking water standard (Si)*	*Allocated weights (AW)*	*Relative weight (RW)*
Nitrate ($mgNO_3^-/l$)	50	2.2	0.156028
Nitrite ($mgNO_2^-/l$)	3	2	0.141844
Total hardness ($mgCaCO_3/l$)	500	1.1	0.0780142
EC (µS/cm)	250	2.7	0.191489
Dissolved oxygen (mg/l)	5	4	0.283688
pH	6.5	2.1	0.148936
Total		14.1	

Table 2:Weights allocated to the parameters based on references and experts' views

Nitrate ($mgNO_3^-/l$)	*Nitrite ($mgNO_2^-/l$)*	*Total hardness ($mgCaCO_3/l$)*	*EC (µS/cm)*	*DO (mg/l)*	*pH*	*References*
2	2	1	4	4	1	Merchán et al., 2013
3	-	-	-	4	1	Boyacioglu, 2007
-	-	2	4	4	4	Tyagi et al., 2013
-	-	1	2	4	4	Dwivedi and Pathak, 2007
2	2	1	1	4	1	Kannel et al., 2007
2	2	1	2	4	1	Karakaya et al., 2011
-	-	1	2	4	4	Lumb et al., 2011
2	2	1	4	4	1	Pesce and Wunderlin, 2000
2.2	2	1.1	2.7	4	2.1	Averages

Table 4: Qualitative classification of natural water based on the overall WQI score

Qualitative classification	*WQI*
Unsuitable	300
Very poor	200-300
Poor	100-200
Good	50-100
Excellent	<50

Ramakrishnaiah et al., 2009; Gajendra et al., 2014

Results

Tables 5 and 6 present results of the measured physical and chemical factors of water at the eight stations and in the different sampling seasons, respectively.

The results of analysis of the variance of data on water quality parameters at eight sampling stations in Table 7 prove that there is no significant difference between the parameters of dissolved oxygen in different stations ($P > 0.05$), But other parameters at 5% level in different stations have a significant difference ($P < 0.05$).

The yearly results of analysis of the variance of data in Table 8 showed that the measured qualitative parameters did not vary significantly in the different months of the year ($p > 0.05$), except for dissolved oxygen ($p < 0.05$).

WQI was calculated using the six factors of nitrate, nitrite, dissolved oxygen, EC, hardness, and pH. In describing WQI, it is assumed that water pollution will increase and water quality will decrease at higher WQI

Table 5: Mean parameter concentrations at the sampling stations

Station parameter (yearly average)	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*Mean*	*Std. Deviation*
Nitrate ($mgNO_3^-/l$)	4.92	1.63	4.89	4.67	5.72	6.12	4.35	5.16	4.68	1.27
Nitrite ($mgNO_2^-/l$)	0.02	0.02	0.01	0.01	0.04	0.05	0.01	0.02	0.02	0.01
Dissolved oxygen (mg/l)	9.53	9.78	9.09	9.19	9.42	8.93	9.31	8.87	9.27	0.29
EC (μS/cm)	972.3	1103.29	1110.25	1075.67	721.75	796.83	1005	1083.58	983.58	138.24
Total hardness ($mgCaCO_3/l$)	132.92	278.25	289	314.12	212.93	302.92	134.17	258.75	240.38	68.07
pH	8	7.74	7.73	7.86	8.34	7.91	7.99	8.04	7.95	0.18

Table 6: Parameter concentrations in the different seasons

Parameter	*Season*	*Spring*	*Summer*	*Autumn*	*Winter*	*Mean*	*Std. Deviation*
Nitrate ($mgNO_3^-/l$)		4.76	4.83	4.62	4.37	4.68	0.18
Nitrite ($mgNO_2^-/l$)		0.02	0.02	0.01	0.03	0.02	0.01
Dissolved oxygen (mg/l)		8.48	7.53	9.83	11.22	9.27	1.39
Electrical conductivity (μS/cm)		890.75	908.71	956.63	1178.27	983.59	114.95
Total hardness ($mgCaCO_3/l$)		220.06	202.86	231.58	307.01	240.38	39.80
pH		7.80	8.01	8.00	8.00	7.95	0.09

Table 7: The results of ANOVA test of parameters in sampling stations

Parameters	*Sum of squares*	*Df*	*Mean square*	*F*	*Sig.*
Nitrate ($mgNO_3^-/l$)	148.163	7	21.166	5.814	<0.001
Nitrite ($mgNO_2^-/l$)	0.01	7	27.03	0.02	<0.001
Dissolved oxygen (mg/l)	7.876	7	1.125	0.401	0.899
Electrical conductivity (μS/cm)	1834456.352	7	262065.193	2.332	0.031
Total hardness ($mgCaCO_3/l$)	444803.013	7	63543.288	9.335	<0.001
pH	3.231	7	0.462	2.870	0.010

Table 8: ANOVA results for annual average values

Parameters	*Sum of squares*	*Df*	*Mean square*	*F*	*Sig.*
Nitrate (mgNO_3^-/l)	41.150	11	3.741	0.735	0.702
Nitrite (mgNO_2^-/l)	0.018	11	0.002	2.559	0.108
Dissolved oxygen (mg/l)	190.004	11	17.273	22.386	<0.001
Electrical conductivity (µS/cm)	2181912.279	11	198355.662	1.746	0.077
Total Hardness (mg$CaCO_3$/l)	174751.393	11	15886.490	1.535	0.134
pH	1.356	11	0.123	0.646	0.784

values. There were no significant differences between the numerical values of WQI at the various sampling stations or in different seasons ($p > 0.05$).

Table 9 shows the calculated values of WQI at various sampling stations and in different seasons. Comparison of WQI values with water quality standards (Table 4) reveals that water quality was not below the range of good water quality (50-100) at any station or in any season and the water is good for utilization by human.

Table 9: Calculated WQI values at the stations and in different sampling seasons

Station	*WQI*	*Season*	*WQI*
1	63.373	Spring	67.496
2	81.653	Summer	65.178
3	85.661	Autumn	62.684
4	79.167	Winter	76.747
5	35.878		
6	57.555		
7	66.620		

Figures 2 and 3 demonstrate the trend of changes in WQI at different stations and in various sampling times, respectively and show that the changes in water quality in the different stations do not follow any specific pattern and are not statistically significant.

Results indicate that the highest WQI value (85.661) was recorded at Station 3 and the lowest (35.878) at Station 5 (Table 9 and Figure 2). In addition, the highest numerical value of WQI (76.747) was observed in winter and the lowest (62.684) in autumn (Table 9 and Figure 3).

In general, a careful examination of WQI values at different stations and seasons revealed differences in water quality between the various stations and seasons; wherever and whenever WQI increases attention must be paid to the health and safety of the consumers. However, water quality in the lake did not decline below the good quality range, and the water is suitable for drinking purposes.

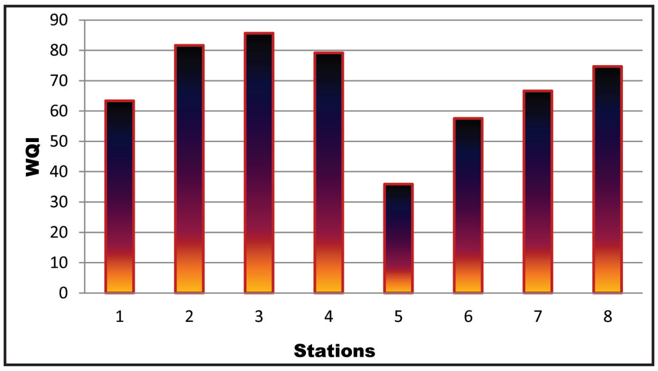

Figure 2: WQI values at the sampling stations.

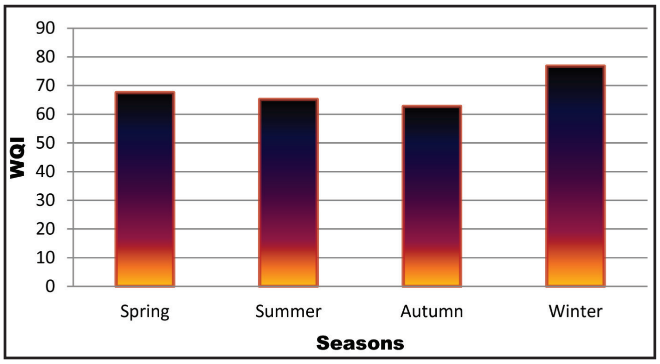

Figure 3: WQI values in sampling seasons.

Discussion and Conclusion

WQI is used world-wide as an indicator of water quality. Its major advantage is the use of a simple method to reduce large volumes of data related to a variety of water parameters to a single value.

The results showed no significant differences between various stations with regard to dissolved oxygen whereas the values for other factors monitored – e.g., nitrate, nitrite, EC, total hardness, and pH – differed significantly in various parts of the reservoir. The water quality results from the eight stations varied for reasons including proximity to the inlet and outlet (where water flow intensities can differ), and differences in depth, etc. (Alobaidy et al., 2010).

However, none of the parameters measured varied significantly during the year ($p > 0.05$), except for dissolved oxygen, which was affected mainly by temperature and weather changes, and showed significant changes during the year ($p < 0.05$). Hou et al. (2016) and Lobato et al. (2015) reported similar findings.

The highest nitrate concentration was recorded at Station 6, because of its proximity to the research fields and the tourist areas on near the shore, where agricultural and domestic wastewater entered the reservoir. Because of this, Station 6 also reported the highest nitrite concentration. Nitrate and nitrite contents did not exhibit significant differences over time. The EC value of the water in the reservoir exceeded the WHO recommended maximum level because of the water's high salt content, the flood flows entering the reservoir, and the large quantities of suspended sediment (Karakaya et al., 2011).

The high EC value is one of the qualitative problems of the water in the Chahnimeh Reservoir that can even influence its flavour and taste and its acceptance as drinking water.

In general, values for EC were different at the various sampling stations but they were close to each other in different seasons and did not exhibit any significant differences.

Hardness is important in assessing water quality for domestic, industrial, agricultural, and aquaculture purposes. The hardness of the water in the reservoir was generally below the maximum level recommended in the WHO recommendations for drinking water. The highest concentration was measured at Station 4, at the main entry point of water into the reservoir.

Fluctuations in pH in different seasons were not statistically significant, but the pH values reported at the various sampling stations were significantly different because of variations in hardness around the reservoir, etc. The buffer state established the presence of various salts like carbonate (especially in stations close to the inlets and outlets), and because of the differences in the hydrologic characteristics in the reservoir (Lobato et al., 2015).

Values for dissolved oxygen in water at the various stations were close to each other, but significant differences in dissolved oxygen content were observed between different sampling seasons ($p < 0.05$). Dissolved oxygen concentration was the highest in winter and the lowest in summer when water temperature and bioactivities increased. In all, the WQI values in this study indicated that the water at all stations and in all sampling months had suitable quality and could be used.

However, if the First Chahnimeh Reservoir is divided into entry, middle, and outlet sections, the best water is found in the middle section, around Station 5, Alobaidy et al. (2010) and Karakaya et al. (2011) reported similar results. The relative depth of this section, and its distance from the reservoir inlet and outlet, which reduces the effects of water and salt movement, are considered the most important factors likely to be involved.

The reservoir zones near the water inlet and outlets are thought to have had lower water quality due to water level fluctuation, changes in sediments and salts, etc. The trend of changes in and around the reservoir, especially in land and water use, the severe reduction in inflow volumes, the extended droughts, the growth of tourism, and in expert land use in the Sistan Basin, lead the authors to recommend more detailed studies, as well as continuous water quality assessment and monitoring. It is also suggested that water should be taken from the middle of the reservoir.

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