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Original Article

Assessment of Water Quality Indices Using Physico-chemical Parameters in Zayande Rood Dam Lake

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Abstract
Background: Biological and ecological studies of water resources play the primary role in the researches. The Zayande-rood's dam lake is one of the vital water resources that provide drinking water for the populations in Isfahan. It is also a water resource for agricultural sections of the province.
Methods: Five spots were defined as the sampling stations. Sampling was conducted in seven steps, with one sampling event every 45 days. The water quality parameters including dissolved oxygen (DO), nitrate, nitrite, electrical conductivity (EC), pH, hardness, total dissolved solids (TDS), ammonium, and biochemical oxygen demand (BOD) were measured in all the stations and stages. Next, the water quality indices were calculated.
Results: The study's results illustrated that the water quality, with an average score of 74.41 on the water quality index (WQI), fell within the 'well' class, indicating its suitability for human consumption and drinking purposes. Station 4 scored the highest NSFWQIa (74.93), while station 3 had the lowest (70.57). According to the NSFWQI classification, all stations are categorized as 'good' in terms of water quality. The NSFWQIm ranged from 50.94 to 59.04, showing moderate changes in water quality. Both the NSFWQIa and NSFWQIm classify it as 'moderate' or 'mid-class' quality.
Conclusion: Considering the significance of Zayande-rood's dam lake as a crucial source of drinkable water for Isfahan, it becomes evident that there is a pressing need for significant attention to be directed toward lake watershed management to protect water quality.
Keywords: WQI, Shadegan Dam, NSFWQI, Zayande-rood, Nutrients, Esfahan

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Introduction

The hydrologic status of the lake's water results from intricate processes involving physical, chemical, and biological factors.[1] Water is one of the primary natural resources on Earth, traditionally shared among all living organisms. Continuous monitoring and assessment of surface water quality are essential for safeguarding the global ecosystem and human health.[2] Consequently, after studying the state of water quality, the next step is to find solutions to reduce pollution and effectively manage water resources.[3,4] Water quality indices are impressive gadgets used for water quality appraisal. They have been in use since 1965 when Horton extended the first type of the water quality index (WQI).[5] The original purpose of quality indices is to condense a significant number of physical, chemical, and biological measurements into a single value that reflects the ecological status of a specific watercourse.[6,7] There are diverse ways to recognize the quality of water. One of the most critical ways to estimate water quality is the WQI method.[8] The WQI is based on various physico-chemical and biological virtues of water accumulated during the sampling period. In the field of limnology, dams are often referred to as artificial lakes, and their purposes have expanded to include goals that encompass both quality control and quantity targets.[9] The Zayande-rood Lake dam is critically important due to its multiple applications, which include providing drinking water for Isfahan, Yazd, and Chahar Mahal Bakhtiari, securing water for agricultural and industrial use in Esfahan province and neighboring provinces, as well as power generation. Furthermore, it plays an essential role in the economic life of the region due to its proximity to large urban centers, industry, and tourism. The objective of this study was to determine the physico-chemical parameters, as well as evaluate water quality using the WQI and national sanitation foundation WQI (NSFWQI) in the Zayande-rood Lake dam.

Materials and Methods

Study Zone

The dam is located in the city of Isfahan, with coordinates of approximately 34° 43’ 32” and” 5 ‘43 ° 32 norths and “18 ‘44 ° 50 and” 4 ‘36 ° 50 east, with 110 kilometers in west of the city. Based on previous studies conducted on the lake, five sampling stations were selected at various levels within the lake. The sampling locations and their geographical coordinates have been presented in Figure 1 and Table1, respectively. To access these points consecutively, GPS devices were used. Sampling was conducted in 7 steps, with one sampling event every 45 days in each of the four seasons (2 times in each season).

Sampling of Water and Analysis

The lake water was sampled in 7 steps, with one sampling event every 45 days during each of the four seasons (a total of 2 times in each season) at 5 stations. After collecting water samples, dishes were washed at the same site. Water samples were collected from depths of 0.5, 3, 5, and 10 meters, as well as near the bed using Nansen bottles, and they were transported to the laboratory under traditional conditions. Physico-chemical parameters were measured using standard methods.[10]

Water Quality Index

The WQI was developed based on critical parameters related to human health. The WQI includes the following stages[11]:

Stage 1: Each parameter was assigned a weight (AW) ranging from 1 to 4, as determined by experts in previous studies.[12-18] The weight assigned to each parameter is documented in Table 2. The weight connections of 1 and 4 represent the lowest and highest levels of association, respectively.

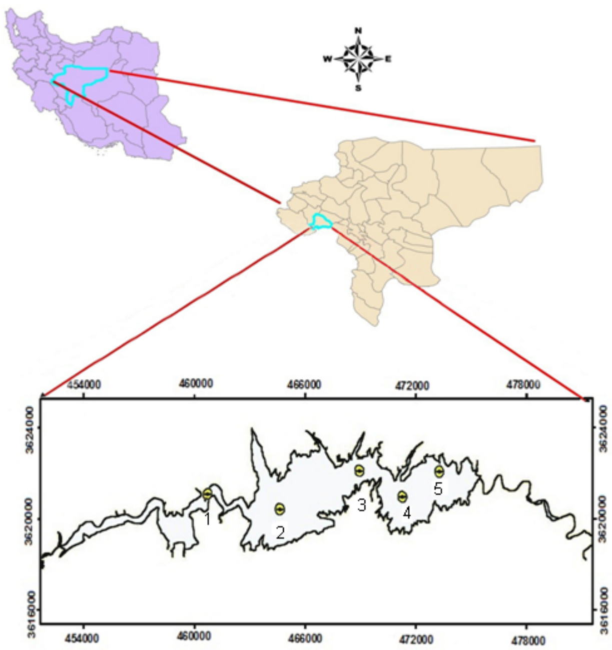

Figure 1. The Geographical Location of the Sampling Stations in Zayande Rood Lake

Stage 2: Relative weight (RW) was computed using equation 1.

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

AW: Each parameter was assigned a specified weight, denoted as RW (Relative Weight). The computed relative weight for each parameter is presented in Table 2.

Stage 3: Equation 2 was employed to establish a quality rating scale (Qi) for all parameters, except for pH and dissolved oxygen (DO), for which Equation 3 was utilized.

$$Qi = (Ci / Si) \times 100 \quad (2)$$

$$Qi = (Ci - VI / Si - VI) \times 100 \quad (3)$$

In which Ci is the quantity of water quality parameter gains from the laboratory analysis, Si is the quantity of water quality parameter presented in world standards or standards of Iran, Qi is the quality ranking. Also, VI is the superior value of 7.0 for pH and 14.6 for DO.[11]

Stage 4: The sub-indices (Sri) were computed for each parameter using equation 4. WQI was estimated using total Sri (Equation 5). Water quality class was specified using Table 3.

$$SIi = RW \times Q \quad (4)$$

$$WQI = \Sigma\, SIi \quad (5)$$

NSFWQI

DO, biochemical oxygen demand (BOD_5), pH, nitrate, phosphate, changes in temperature, and dissolved solids were calculated in the Zayande rood lake dam to estimate the NSFWQI. The weight assigned to fecal coliforms in

Table 1. The Geographical Location of the Sampling Stations in Zayande Rood Lake

Stations	Longitude	Latitude
1	50 °34′ 50″	32°43′37″
2	50°37′20″	32°43′16″
3	50°40′5″	32°44′11″
4	50°41′37″	32°43′35″
5	50°42′53″	32°44′71″

Table 2. Weight Factor of NSFWQI

Water Quality Parameters	Unite of Measurement	Weight Factor
DO	Saturate percent	0.21
pH	-	0.14
BOD_5	mg/L	0.14
NO3	mg/L	0.13
PO4	mg/L	0.13
Temperature change	°C	0.13
TDS	mg/L	-

Table 3. Water Quality Classification Based on WQI[12]

Status	WQI Values
Excellent	<50
Good	50-100
Poor	100-200
Very poor	200-300
Unsuitable	>300

Zayande Rood Dam Lake is relatively low due to their small presence in the lake. Additionally, the weight for the turbidity index is affected by factors such as inaccurate estimation resulting from dirty glassware, air bubbles in the sample, and other considerations when compared to other parameters. There are different methods for weight distribution between other parameters. In this study, we assigned ratios to each parameter based on their respective importance, as outlined in Table 3.

Statistical Analysis

Statistical analysis of the data was conducted using SPSS 19. Normalization and homogeneity of variances were assessed using the Kolmogorov–Smirnov and Levene tests. To assess differences between sampling stations and stages, one-way ANOVA analysis and the Duncan test were performed.

Results and Discussion

Physicochemical Characteristics of Water

Evaluation of the water quality based on physical, and chemical parameters are as photographs of occurrence that occurred in the water masses. Hence, it can only depict the impact of events as they occur. Assessment based on quality indices can provide estimates of the long-term impact of events even after their occurrence. The measurements of water physical and chemical parameters for Zayande rood dam lake are presented in Figures 2 and 3. Among the parameters evaluated at the sampling stations throughout the year, only dissolved oxygen, nitrate, nitrite, and ammonium exhibited a significant difference between sampling stations ($P<0.05$) (Figure 2). However, all evaluated parameters (dissolved oxygen, nitrate, nitrite, ammonia, stiffness, electrical conductivity [EC], total dissolved solids [TDS], and BOD5) showed a significant difference ($P<0.05$) in terms of time (Figure 3). Comparison of the WQI during the study period revealed significant differences in both spatial and temporal dimensions ($P<0.05$) (Figures 2 and 3). Additionally, the NSFWQIa and NSFWQIm indices exhibited significant differences only at the time of sampling ($P<0.05$).

The study of dissolved oxygen, nitrite, nitrate, and ammonium levels across sampling stations commonly indicated higher values (except for nitrate) at the first station throughout the study period. This distinct pattern sets the first station apart from the others. Based on the research findings, stations 3, 4, and 5 did not show significant differences in the studied parameters. In contrast, stations 1 and 2 exhibited significant differences in some parameters compared to Stations 4 and 5 ($P<0.05$) (see Figure 2). The position of Station 1 at the entry zone of the Zayande Rood River into the lake appears to be the primary factor contributing to these changes. For instance, the turbulent flow of the river and the lower water temperature in this area provide favorable conditions for better atmospheric oxygen absorption, leading to an increase in oxygen concentration.[13] The gradual reduction in mineral nitrogen compounds away from the first station is attributed to the deposition of transported materials, as found by other researchers.[14] Furthermore, it is important to consider the role of human activities upstream as a contributing factor in altering the physical and chemical characteristics of water, particularly at Stations 1 and 2. Dissolved oxygen levels varied across sampling stations throughout the year, with Station 1 showing a higher average and a broader range compared to the other stations. The dissolved oxygen showed a significant difference in this station (Figure 2a) ($P<0.05$). The changes in dissolved oxygen levels exhibited a declining trend from early spring to early autumn (see Figure 3a). This decline can be attributed to factors such as increased water temperature, heightened biological activity, increased oxidation processes of organic matter, and seasonal variations, all contributing to a reduction in oxygen levels within the water environment.[15] Conversely, during autumn and winter (from October to March), there was an increase in dissolved oxygen levels. This increase can be attributed to factors such as a decrease in water temperature, reduced biological activity and oxygen consumption, as well as the wind causing turbulence in the water. Cold and turbulent water tends to hold more oxygen at the surface compared to warm and calm water conditions.[13] The results obtained in this study, which are based on spatial and temporal changes in oxygen concentration in lakes, are consistent with observations in previous studies, including in Choghakhore wetland,[16] on the same lake,[17] and on Hadji Samb lake.[13] In a study conducted by Yogendra and Puttaiah in 2008 on the water masses of Chicago city, they observed that the dissolved oxygen concentration was highest during the cold season and reached its lowest value in the warm season.[18] It appears that the fluctuations in the nutrient levels of water resources across different seasons are associated with human activities, such as agriculture and animal husbandry, within the watershed. The increase in nitrogen compounds (nitrate, ammonium, and nitrite) appears to be proportional to the volume of input flows into the lake, particularly during the early spring, especially at Stations 1 and 2. Furthermore, the rise in the latter half of the summer may be attributed to the use of nitrogen fertilizers and organic agricultural practices during the spring and early summer (Figure 2b, c, d and Figure 3b, c, d). The reduction in the phytoplankton population during winter, attributed to the freezing of the lake (an infrequent occurrence observed during the study and over the last

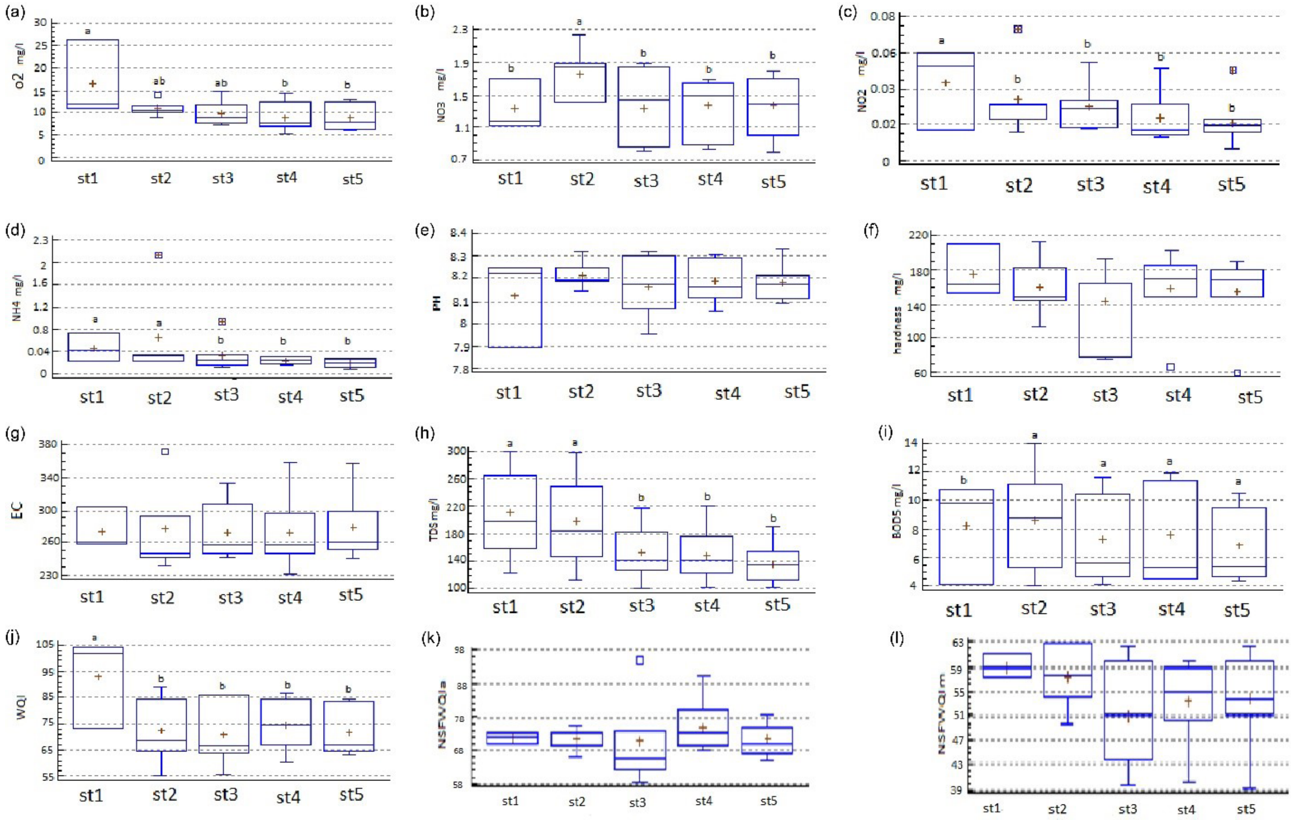

Figure 2. The Depict Changes in Water Physical and Chemical Parameters Across the Study Stations. a) DO, b) NO3, c) NO2, d) NH4, e) pH, f) hardness, g) EC, h) TDS, i) BOD5, j) WQI, k) NSFWQIa, l) NSFWQIm

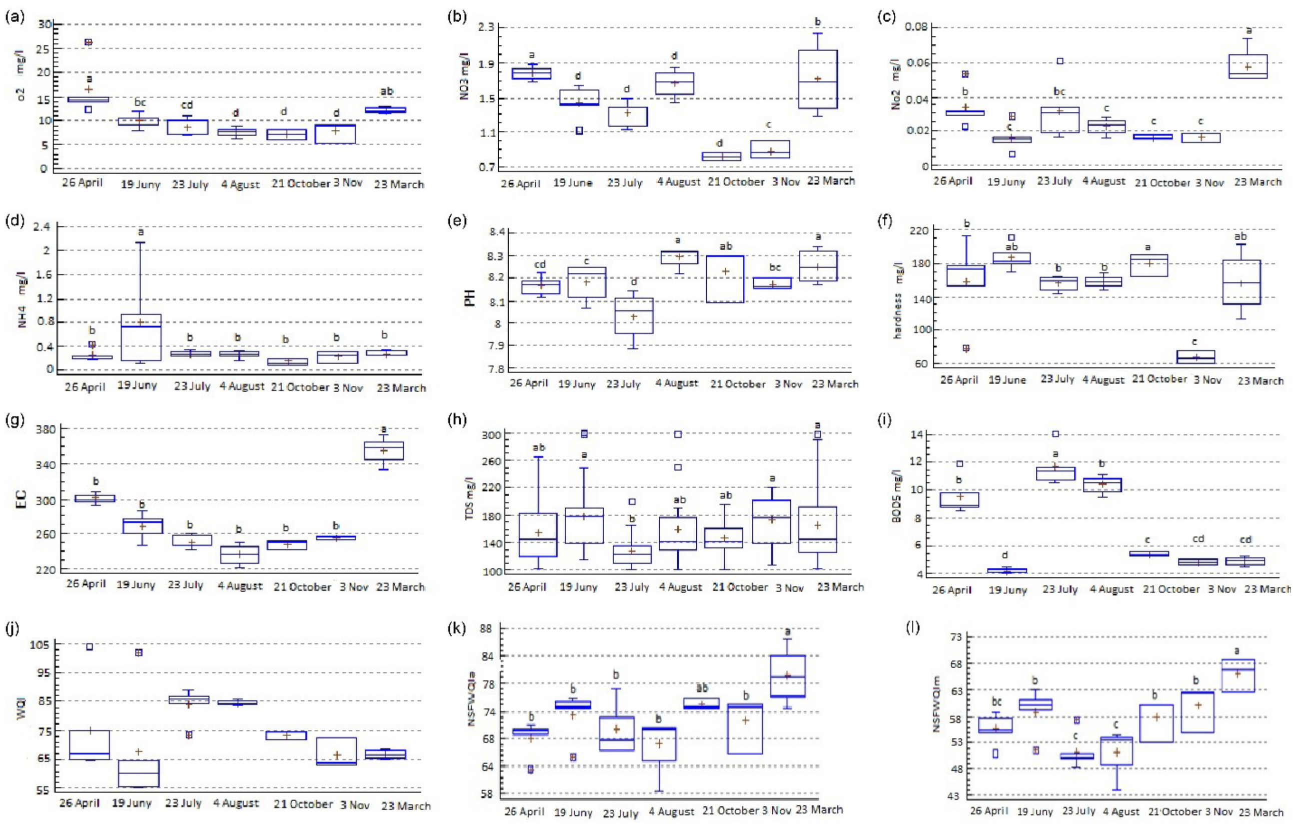

Figure 3. The Change in Physical and Chemical Parameters of Water in Different Stages of Sampling. a) DO, b) NO_3, c) NO_2, d) NH4, e) pH, f) hardness, g) EC, h) TDS, i) BOD_5, j) WQI, k) NSFWQIa, l) NSFWQIm

30 years), has been associated with decreased nutrient consumption and an increase in nutrient concentrations. Additionally, the activity of bacteria in the nitrogen cycle can lead to changes in the forms of nitrogen present in the water. Nitrification is responsible for the conversion of nitrite to nitrate.[11] In their study, Bani demonstrated a negative relationship between nutrient levels (nitrate and phosphate) and the frequency of phytoplankton, indicating that a reduction in nutrient levels leads to an increase in phytoplankton frequency.[19] Additionally, a study by Taowu et al in 2008, conducted in Lake Manchar, Pakistan, revealed that nitrate, ammonium, nitrite, and phosphate levels could result from contaminated water entering the environment due to domestic wastewater and fertilizer use in agriculture.[20] The significant increase in ammonium concentration observed in June, as compared to other stages in the present study, suggests a higher volume of wastewater input during the spring. A study of the Tet River has confirmed that elevated nitrogen levels result from various human activities, including the use of fertilizers in agriculture and the discharge of organic pollutants into the environment.[21] Similarly, a study by Lodh et al in 2014, conducted on an ancient lake in India, identified nitrate as the primary nutrient driving the growth of phytoplankton and algae. It has been established that the major sources of ammonium and nitrate in water bodies stem from human activities encompassing food production, agriculture, industry, and domestic wastewater.[22,23] The geological structure of the Zayande-rood lake dam is associated with the Precambrian period.[24] Changes in water hardness levels in the lake over the years have indicated significant differences ($P<0.05$), and the observed range falls within the expected hardness range due to the metamorphic nature of the area.[25] Additionally, there were no significant differences observed among the sampling stations. The pH levels in various regions of the lake differ due to variations in the geological and hydrological characteristics of these areas, as well as differences in the abundance of acidic substances and fertility rates. Generally, the pH of most lakes falls within the range of 6 to 9. However, there are exceptions, such as Volcanoes Lake, where the pH can reach as low as 2 due to the presence of sulfuric acid, a potent mineral acid .The geological structure of Zayande Rood Lake Dam primarily consists of $CaCO_3$, resulting in a relatively stable and oligotrophic pH level.[24] pH plays a crucial role in water health and fertility, making it a significant factor in assessing water quality.[26] It is a vital parameter in aquatic ecosystems due to its influence on numerous chemical and biological processes within the water body. Changes in pH levels at different sampling stages are often linked to variations in photosynthetic activity within the lake. The observed range of pH change indicates alkaline water characteristics. The normal pH level in the lake is attributed to the water's hardness, its buffering capacity, and the abundance of carbonate minerals. Similar studies have demonstrated that water alkalinity is a result of the presence of carbonate and bicarbonate ions. These findings suggest that the alkaline pH range remains relatively unaffected by significant human activities. EC serves as an indirect indicator of dissolved salts in the water. The high EC levels can be attributed to various factors, including natural weathering, sedimentary rocks, human activities, or sea discharge.[26-28] EC is influenced by the concentration of dissolved solids in water and plays a significant role in shaping biological communities.[29] The observed EC levels in March and early spring may result from late winter and early spring precipitation, leading to increased surface flow in water bodies. Additionally, the season changes often bring strong winds that redistribute lake bed sediments in shallow areas and beaches, contributing to changes in EC.[16]

A study conducted by Yogendra and Puttaiah in 2008 reported an increase in EC during the summer. However, it is worth noting that the results may not directly align with this study, as the lake is located in an urban area.[18] In contrast, a study by Movahedi Nasab in 2011 on Zayande Rood Lake Dam showed a decrease in EC from May to September, which corresponds to the findings of this study.[17] Changes in TDS levels mirror those of EC in the present survey, with reduced rainfall from spring to summer leading to decreased flows into the lake and subsequently lower TDS levels. The dependence of total soluble solid particles on seasonal and rainfall intensity changes has been demonstrated in similar studies. BOD_5 is a measure used to assess the amount of decomposing organic matter in water.[30] A BOD_5 level of less than three ppm is indicative of non-polluted water.[16] While BOD_5 levels did not exhibit significant differences between sampling stations over the course of the year (Figure 2i), there was a notable distinction between stations 1 and 2 compared to stations 3, 4, and 5, which are situated farther from the lake's inflow point. Changes in BOD_5 at various sampling stages (Figure 3i) demonstrated an increase in organic matter within the water body during the warm season and a decrease during the cooler months of the year. The improved production conditions, including higher temperature and increased light, during the summer lead to greater organic matter production, consequently resulting in an increase in BOD_5 during that season. In winter, the decrease in temperature, reduced daylight duration, and diminished intensity collectively result in a decrease in photosynthetic activity. Consequently, this leads to a reduction in the production of organic matter and a decrease in BOD_5 levels. Spatial and temporal changes in BOD_5 indicate an increase in organic matter within the Zayande Rood Lake Dam. This trend is a cause for concern as it suggests a prolonged issue that demands attention for effective water quality management of the lake. In support of these studies, Fathi found that local pollution is the primary factor contributing to the increase in BOD_5 in Choghakhor water wetland.[16] Additionally, a study conducted by Lodh et al in 2014 on an ancient lake in India revealed that the primary reasons for the increase in BOD_5 are wastewater from agriculture, households, and human activities.[22] Furthermore, Yogendra and and Puttaiah observed a seasonal relationship between the levels of BOD_5 and Shimano city waters during their study. The average WQI value at the first station was 92.5, which was significantly higher ($P<0.05$) than that of the other stations. It is located near the lower end of the spectrum for good quality waters (Figure 2j). The WQI ranged from 70 to 75, and there were no significant differences identified between these values, indicating relatively better water quality than the first station. When examining the WQI across different sampling stages during the study period (see Figure 3j), significant differences were observed between the sampling stages ($P<0.05$). However, based on the water quality classification outlined in Table 2, the changes in water quality indicators across the sampling stations and stages were consistently within the 'good' range (50-100). In general, the water quality, with an average WQI of 74.41, fell within the 'well' class, making it suitable for human consumption and drinking purposes. Most of these indicators exhibited their lowest quality during late summer, with the best rates observed in late autumn and winter. NSFWQI values remained relatively steady across different stations, with no significant differences observed. Station 4 had the highest NSFWQIa value at 74.93, while the lowest value, equal to 70.57, was recorded at the third station. According to the water quality classification based on NSFWQI, all stations fall within the 'good' quality class. Analysis of variance showed a significant difference between the different stages of sampling ($P<0.05$). The lowest index value was recorded during the fourth sampling stage (late summer), while the highest was observed during the seventh stage (late winter). It is noteworthy that the most crucial factors influencing the WQI are dissolved oxygen and BOD_5. Therefore, the decline in water quality, as indicated by this index in September, can be attributed to the decrease in dissolved oxygen levels and the increase in BOD_5 concentrations during this sampling stage. As a result, the increase in dissolved oxygen during winter contributes to an enhancement in the quality index. The classification of water using the NSFWQI highlights the sensitivity of the index to the characteristic of DO, as a low value of this parameter can lead to a decrease in the index value. The NSFWQIm ranged from 50.94 to 59.04, with the maximum value observed at Station 1 and the minimum value at Station 3, showing variation among stations. Overall, the changes in the index fell within the medium range. Assessment of the indicator across different sampling stages (Figure 3l) revealed significant differences over time ($P<0.05$). The highest level of this index was recorded in late winter, while the lowest was observed in early summer. In general, the indicator showed an increase from early spring to late spring, followed by a decrease in summer, and another increase in winter. The lower values of NSFWQI during summer can be attributed to the influx of agricultural and domestic wastewater into Zayande Rood Lake Dam, which significantly affected the levels of PO_4 and BOD_5, consequently influencing the NSFWQI and overall water quality.

Conclusion

This study assessed the water quality of Zayande Rood Lake Dam using the WQI. Overall, the water quality fell within the 'good quality' category (50-100), but it varied by season. Summer recorded the highest WQI (63.84), while the lowest was observed in the fall (41.66). Stations receiving water flow from the Dam watershed consistently exhibited lower water quality throughout the year. While the WQI suggests that the water was not suitable for human consumption, the NSFWQIa indicated moderate to good quality. The highest values were in the winter (79.42), and the lowest in the summer (67.02). Using the NSFWQIm, the water quality was categorized as moderate. The highest and lowest index levels occurred in winter (66.03) and summer (51.27). A higher NSFWQI value reflects better water quality. In conclusion, the water quality of Zayande Rood Lake Dam fells within the moderate range, transitioning from good quality. This may be influenced by seasonal variations, emphasizing the need for more precise management to maintain water quality. Watershed management can help prevent incompatible human activities and preserve ecological characteristics, existing agricultural patterns, and mitigate drought occurrences.

Authors' Contribution

Conceptualization: Mahtab Khalaji.
Data curation: Mahtab Khalaji, Eisa Ebrahimi.
Formal analysis: Mahtab Khalaji, Eisa Ebrahimi.
Funding acquisition: Eisa Ebrahimi.
Investigation: Mahtab Khalaji, Eisa Ebrahimi.
Methodology: Mahtab Khalaji, Eisa Ebrahimi.
Project administration: Mahtab Khalaji, Eisa Ebrahimi.
Resources: Mahtab Khalaji, Eisa Ebrahimi.
Software: Mahtab Khalaji, Eisa Ebrahimi.
Supervision: Eisa Ebrahimi.
Validation: Mahtab Khalaji, Eisa Ebrahimi.
Visualization: Mahtab Khalaji, Eisa Ebrahimi.
Writing–original draft: Mahtab Khalaji.
Writing–review & editing: Mahtab Khalaji.

Competing Interests

The authors declare no competing interests.

Data Availability Statement

The data are available upon request.

Ethical Approval

This study was ethically approved by the host university: Isfahan University of Medical Sciences.

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