ISSN: 2538-2152; ECOPERSIA 2023;11(4):337-347.

Water Quality Modeling in the Zabol Chahnimeh using Multivariate Statistical Methods

ARTICLEINFO

Article Type
Original Research

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How to cite this article
Homayoonnezhad I., Amirian P., Mahdavi Lasibi MJ. Water Quality Modeling in the Zabol Chahnimeh using Multivariate Statistical Methods. ECOPERSIA 2023;11(4): 337-347

DOR:
20.1001.1.23222700.2023.11.3.1.5

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Article History
Received: August 19, 2023
Accepted: October 30, 2023
Published: December 20, 2023

ABSTRACT

Aims: This research aims to formulate a program and design a suitable model for environmental monitoring of water quality to reduce the costs of water quality monitoring and evaluation in Zabol Chahnimeh 1.

Material & Methods: In this study, eight sampling stations were selected in the bed of reservoir 1 in order to monitor and measure physical, chemical, and microbial factors. Sampling was conducted systematically every month for one year. Then, the data were analyzed with the help of multivariate statistical methods such as cluster analysis, Principal Component Analysis (PCA), and factor analysis.

Findings: Using multivariate statistical methods, stations 4, 5, and 6 were selected as the main stations for sampling and factors of temperature, turbidity, DO, COD, magnesium, sodium, calcium, phosphate, chlorine, nitrite, sodium Absorption Ratio, and pH was determined as the main water quality indicators. It was revealed that temperature, DO, nitrate, and turbidity factors should be sampled monthly. However, the other factors could be sampled periodically or quarterly to model optimal water quality monitoring in reservoir 1 during a year.

Conclusion: In general, the evaluation of the quality status of this valuable water resource by reducing the number of sampling stations, eliminating some unnecessary factors, and reducing the frequency of sampling completely and without defects and at a much lower cost is done for this reason, having the lowest costs and proper timing, management of the main reservoir will be possible considering all effective factors.

Keywords: Chahnimeh reservoirs; Environmental monitoring; indicator Stations; sampling frequencies; Water quality factors.

CITATION LINKS

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[DOI: 10.22034/ecopersia.11.4.337]

Introduction

The monitoring process consists of plans and activities that monitor the water quality of various water sources, including ground or surface water, with many variables and how to minimize their pollution in different periods. A monitoring network to analyze the water quality of sources includes locating index sampling stations, selecting principal water quality factors, and assigning sampling frequency in each station [1, 2]. A plan suited for monitoring water quality can reduce the costs of surveillance and assessment of water quality in the proper time and place. In terms of dimensions and volume, Chahnimeh 1, with an area of 20 km^2 and a capacity of approximately 210 Mm^3, is the largest among the three Chahnimeh reservoirs in Zabol which are located in the north of Sistan and Baluchistan Province [3]. At present, the water of Chahnimeh reservoirs is used to supply potable water for Zabol and Zahedan, irrigation of a large part of the farmlands of Sistan, and even for recreation and tourism [4]. It is noteworthy that because the main inlet and outlet of reservoir 1 are arranged in a manner that water travels from the first reservoir to the second and the third ones, it is more crucial compared to reservoirs 2 and 3. Based on this critical role in regional development, the necessity of preserving and maintaining this source is revealed. In addition, since the area is along the border and Chahnimeh reservoirs are recharged by the Helmand River in Afghanistan and due to climatic conditions of Sistan, including 120-day winds, although there is no industrial and microbial pollution to contaminate the Chahnimeh reservoirs, variations of water quality as a result of climate and seasonal floods is possible [1, 5]. Determining the quality status of water resources is necessary to adopt appropriate solutions to prevent the reduction of water quality or to improve it. A suitable model for monitoring and controlling water quality over time is used as a vital management tool in decisions related to water resources management. Therefore, considering the necessity of measuring and determining water quality factors and the importance of the Chahnimeh, it is necessary to design a water quality monitoring program with a temporal and spatial model for Chahnimeh reservoirs in Sistan. Moreover, this research has been done to achieve this program for the main reservoir.

Materials & methods

Study Area

The current research is applied and fundamental. In terms of the method, according to the nature of the topic and research objectives, this study was of a monitoring-experimental type. The area under study is the first Chahnimeh, located in the north of Sistan and Baluchistan Province and near Zahak. Eight sampling stations were selected in inlets and outlets and the bed of reservoir 1 to monitor and measure physical, chemical, and microbial factors (Figure 1 & Table 1). Sampling was conducted systematically monthly (in the middle of each month) for which year.

In each station, water quality characteristics including temperature, acidity, Total Dissolved Solids (TDS), Dissolved Oxygen (DO), Electrical Conductivity (EC), Biological Oxygen Demand (BOD), nitrates, ammonia, Calcium, Magnesium, sulfates, total hardness, Sodium, Sodium Adsorption Ratio (SAR), Chlorides and fecal coliforms were measured according to standard international methods [6].

In this research, based on international guidelines, a surface water monitoring program, and taking into account the general location of the region and the characteristics of Lake 1, sampling stations were determined, and water sampling was done according to the schedule [7]. Measurement and analysis of physical, chemical, and microbial factors

[DOI: 10.22034/ecopersia.11.4.337]

Figure 1) Locations of eight sampling stations along Chahnimeh 1 in Sistan.

were done in the laboratory with the help of international standard methods [6-7]. Then, using multivariate statistical analysis methods such as ANOVA, cluster analysis, Principal Component Analysis, and factor analysis of index factors [8, 9, 10], primary and secondary stations, and sampling frequency, an appropriate plan was designed for monitoring water quality of Reservoir 1 of Chahnimeh reservoirs in Zabol.

Findings

-Analysis of variance and mean comparison of the water quality data of Chahnimeh 1 in Zabol

The results of sampling and analysis of the water quality factors in eight sampling stations are shown in Table 2.

Comparison and analysis of mean values and their difference from international standards, as shown in Table 2, suggested differences between water quality factors of each station, in which some factors are more critical than others based on mean differences and standard deviations [11]. At station 1, total hardness, CA, and Mg differ significantly from the mean, and their high fluctuations are evident.

At station 2, EC, DO, COD, temperature, phosphates, turbidity, Mg, and nitrates are far from the mean and the index. At station 3, EC, pH, COD, sulfates, Mg, and chlorides were index factors. At station 4, factors such as TDS, total hardness, phosphates, and nitrates had significant variance, and the measured mean shows high fluctuations, resulting in these factors being the index ones. At station 5, pH, EC, TDS, phosphates, turbidity, and Ca; at station 6, SAR, DO, BOD, phosphates, chlorides, Ca, and Mg; at station 7, SAR, COD, hardness, Na, sulfates, chlorides, Ca and Mg and finally at station 8 DO and ammonia were different from the mean. For this reason, they were indicators. Table3. indicates that mean squares resulting from analysis of variance of the factors assessed based on months of

Table 1) Characteristics of the sampling stations of Chahnimeh 1.

Station No.	Location	UTM Coordinates X	UTM Coordinates Y	Elevation above mean sea level(m)	Reason of selection
1	Along the Afghanistan border in reservoir 1	61° 42′ 20″	30° 51′ 27″	468	Analysis of water quality at the southeastern end of the reservoir
2	Inlet canal from Reservoir 1 into Reservoir 2	61° 43′ 09″	30° 48′ 16″	468	Analysis of water quality at the canal between Reservoirs 1 and 2
3	Inlet canal from Reservoir 1 into Reservoir 3	61° 42′ 00″	30° 46′ 43″	466	Analysis of water quality at the canal between Reservoirs 2 and 3
4	Inlet canal from Sistan River into the reservoir	61° 41′ 43″	30° 44′ 58″	467	Characterization of Water quality at the inlet canal into Reservoir 1
5	sheet of the reservoir in the deepest part of the reservoir	61° 41′ 10″	30° 46′ 38″	464	Analysis of water quality at the middle and deep parts of the reservoir
6	Along research centers of Zabol University in Reservoir 1	61° 40′ 24″	30° 44′ 55″	465	characterization of water quality and analysis of likely impacts of research centers
7	At Northeastern bank of Reservoir 1	61° 39′ 20″	30° 48′ 04″	465	Analysis of water quality at Northeastern bank of Reservoir 1
8	Outlet canal of Reservoir 1 into Sistan River	61° 42′ 20″	30° 46′ 45″	465	Analysis of water quality at the Outlet canal of the Reservoir

sampling for turbidity, TDS, BOD, nitrites, and temperature and mean comparison of the data of all water quality factors collected at eight stations during 12 months at 1% ($p<0.01$) and 5% ($p<0.05$) are significantly different. Therefore, for a good monitoring of these factors, each should be measured every month or less. Also, other factors showed significant differences, and monthly measurement is optional.

In addition, analysis of variance and comparison of squared means of the sampled factors showed that TDS, DO, and BOD at 1% ($p<0.01$) and 5% ($p<0.05$) have no significant difference among eight sampling stations; however, other factors have a significant difference among these stations. As observed in Table 4, this difference means varied water quality in various parts of Chahnimeh 1 in terms of the factors whose difference is significant.

-Cluster analysis of the sampling stations

In this research, cluster analysis, one of the multivariate analysis methods, was used to group stations so that according to their attributes, similar stations were classified into one group. The stations in one category are more homogenous compared to other

[DOI: 10.22034/ecopersia.11.4.337]

Table 2) Mean values of all factors in eight study stations.

Station / Variables	BOD (mg.l⁻¹)	COD (mg.l⁻¹)	DO (mg.l⁻¹)	EC (µS.cm⁻¹)	pH	SAR (meq.l⁻¹)	TDS (mg.l⁻¹)	Ammonia	Temperature (°c)	Total Hardness ($mgCaCO_3.l^{-1}$)	Sodium (mg.l⁻¹)	Sulfate (mg.l⁻¹)	Phosphate (mg.l⁻¹)	Turbidity (NTU)	Chloride (mg.l⁻¹)	Calcium (mg.l⁻¹)	Magnesium (mg.l⁻¹)	Nitrate ($mgNO_3.l^{-1}$)	Nitrite ($mgNO_2.l^{-1}$)
1	1.53	24.42	9.53	972.33	8.03	5.22	638.58	0.00	22.50	132.92	140.26	162.07	0.28	16.93	175.05	21.25	20.50	4.92	0.02
2	1.78	18.98	9.78	1103.29	7.74	3.14	670.18	0.00	22.42	278.25	119.84	252.01	0.15	3.85	176.64	33.05	47.39	1.63	0.02
3	1.64	27.25	9.09	1110.25	7.73	3.02	675.34	0.00	22.58	289.00	113.41	250.44	0.18	6.01	159.91	34.95	44.14	4.89	0.01
4	1.64	23.17	9.19	1075.67	7.86	3.21	712.25	0.00	22.58	314.12	107.07	177.38	0.01	10.15	171.14	32.35	33.56	4.67	0.01
5	1.67	25.50	9.42	721.75	8.34	3.43	474.33	0.00	22.58	212.93	116.14	172.01	0.03	18.16	189.45	34.80	32.57	5.42	0.04
6	1.28	24.08	8.93	796.83	7.91	2.39	495.83	0.07	22.58	302.92	83.69	151.71	0.64	6.87	165.45	35.17	35.91	6.12	0.05
7	1.94	28.33	9.31	1005.00	7.99	5.36	652.33	0.00	22.46	134.17	143.72	144.78	0.26	9.80	193.97	21.83	20.05	4.35	0.01
8	1.94	22.42	8.87	1083.58	8.04	3.67	669.17	0.17	22.50	258.75	124.08	209.15	0.39	9.67	177.45	33.67	35.02	5.16	0.02
Mean	1.68	24.27	9.26	983.59	7.95	3.68	623.50	0.03	22.53	240.38	118.53	189.94	0.24	10.18	176.13	30.88	33.64	4.64	0.02
Standard Deviation	0.21	2.91	0.30	147.77	0.19	1.06	88.18	0.06	0.06	72.76	18.95	42.49	0.20	5.04	11.34	5.85	9.74	1.33	0.01

Table 3) Squared mean of analysis of variance of the factors assessed based on months of sampling.

Source of Change	Freedom degree	Turbidity	TDS	EC	pH	Total Hardness	DO	BOD	COD	Chloride	Sulfate
Month	11	150.3	83256.9	198355.6 ns	0.123 ns	15886.4 ns	17.2	2.8	13.2 ns	264 ns	2034.3 ns
Source of Change	**Freedom degree**	**Nitrate**	**Nitrite**	**Calcium**	**Magnesium**	**Sodium**	**SAR**	**Ammonia**	**Phosphate**	**Temp**	
Month	11	3.7 ns	0.02	72.0 ns	59.7 ns	261.6 ns	0.266 ns	21.1 ns	0.96 ns	0.4	

ns=non-significant.

Table 4) Mean of squared resulting from analysis of variance of the factors assessed among eight sampling stations.

Source of Change	Freedom degree	Turbidity	TDS	EC	pH	Total Hardness	DO	BOD	COD	Chloride	Sulfate
Station	7	305.04	93319.04 ns	262065.19	0.462	63543.28	1.12 ns	0.64 ns	102.25	1544.41	21667.6
Source of Change	**Freedom degree**	**Nitrate**	**Nitrite**	**Calcium**	**magnesium**	**Sodium**	**SAR**	**Ammonia**	**Phosphate**	**Temp.**	
Station	7	21.16	27	410.5	1139.9	4313.4	13.4	49.17	20.5	0.03 ns	

ns=non-significant

stations. Similar to this research, Hajiglizadeh and Debgarwal used cluster analysis to investigate surface water quality in 2017 [12, 13]. For cluster analysis and classification of the stations, the factors sampled in each station based on varied dissimilarity scales were categorized from 0 to 20. Finally, cluster analysis was performed using UP-GMA based on Euclidian least squares after standardized data. The dendrogram (Figure 2) shows that

[DOI: 10.22034/ecopersia.11.4.337]

Table 5) ANOVA of the quality factors obtained from cluster analysis.

Factor	Mean Square	F	P-Value
Temperature (°C)	0.006	1.38	0.33
Turbidity (NTU)	30.08	1.32	0.34
TDS ($mg.l^{-1}$)	26423.3	83.1	0.00
EC ($\mu s.cm^{-1}$)	74363.3	89.7	0.00
pH	0.065	0.28	0.76
Total hardness ($mg.l^{-1}$)	15709.2	13.90	0.009
DO ($mg.l^{-1}$)	0.03	0.283	0.76
BOD ($mg.l^{-1}$)	0.035	0.575	0.595
COD ($mg.l^{-1}$)	8.1	0.94	0.44
Chloride ($mg.l^{-1}$)	118.9	0.89	0.46
Sulfate ($mg.l^{-1}$)	4209.5	4.98	0.06
Nitrite ($mg.l^{-1}$)	0.001	33.89	0.001
Phosphate ($mg.l^{-1}$)	0.016	0.31	0.74
Nitrate ($mg.l^{-1}$)	1.89	1.10	0.40
Calcium ($mg.l^{-1}$)	117.8	151.1	0.000
Magnesium ($mg.l^{-1}$)	220.6	9.06	0.02
Sodium ($mg.l^{-1}$)	908.6	6.50	0.04
SAR ($meq.l^{-1}$)	3.52	22.09	0.003
Coliforms	0.047	1.87	0.24

eight sampling stations were categorized into three groups (clusters) based on the farthest Euclidian least distance.

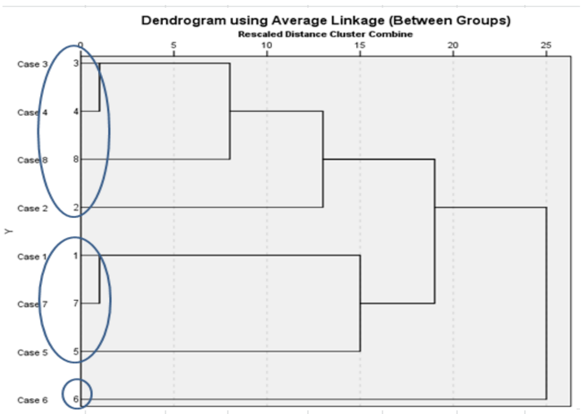

Figure 2) Dendrogram resulting from cluster analysis of the stations in Chahnimeh 1.

As illustrated in Figure 3, cluster analysis of the stations based on homogeneity of the measured quality factors suggested that stations 2, 3, 4, and 8 were in cluster 1; stations 1, 7, and 5 were in cluster 2, and station 4 was in cluster 6. Moreover, analysis of variance in the mean water quality factors for cluster analysis, as mentioned in Table 5, clearly showed that among 20 different factors, only eight factors, including TDS, EC, hardness, nitrites, Ca, Mg, Na, and Sodium adsorption ratio, had a significant difference at 1% and 5% levels. The difference between the stations was due to fluctuations of these eight factors, which resulted in three distinct clusters.

-Principal Component Analysis and factor analysis of the water quality factors in Chahnimeh 1

Owing to the high quantity and high volume of the variables involved in this study, PCA and factor analysis were used to reduce the volume of the data so that the remaining data almost cover all characteristics of the primary data. Ayeni in 2013 and Yang in 2020 also used factor analysis and Principal Component Analysis to determine spatial and temporal changes in water quality [14, 15]. Factor analysis suggested that three principal components justify 77.3% of the total variance, i.e., the physical, chemical, and microbial factors of water embedded in these three components. Figure 3 clearly shows the results of factor analysis of water quality factors and the variations process of the three primary factors with the highest variations. This paper separated 20 water quality factors using Principal Component Analysis and a rotated component matrix. Negative coefficients imply a reduction of their effects on the station factors and vice versa. In contrast, positive coefficients show an increase in the effect of that factor in the stations. Table 6 denotes the values of principal components in PCA and factor analysis.

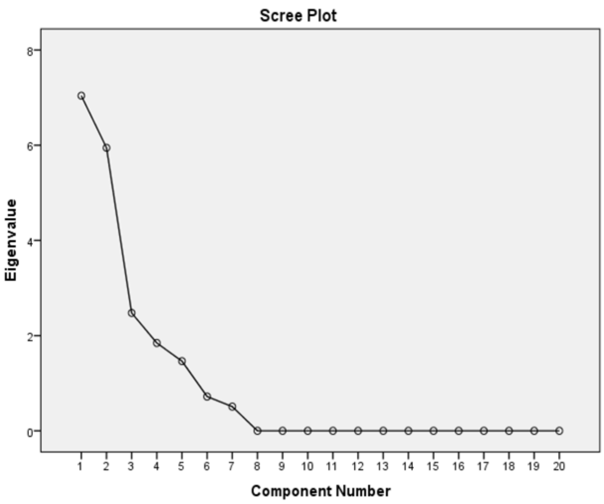

Figure3) The relationship between factors and their effects on Principal Component Analysis.

Table 6) The values of three components in factor analysis and rotated component matrix along with values of each factor.

Rotated Component Matrix[a]			
	Component		
	1	2	3
Temp	-.268	.604	.310
TU	.635	.544	-.204
TDS	-.008	-.935	-.086
EC	-.166	-.965	-.032
pH	.530	.696	-.103
TH	-.929	.001	.239
DO	.099	-.106	-.870
BOD	.235	-.227	-.802
COD	.526	.215	.118
CL	.648	.182	-.446
Sulfate	-.677	-.494	-.249
Nitrite	-.164	.893	.260
Phosphate	.045	.066	.828
Nitrate	.248	.588	.648
Ammoniac	-.070	-.065	.744
Ca	-.875	.311	.137
Mn	-.956	-.130	-.093
Na	.754	-.450	-.385
SAR	.934	-.287	-.197
E-coli	-.267	.451	.625

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

The above table shows how each variable's factorial loading depends on the three main components and on which component each variable creates more factorial load. As shown in Table 6, turbidity, hardness, COD, chlorides, sulfates, ions of Ca and Mg, and Sodium adsorption ratio in the first component are of high quantity. In the second component, temperature, TDS, EC, pH, and nitrites, and the third component, DO, BOD, phosphates, nitrates, ammonia, and coliform are of higher quantity than other factors.

Discussions

Water resource management consists of qualitative and quantitative aspects

[DOI: 10.22034/ecopersia.11.4.337]

covering different parts and details. In Italy, in 2016, Dettori and his group researched various quantitative and qualitative aspects of drinking water. Also, Ajorlo and Abdullah evaluated water quality and its quantitative and qualitative aspects in pastures in 2014 [16, 17]. Qualitative monitoring is also a small part of the water resource management plan [18, 19, 20]. About the vital role that Chahnimeh reservoirs in Sistan play in protecting the livelihood of the area and the increasing pollution of various types in surface waters [21, 22], taking predictive actions through a monitoring plan for Chahnimeh 1 as the biggest and the only water inlet into the three reservoirs seems necessary. In general, in this research, for the first time, with the help of a set of statistical methods, a water quality monitoring model has been designed in Chahnimeh. The purpose of creating this model is to maintain the water quality of Chahnimeh for various human uses. After the emphasis on the necessity and importance of a monitoring plan for reservoir 1 in Zabol, at the implementation phase for finalizing a monitoring plan suitable for the natural conditions of the study area, study objectives, financial, technical, and human sources, the actions should be carried out through identification of sampling stations, and determination of the index factors and proper frequency of sampling [12].

-Monitoring stations

Based on the cluster analysis results and considering the stations' internal characteristics, there was high similarity between the eight stations. Therefore, eight sampling stations were divided into primary and secondary groups using multivariate statistical methods and cluster analysis in Reservoir 1 in Zabol. Stations 4 to 6 were primary, and the others were secondary. In fact, by considering only three stations, all the information needed for water quality analysis in Reservoir 1 can be obtained. These stations were separated from three clusters resulting from cluster analysis: station 4 from cluster 1, station 5 from cluster 2, and station 6 from cluster 3.

- Water quality indices

Various elements and compounds that affect water's chemical and physical quality are found in water [23]. Given the variations and fluctuations of the factors, a significant difference between means of quality factors, and by using analysis of the primary components and factor analysis, in eight sampling stations of Reservoir 1 of Chahnimeh, factors which have the highest effect on water quality include temperature, turbidity, Mg, Na, phosphates, COD, Sodium adsorption ratio, DO, pH, Cl, and nitrites. Indeed, these factors are the primary ones among all the factors of water quality measured in Reservoir 1, the necessity of sampling and measurement of which is higher than the secondary factors.

-Sampling frequency

A higher sampling frequency corresponds to a shorter interval between the samples. However, not only is the high sampling rate not cost- and time-effective, but it may also not be necessary. Thus, quantity and time intervals of sampling should be determined concerning the viewpoints of the planning expert, which results from his awareness of the variability of water quality factors, statistical conditions of sampling, available budget and credit of the plan, and the expected schedule. The effect of sampling frequency on the water quality monitoring model has been investigated many times. Li Yu and his group, Piniewski and his colleagues emphasized the best repetition of sampling in the design of the water quality monitoring model [24, 25].

Based on the results of ANOVA of water quality factors, all measured monthly, it was discovered that turbidity, TDS, DO, BOD, nitrites, and temperature significantly differ

[DOI: 10.22034/ecopersia.11.4.337]

at 1% and 5% levels in samples of different months. They should, therefore, be measured monthly or less (if necessary). However, since other factors were not different in samples of different months, they should be measured periodically or seasonally (if necessary). This vastly reduces the costs of monitoring water quality in Chahnimeh.

Finally, according to the results of statistical analyses of the measured data, the monitoring model of Reservoir 1 of Chahnimeh in Sistan could be designed and operated in terms of primary and secondary sampling stations, frequency of sampling, and indices, as mentioned in Table 7.

According to Table 7, by monthly sampling of turbidity, DO, COD, chlorides, Na, pH, Ca, Mg, SAR, and temperature, it can be concluded that water quality monitoring in Reservoir 1 of Chahnimeh is only possible in stations 4, 5 and 6. That is, when the number of sampling stations decreased, some unnecessary and secondary factors were eliminated, and sample collection time reduced; not only

Table 7) Stations, index factors, and sampling frequency are used to present the water quality monitoring model of Chahnimeh 1 in Zabol.

Factor	Factors of frequency of sampling		
	Type of factor		Frequency of sampling
	Primary	Secondary	
Temperature	■		Monthly and first six months-monthly
Turbidity	■		Monthly
pH	■		Seasonal-periodical
DO	■		Monthly
COD	■		Seasonal-periodical
Nitrites	■		Monthly
Phosphates	■		Seasonal-periodical
Ca	■		Seasonal-periodical
Mg	■		Seasonal-periodical
Chlorides	■		Seasonal-periodical
SAR	■		Seasonal-periodical
Na	■		Seasonal-periodical
Hardness		■	Seasonal-periodical
TDS		■	Monthly
BOD		■	Monthly
EC		■	Seasonal-periodical
Nitrates		■	Seasonal-periodical
Ammonia		■	Seasonal-periodical
Sulfates		■	Seasonal-periodical
Coliforms		■	Seasonal-periodical

[DOI: 10.22034/ecopersia.11.4.337]

monitoring and assessment of the quality of this water source is carried out perfectly and flawlessly, but a considerable part of measurement and monitoring costs will decrease.

Conclusion

In most of the research on water resources conducted in arid and semi-arid regions of Iran, the quantity of water has been mentioned, and more attention needs to be paid to the quality of water. Quality management of reservoirs and lakes such as Chahnimeh should be done continuously according to their characteristics. One of the best methods of quality management of water resources is to obtain a time and place quality monitoring program and model, considering cost management. It is worth noting that the model for monitoring the water quality of Chahnimeh 1 in Zabol was performed based on local ecological conditions, the schedule of sampling, and the principal objectives of the project, and one of the most fundamental pillars of an effective monitoring system is its capability to change according to conditions and changes of monitoring objectives and the study area [26]. In this paper, the current monitoring system can be used for effective controlling and monitoring of water in Chahnimeh so that through sampling a maximum of 12 factors only in 3 stations with minimum costs and time, a comprehensive knowledge of water quality and even its variabilities was achieved, which is the most substantial step for managing a vital water resource including three Chahnimeh in Zabol.

Acknowledgments

None declared by Authors.

Ethical permissions: None declared by Authors.

Conflict of interests: The authors have declared no conflict of interests (None declared by Authors).

Authors' contributions: All authors contributed to the manuscript and read and approved its final article version.

Funding/ Support: The funding support from personal investment.

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[DOI: 10.22034/ecopersia.11.4.337]