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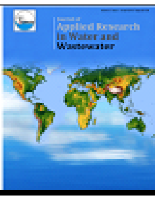

Novel approach for assessing reservoir water quality using the water quality index: A case study on Talvar Dam reservoir, Kurdistan, Iran

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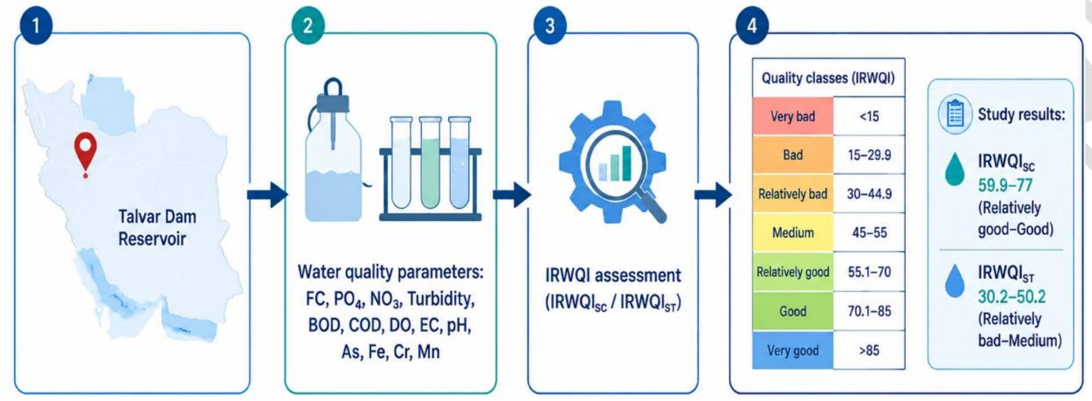
GRAPHICAL ABSTRACT



Quality classes (IRWQI)	
Very bad	<15
Bad	15–29.9
Relatively bad	30–44.9
Medium	45–55
Relatively good	55.1–70
Good	70.1–85
Very good	>85

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ABSTRACT

In this study, by modeling water temperature and some quality parameters using the CE-QUAL-W2 numerical model during different months of the year in the Talvar Dam reservoir, the thermal stratification and mixing times were determined. According to the temperature profile in thermal stratification period, epilimnion, metalimnion and hypolimnion depths were determined. Water quality of the dam reservoir was evaluated using Iran Water Quality Index for Surface Water Resources - Common Parameters ($IRWQI_{SC}$) and Iran Water Quality Index for Surface Water Resources - Toxic Parameters ($IRWQI_{ST}$). For calculation of $IRWQI_{SC}$, some parameters were used including Fecal Coliform, Phosphate, Nitrate, Turbidity, BOD, COD, DO, EC, pH and for calculation of $IRWQI_{ST}$, some parameters were used including Arsenic, Iron, Chrome and Manganese. Considering the effects of thermal stratification on water quality in different points of dam reservoir (hypolimnion, epilimnion) and at different times, a new method was used to evaluate water quality in dam reservoirs based on water quality index. In this method, water quality index was calculated in hypolimnion and epilimnion at different times. In this way, during thermal stratification period of the dam reservoir, the water quality indices were calculated separately for the hypolimnion and epilimnion. Moreover, during mixing period, these indices were calculated for the entire reservoir. Results of the present study showed that water quality of the dam reservoir lied in the relatively good and good class in terms of common parameters ($59.9 \leq IRWQI_{SC} \leq 77$), and in the medium and relatively bad class in terms of toxic parameters ($30.2 \leq IRWQI_{ST} \leq 50.2$).

1. Introduction

With the development of human activities, various water resources, especially surface water resources, have been exposed to various types of pollution, which can be in the form of point or non-point Source pollutions. Controllable and uncontrollable factors can also affect water quality. Controllable factors include the construction of dams and irrigation projects, and uncontrollable factors include climate change, reduced rainfall, and temperature increase (Chabuk *et al*., 2020). Overall, in recent years, water pollution has become a major concern that threatens both the humans and natural ecosystems (Hammoumi *et al*., 2024). In water resources studies, water quality is as important as its quantity. Surface water quality is one of the important topics in applied hydrology since the main activities of water resource development are aimed at providing water for drinking, agricultural and industrial purposes, each of which must have specific quality characteristics and standards, and if such water is not provided, these activities will not be profitable. Therefore, water resources quality should be evaluated periodically and continuously in order to better manage water resources (Yusuf and Rafindadi, 2018). Dam reservoirs are very important in terms of meeting various water demands, including drinking, agriculture, industry and water recreation, etc. Since water in the dam reservoirs is used for different purposes, it is necessary to consider the quality standards related to these applications when evaluating water quality of the dam reservoir. The use of various indices, including the water quality index, can convey the

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results of quality evaluation to the audience in an understandable way and provide a correct view of the overall water quality condition in the audience's mind in a short time (Jakovljević *et al*., 2025; Ebrahimi, 2025; Dindar, 2025).

Shoaei *et al*. studied the concentration of heavy metals (nickel, cobalt, cadmium, lead, zinc and copper) in the Shahid Rajaee Dam reservoir and found that fertilizers which are used in the upstream farms can be the source of nickel, zinc, cadmium and copper metals, and pesticides can be the source of cobalt and lead metals. It was also found that the concentration of cadmium and lead in the reservoir water can be harmful to health (2014). Torres *et al*. used the CE-QUAL-W2 model to simulate the flow and water quality of the Sancho reservoir, Spain to predict the formation of thermocline and oxycline, as well as the concentration of salinity, ammonium, nitrate, phosphorus, algae, chlorophyll a and iron. The model resulted in a satisfactory simulation of water level, temperature, salinity, dissolved oxygen, ammonium, nitrate, and phosphorus, and simulated chlorophyll a concentration with less accuracy. Dissolved oxygen was well simulated by artificial introduction of iron oxidation for the consumption of the required oxygen in this process. To evaluate the effect of iron oxidation on oxycline formation, the relationship between iron and dissolved organic matter was introduced to the model. The results showed that iron oxidation was the main factor in reducing oxygen in the hypolimnion of the Sancho reservoir (2016). Winton *et al*. studied the effects of dam constructing on water quality by focusing on low latitude areas and resulted that dams can have negative qualitative effects on downstream ecosystems due to sediment and nutrient trapping and thermal stratification (2019). Al-Sabih *et al*. conducted studies on several dams in Saudi Arabia, in which the concentration of parameters such as sodium, potassium, calcium, magnesium, electrical conductivity, sulfate, chlorine, fluoride, and several heavy metals was measured at different stations. In this study, by determining the irrigation indices and the irrigation water quality index (IWQI), it was determined that the surface water samples lied in the classes suitable for irrigation (2022). Karunanidhi *et al*. studied the drinking water quality of groundwater in the Shanmuganathi River Basin in India. In this study, according to the water quality index, 52% of the samples were classified as poor, very poor and unsuitable, and 48% of the samples were classified as good and excellent. In this study, it was found that the southern parts of the study area have better water quality (2021). Nong *et al*. used 19 different parameters to obtain the water quality index to study the water quality status of the middle route of the South to North of China Water Diversion Project and found that the water quality in this project was excellent (2020). Nazari *et al*. used Iranian water quality indices ($IRWQI_{SC}$ and $IRWQI_{ST}$) to evaluate the water quality of the Balkh Sea (Baghlan River) in Afghanistan and found that the river water lied in the weak class due to the presence of heavy metals and based on $IRWQI_{ST}$ and was not suitable for drinking purpose and it may also have destructive influence for other purposes such as agriculture and animal husbandry (2024).

Water quality indices express the status of water quality by considering various parameters, and using these indices, the effect of the simultaneous existence of different parameters on water quality can be determined. These indices represent the average water quality status, which was first invented in 1965 by Horton, R.K. Due to different applications, numerous indices have been developed to determine the quality of water resources and are different regarding the influential parameters and the weight of each parameter in these indices (Basturk, 2019). The weight of the parameters in each water quality index is different, and the effect of each parameter on the water quality index is also different (Ewaid *et al*., 2018; Noori *et al*., 2018; Tiri *et al*., 2018). The present study was aimed to evaluate the changes in the water quality of the Talvar Dam reservoir in Kurdistan Province, located in west of Iran, and to present a method for using the water quality index at different locations and times in the dam reservoir. In this paper, first, the thermal stratification in the Talvar Dam reservoir was studied as one of the effective factors in quality changes of the reservoir water, and the periods of thermal stratification and turnover in the dam reservoir were identified. Then, the Iranian Water Quality Index was used to determine the quality class of the dam reservoir water in the hypolimnion and epilimnion in terms of the presence of common and toxic source pollutions.

2. Materials and methods

2.1. Iran water quality index (IRWQI)

The Iranian Water Quality Index is one of the indices for determining the water quality status, which is divided into four groups: Iran Water Quality Index for Surface Water Resources - Common Parameters ($IRWQI_{SC}$), Iran Water Quality Index for Groundwater Resources - Common Parameters ($IRWQI_{GC}$), Iran Water Quality Index for Surface Water Resources - Toxic Parameters ($IRWQI_{ST}$), and Iran Water Quality Index for Groundwater Resources - Toxic Parameters ($IRWQI_{GT}$). In this study, the $IRWQI_{SC}$ and $IRWQI_{ST}$ indices were used. To determine the quality of surface waters based on $IRWQI_{SC}$, 11 different parameters were used, including percentage of oxygen saturation, electrical conductivity (EC), fecal coliform, nitrate, ammonium, phosphate, turbidity, total hardness, chemical oxygen demand (COD), biochemical oxygen demand (BOD), and pH. To determine the quality of surface water based on $IRWQI_{ST}$, 11 parameters were used, including arsenic, mercury, detergent, lead, cadmium, phenol, chromium, cyanide, iron, manganese, and petroleum hydrocarbons (TPH) (Department of Environment of Iran, 2012; Rasouli *et al*., 2020).

To calculate each of the mentioned indices, the values of all parameters were first converted into the index of that parameter using the graphs provided in the guideline to calculate the quality index of Iranian water resources. Then, based on the tables in this guide, the weight of each parameter was determined, and finally, the water quality index was determined using the following relationships. If the number of parameters under study was less than the 11 parameters specified in the aforementioned indices, that index can be used without any modification and only the weight of those parameters in the Eq. 1 is considered zero (Department of Environment of Iran, 2012; Aminirad *et al*., 2021; Ghamarnia *et al*., 2023).

$$IRWQI = [\prod_{i=1}^{n} I_i^{W_i}]^{\frac{1}{\gamma}} \qquad (1)$$

$$\gamma = \sum_{i=1}^{n} W_i \qquad (2)$$

where, W_i is the weight of the i*th* parameter, n is the number of parameters, I_i is the index value for the i*th* parameter from the ranking curve, and γ is the sum of the weights of the parameters. Table 1 was also used to interpret different values of the Iran water quality index.

Table 1. Classification of the IRWQI values (Department of Environment of Iran, 2012).

Quality class	The numerical value of the index
Very bad	< 15
Bad	15 - 29.9
Relatively bad	30 - 44.9
Medium	45 - 55
Relatively good	55.1 - 70
Good	70.1 - 85
Very good	> 85

2.2. Study area and sampling

Talvar Dam is located in Iran at 35°47′30″N latitude and 47°54′27″E longitude, approximately 54 km southeast of the city of Bijar, constructed on the Bijar River. The main purpose of the dam construction was to increase the cultivated areas and agricultural production, provide drinking water for some of the surrounding cities and villages, and prevent floods and control the overflow of the Talvar River. This earthfill dam with a clay core has a total reservoir capacity of 500 million cubic meters and regulates 231 million cubic meters of water annually. The Talvar Dam's catchment area is 6441 square kilometers and the average river flow is 283 million cubic meters per year (Fig. 1). A longitudinal depth profile of Talvar Dam Reservoir from St1 (Segment 52) to St 2 (Segment 3) is presented (Fig. 2), showing the variation in reservoir bed elevation along the main axis. Note that the profile represents the topography of the reservoir bottom.

Sampling operations were carried out on a monthly basis from April 2019 to March 2020 from two stations, St1, located near the dam body and St2, located in the initial parts of the reservoir and near the river inlet to the reservoir (Fig. 1). The sampling depth at St1 varied from 1 to 40 meters, and at each sampling time, a minimum and a maximum of 1 and 5 samples were collected, respectively. During warm seasons, when there are large temperature changes due to the thermal stratification phenomenon, the number of samples taken at St1 was higher to more accurately study the depth changes in qualitative parameters. At St2 station, due to the relatively shallow depth of the reservoir, only 1 sample was taken at each time (Table 2). Dissolved oxygen (DO) and Biochemical Oxygen Demand (BOD) are among parameters of water quality indexes (Yengejeh, Morshedi and Yazdizadeh, 2014). From the samples taken, the values of temperature, dissolved oxygen, electrical conductivity, fecal coliform, nitrate, phosphate (in terms of P), turbidity, BOD, COD and pH were measured as common parameters and the values of arsenic, iron, chromium and manganese were measured as toxic parameters.

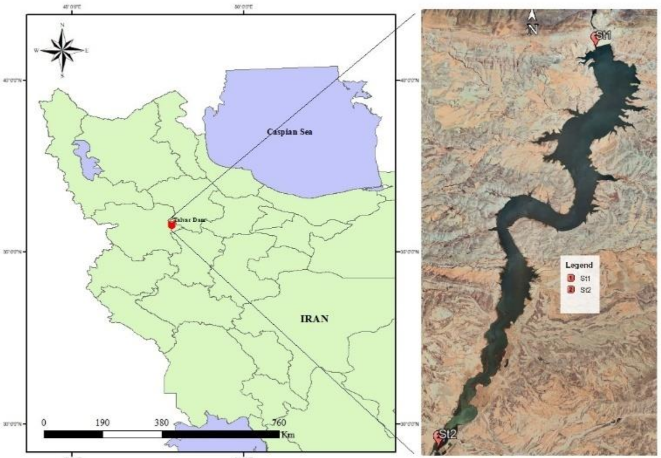


Fig. 1. Location of the Talvar Dam and sampling stations of St1 located near the dam body and St2 at the beginning of the reservoir near the river inlet to the reservoir.

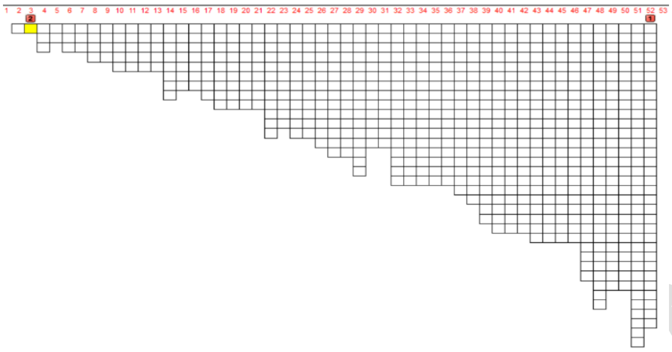


Fig. 2. longitudinal depth profile of Talvar Dam Reservoir.

Monthly average inflow and outflow of the reservoir are presented (Fig. 3), showing variations over the months during the study period. In general, inflow and outflow were higher at the beginning and end of the period, with lower flows in the middle months. This pattern corresponds with the observed monthly water availability and is consistent with the greater thermal stratification observed during months with lower inflow.

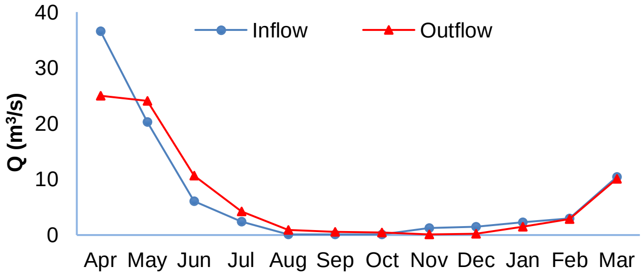


Fig. 3. Monthly average inflow and outflow of Talvar Dam reservoir.

2.3. Simulation of temperature and qualitative parameters of the reservoir

The formation and disappearance of thermal stratification affect the ecosystem of a dam reservoir (Wang *et al.*, 2024) and since temperature influences all chemical and biological interactions, temperature changes can cause changes in water quality, which cannot be ignored in reservoir dams with long water residence times (Chapra, 1997; Javid *et al.*, 2014). In addition, temperature differences at different depths of the dam reservoir cause the formation of water layers with different temperatures and densities. Thermal stratification is a common phenomenon in dam reservoirs, especially in temperate regions (Hassani *et al.*, 2025; Madyouni *et al.*, 2025). In thermal stratification, warmer (lighter) layers are located at the upper levels and cooler (heavier) layers are located at the lower levels of the reservoir. By developing the thermal stratification and considering the different densities of these layers, which prevent them from mixing, and also considering the effect of temperature on water quality, it can be expected that qualitative stratification will also occur in dam reservoirs. In temperate regions, thermal stratification is usually formed in dam reservoirs once a year in the warm months, and in the cold months, stratification mixing occurs. In the mixing process, as the air cools, the temperature and consequently the density of water at different depths of the reservoir become the same, and as a result, thermal stratification is destroyed and water in the dam reservoir mixes. Therefore, the temperature profile at different depths of the dam reservoir can be used as a criterion for identifying the thickness of the different layers and also for identifying the months in which the thermal stratification is developed. Studying stratification is important because thermal stratification can negatively influence water quality by reducing vertical mixing, reducing dissolved oxygen and accumulating source pollution in the hypolimnion (Hutchinson, 1957).

Table 2. Number of samples taken at St1 and St2 Stations.

Sampling time	Number of samples	
	St1	St2
April	1	1
May	1	1
June	5	1
July	5	1
August	4	1
September	5	1
October	5	1
November	5	1
December	3	1
January	3	1
February	3	1
March	3	1

The increasing use of the CE-QUAL-W2 model by researchers indicates the significant potential of the model in simulating hydrodynamics and water quality in various water bodies. In 2022, 113 citations were made to papers in which the CE-QUAL-W2 model was used, showing that the model has been widely used in many countries, with Iran, China, and Brazil leading in terms of the number of publications (Benicio *et al.*, 2024). In this study, first, the temperature, TDS, nitrate, dissolved oxygen, and alkalinity parameters of the Talvar Dam reservoir were simulated using the CE-QUAL-W2 model, and the depth profile of water temperature of the Talvar Dam reservoir was calculated at different times. The water quality index was calculated based on the data collected from the station St1. During the thermal stratification period, the water quality index was calculated separately for the hypolimnion and the epilimnion. During the mixing period, due to low changes in various quality parameters in depth, the index was calculated for the entire reservoir. Separate study of the epilimnion and hypolimnion water quality in the dam reservoir can provide effective assistance in providing management solutions in the selection of the water intake and withdrawal levels, optimal use of water, and providing remedial solutions to increase the water quality of the reservoirs (Rasouli *et al.*, 2020).

3. Results and discussion

3.1. Model calibration and validation

In the modeling of the Talvar Dam reservoir using the CE-QUAL-W2 model, an eight-months period was selected as the calibration period and a three-months period as the validation period. The modeling error of each parameter in the calibration and validation periods was obtained using the error measurement parameters of Mean Absolute Error (MAE) according to Eq. 3 and Normalized Root Mean Square Error (NRMSE) according to Eq. 4 (Table 3). The NRMSE value for all parameters in the calibration and validation periods was less than 0.5, indicating the appropriate modeling accuracy. The reason for using the NRMSE parameter to indicate the error is the large difference in the concentration change range of different parameters, and using NRMSE parameter, the effect of the measurement unit of different parameters and the concentration change range of each parameter is eliminated and the normalized error is obtained (Shcherbakov, 2013).

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|y_i - x_i| \tag{1}$$

$$NRMSE = \frac{1}{x_{max}-x_{min}}\sqrt{\frac{\sum_{i=1}^{n}(y_i-x_i)^2}{n}} \tag{2}$$

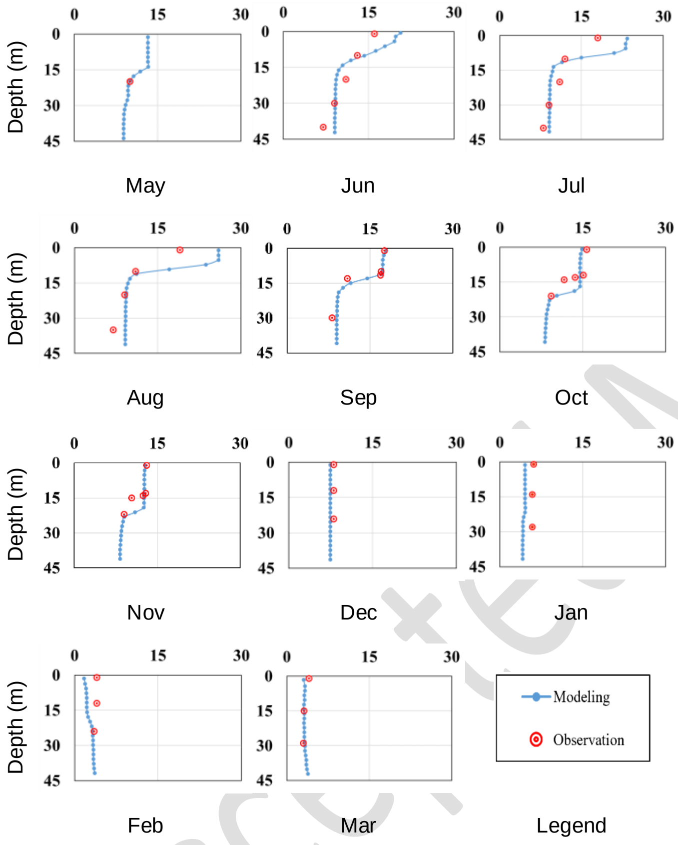
where, the parameter n indicates the number of data, the parameter x indicates the values of the observational data, and the parameter y indicates the values of the modeled data.

Table 3. Error of the modeled parameters during the calibration and validation periods.

Parameters	**Calibration period**		**Validation period**	
	NRMSE	MAE	NRMSE	MAE
Temperature	0.115	1.06	0.137	1.42
DO	0.239	1.45	0.40	2.15
Nitrate	0.306	0.68	0.342	0.55
Alkalinity	0.238	13.46	0.286	9.18
TDS	0.168	45.11	0.297	70.39

3.2. Simulation results of the conventional qualitative parameters

The simulation results of temperature indicated the occurrence of thermal stratification from May 16 to November 20 and the stratification mixing from November 21 to May 15 (Fig. 4). In the epilimnion, temperature was almost constant and always higher than the lower layers. In the metalimnion, temperature decreased suddenly. In the hypolimnion, temperature was also almost constant and always lower than the other layers. Considering the temperature profiles during the thermal stratification period, the depths of the epilimnion, the metalimnion, and the hypolimnion were identified separately at different times (Table 4).



May Jun Jul

Aug Sep Oct

Nov Dec Jan

Feb Mar Legend

Fig. 4. Observed and simulated temperature (℃) at station St1 of the Talvar Dam reservoir from May 2019 to March 2020.

The temperature profile in different months indicated that as the air gets warmer, the temperature in the surface layers of the reservoir increased, but the temperature increase in the lower depths of the reservoir was not noticeable. This causes thermal stratification and the formation of three separate layers. These layers also have relatively separate functions in terms of physicochemical and biological aspects due to differences in flow density and viscosity, and cause significant differences in quality parameters of each layer. The depth of epilimnion was low at the beginning of the thermal stratification period and gradually increased by increasing the air temperature and the penetration of solar energy into deeper layers (Table 4), so that the depth of epilimnion was 5 meters at the beginning and reached 16 meters at the end of the thermal stratification period. The increase in the depth of epilimnion by approaching the end of the thermal stratification period was mainly due to greater penetration of solar radiation into the depths of the reservoir. In the warm months (until September), the turbidity of the dam reservoir water was high (Fig. 9), and this could be due to greater activity of the phytoplankton and zooplankton in the warm seasons. As the air got cool and the activity of these organisms decreased, water turbidity also decreased which in turn increased the penetration depth of solar radiation and hence, the depth of epilimnion. In addition to the depth of epilimnion, the temperature difference between the epilimnion and the hypolimnion also changed during the thermal stratification period (Fig. 4) with the difference that at the beginning of the thermal stratification period, the temperature difference between the hypolimnion and the epilimnion was small, and gradually, as the air got warmer, this temperature difference increased and reached 17 degrees Celsius at the beginning of August, which had a great effect on changes in physicochemical and biological processes in different layers of the reservoir (Khayami, 2008). Then, by approaching the end of the thermal stratification period, this temperature difference decreased. Finally, as the weather got colder from November, the temperature in the surface layers of the dam reservoir decreased, which increased water density in these areas. As the density of the layer increased, the mixing process began (November) and the upper layers moved towards the depths of the reservoir, which caused the water in the dam reservoir to mix leading to the same water quality at different depths of the reservoir.

Table 4. Thermal stratification of the Talvar Dam reservoir.

Months of the year	**Epilimnion (m)**	**Metalimnion (m)**	**Hypolimnion (m)**
Start of the Thermal stratification to the end of June	0 - 5	5 - 10	10 <
July	0 - 5	5 - 12	12 <
August	0 - 7.5	7.5 - 13	13 <
September	0 - 11.5	11.5 - 18	18 <
Start of October to November	0 - 16	16 - 21	21 <

The results of TDS simulation in the Talvar Dam reservoir showed that during the thermal stratification period of the reservoir, TDS values weare higher at the depths of the reservoir than near the surface (Fig. 5), which can be justified considering the positive effect of increasing TDS on increasing water density (Cole and Wells, 2006). During these periods, the minimum TDS value in the epilimnion was 785 mg/L in July 1st and the maximum value was 951 mg/L in May 3rd. During the cold seasons of the year, the TDS concentration was almost constant at different depths of the reservoir. Study of the simulated nitrate changes showed that during the thermal stratification period, the nitrate concentration had an increasing trend from the epilimnion to the metalimnion and then a decreasing trend from the metalimnion to the hypolimnion (Fig. 6). The low nitrate content of surface water can be due to the presence of phytoplankton and algae, which are capable of photosynthesis due to the presence of adequate sunlight and use the nitrate in water as a nutrient for growth. The increasing trend of nitrate concentration with depth to the metalimnion can be explained by the conversion of ammonium to nitrate during the nitrification process in the presence of dissolved oxygen, which was also confirmed by the decreasing trend of dissolved oxygen in this area (Fig. 7). With increasing depth from the end of the metalimnion towards the hypolimnion, due to low dissolved oxygen value, the nitrification process decreased, and as a result of the denitrification process and the conversion of nitrate into sediment and sedimentation, or nitrogen gas and its release to the water surface, the nitrate concentration had a decreasing trend (Fig. 6). The high nitrate concentration in the layers near water surface in May compared to the following months can also be due to the low growth and development of algae and phytoplankton due to the low water temperature and, as a result, the reduced nitrate consumption by these organisms (Fig. 4 and 6). The results of the dissolved oxygen simulation in the Talvar Dam reservoir showed that during the stratification periods in the warm seasons of the year, the amount of dissolved oxygen near the water surface was higher which decreased with depth (Fig. 7). One of the reasons for the higher dissolved oxygen content near the surface was the oxygenation of the surface layers of the reservoir due to wind and wave formation, which disappeared with depth. In addition, the photosynthesis activity of algae and green phytoplankton in the surface layers that receive enough sunlight caused the oxygen production by these organisms. In the depths of the reservoir, dissolved oxygen was consumed due to the oxygen demand of sediments and the presence of some plant and animal organisms, and the amount of dissolved oxygen decreased significantly. This decrease in the amount of dissolved oxygen in the depth of the reservoir was more noticeable during the thermal stratification period due to the lack of exchange of dissolved oxygen between the epilimnion and the hypolimnion.

The decreasing trend of the dissolved oxygen concentration in the depths of the reservoir reached to about zero at the end of the stratification period in October and November, which was adjusted by the mixing of the reservoir water. The simulation results of the reservoir alkalinity parameter showed that the depth changes in alkalinity during the stratification period had an increasing trend (Fig. 8), which can be attributed to the release of carbonates from the sediments with a decrease in dissolved oxygen content (Cole and Wells, 2006).

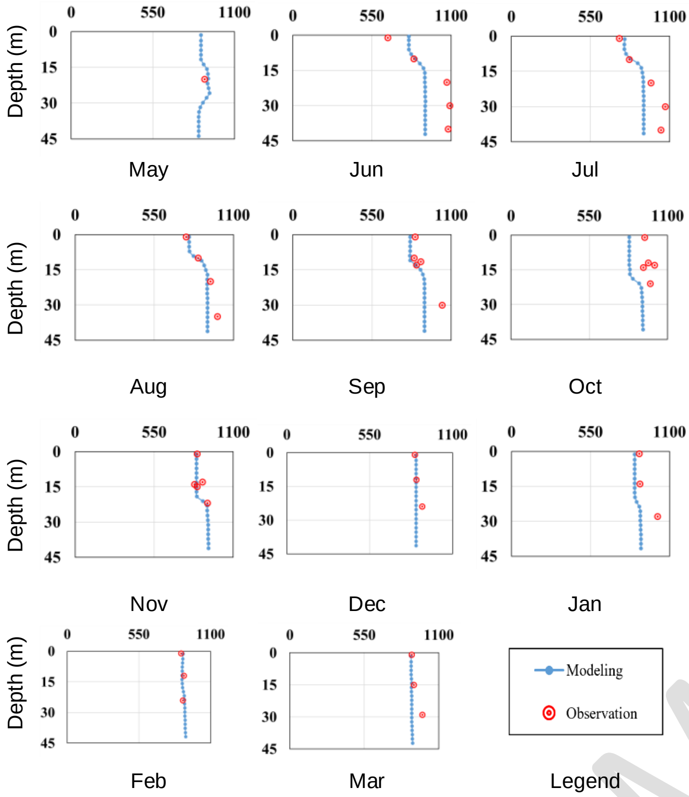


Fig. 5. Observed and simulated TDS (mg/L) at station St1 of the Talvar Dam reservoir from May 2019 to March 2020.

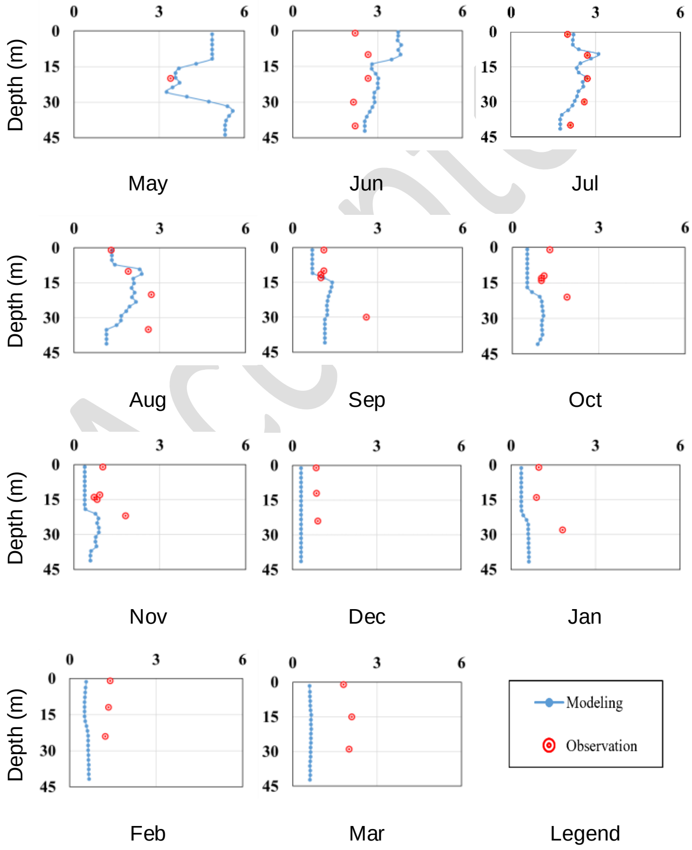


Fig. 6. Observed and simulated nitrate (mg/L) at station St1 of the Talvar Dam reservoir from May 2019 to March 2020.

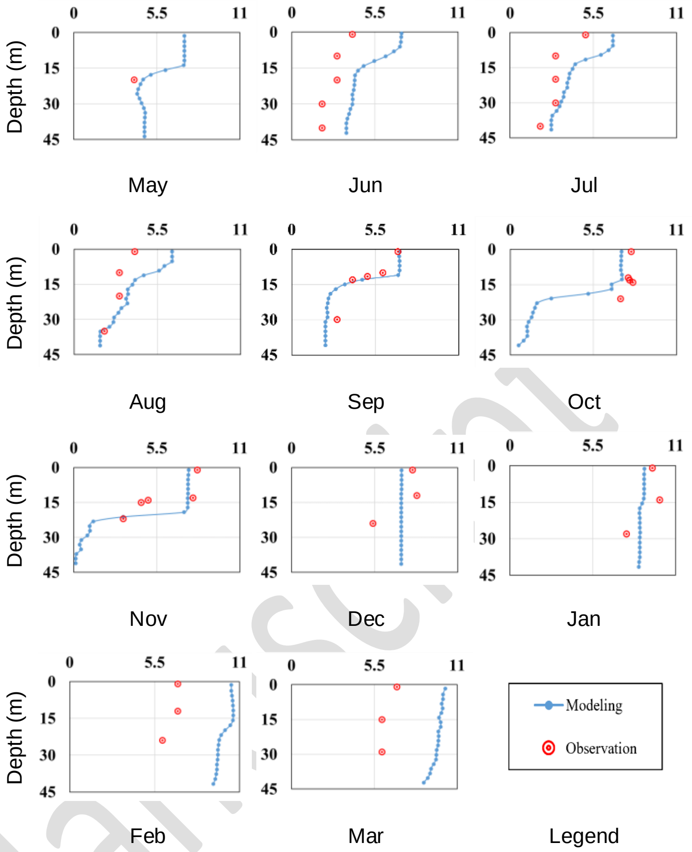


Fig. 7. Observed and simulated dissolved oxygen (mg/L) at station St1 of the Talvar Dam reservoir from May 2019 to March 2020.

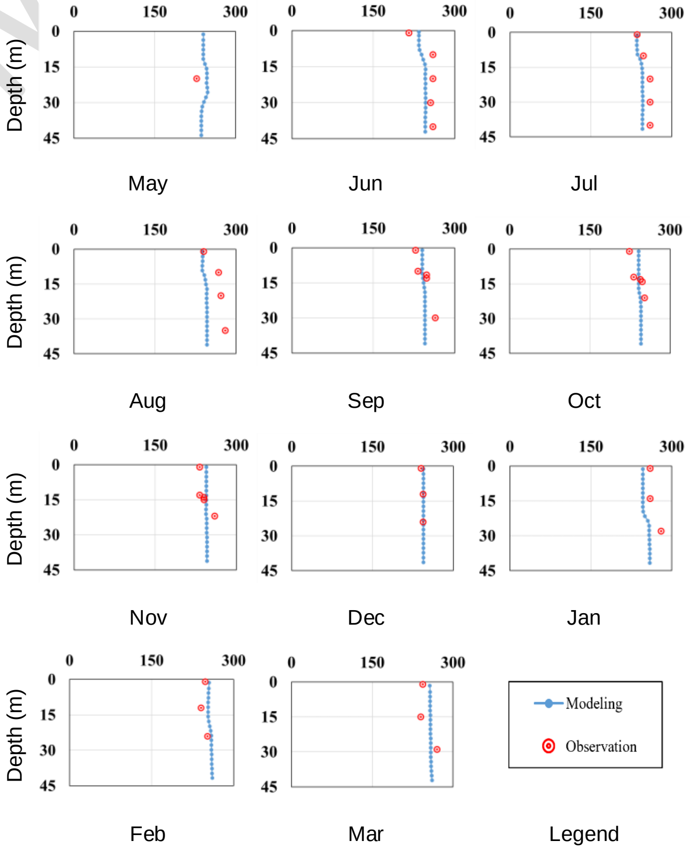


Fig. 8. Observed and simulated alkalinity (mg/L) at station St1 of the Talvar Dam reservoir from May 2019 to March 2020.

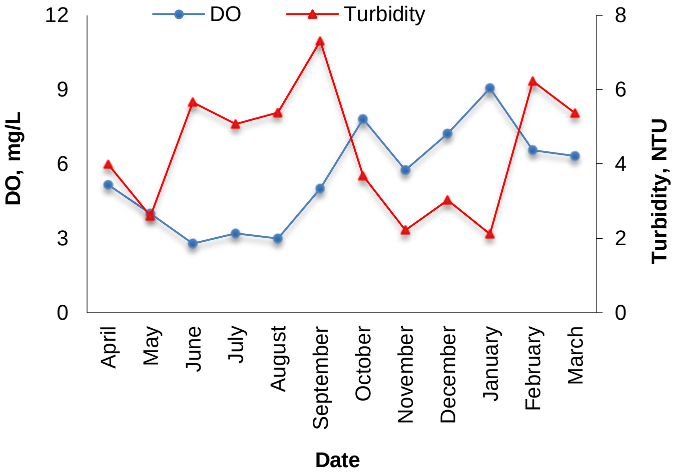


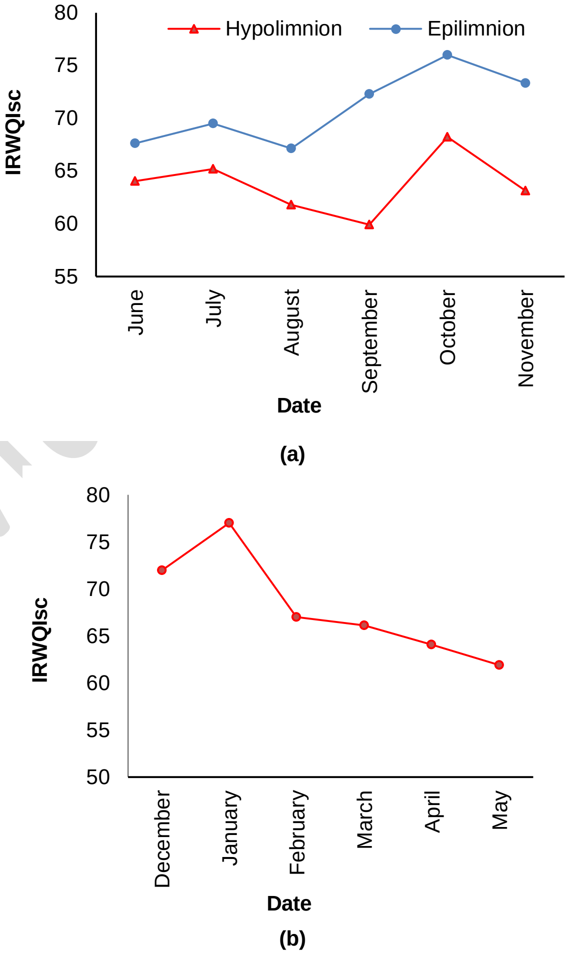
Fig. 9. Time series of the monthly changes of turbidity and DO at station St1 of the Talvar Dam reservoir.

3.3. Water quality evaluation using the Iranian water quality index

Due to the development of the thermal stratification in the warm months of the year and the lack of appreciable exchange of heat and material concentration between the developed layers, as well as the mixing in the cold months of the year, water quality of the reservoir changed at different times of the year and at different depths, and therefore, to comprehensively describe the water quality of the reservoir using the Iranian water quality index, the above-mentioned differences must be considered. In the present study, the water quality index of the dam reservoir was divided temporally into two parts of warm months of the year (days corresponding to the development of thermal and qualitative stratification of the reservoir water) and cold months of the year (days corresponding to the thermal and qualitative mixing of the reservoir water), and spatially into two parts of the epilimnion and the hypolimnion during the thermal stratification period of the reservoir water (Fig. 10 and 11).

At the beginning of the thermal stratification period in June, the IRWQISC in the epilimnion lied in the relatively good class with a value of 67.6. The index value in the epilimnion increased slightly from June to July and decreased slightly from July to August, but this increase and decrease did not change the epilimnion quality class. The epilimnion index increased from August to October, so that the epilimnion quality class in September and October lied in the good class. From October to November and by approaching to the end of the thermal stratification period, the index decreased slightly, without changing the epilimnion quality class (Table 1 and Fig. 10 a). The increase in the IRWQI$_{SC}$ in the epilimnion, especially in September, October and November can be related to the significant difference in the dissolved oxygen concentration in the epilimnion compared to the hypolimnion (Fig. 7). In addition, in the hypolimnion at the beginning of the thermal stratification period, the IRWQI$_{SC}$ lied in the relatively good class with a value of 64. In the hypolimnion, similar to the epilimnion, the index value increased slightly from June to July and decreased from July to August with the difference that the decrease in the index in the hypolimnion continued until September and reached its minimum value of 59.9 with a relatively good quality class in this month (Table 1 and Fig. 10(a)). The increase in fecal coliform in September was the cause of a decrease in the water quality index in the dam hypolimnion in September. From September to October, the index increased, and then decreased until November, similar to the epilimnion. These increases and decreases did not change the quality class of the hypolimnion during the thermal stratification period. At the beginning of the thermal stratification period, the hypolimnion and the epilimnion lied in the same quality class, but with time and increasing the depth of thermal stratification, the hypolimnion and the epilimnion were classified into two separate quality classes (Table 1 and Fig. 10a). In summary, it can be said that during the thermal stratification period (June to November), the quality class of the dam reservoir hypolimnion was relatively good based on common parameters, and this classification was also the same for the epilimnion from June to August. However, the water quality in the epilimnion gradually increased and lied in the good class from September to November (Table 1 and Fig. 10a). The changing trend of the water quality index for common parameters during the stratification period can be considered to be affected by changes in the dissolved oxygen concentration and fecal coliforms.

At the beginning of the mixing period in December, the IRWQI$_{SC}$ of the entire reservoir with a value of 72 lied in the good class. From December to January, the index value increased, reaching its maximum value of 77 in this month. However, this increase was not sufficient to change the quality class of the reservoir, and the reservoir water quality remained in the good class. The improvement in the water quality of the dam reservoir in January compared to December was related to the increase in dissolved oxygen content in January (Fig. 9). From January to February, the index decreased with a steep slope and lied in the relatively good class. This descending trend continued with a gentler slope from February to May, but did not change the quality class of the reservoir water. In summary, it can be said that at the beginning of the mixing period (December and January), water quality in the Talvar Dam reservoir lied in the good class according to the common parameters, but in February to May, it gradually decreased and lied in the relatively good class (Table 1 and Fig. 10b). The changing trend of the water quality index for the common parameters during the mixing period can be considered to be affected by changes in the dissolved oxygen concentration.

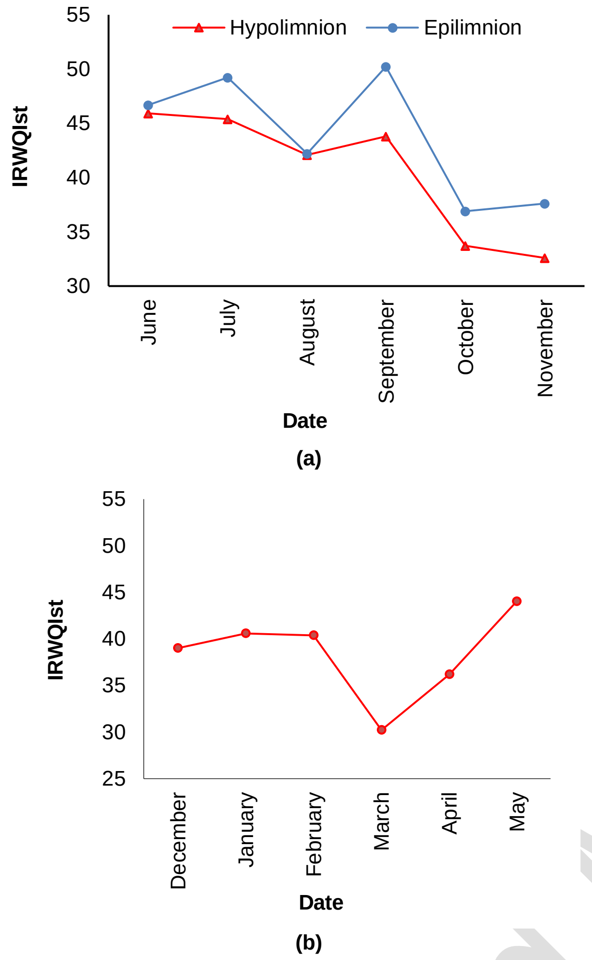


(a)

(b)

Fig. 10. Time series of the IRWQI$_{SC}$ at St1 of the Talvar Dam reservoir.

At the beginning of the thermal stratification period in June, the IRWQI$_{ST}$ in the epilimnion with a value of 46.7 lied in the medium class. The index value of the epilimnion increased slightly from June to July and decreased from July to August. This sudden decrease caused a change in the quality class of the epilimnion, and water quality of the epilimnion lied in the relatively poor class. This decrease in the index value was due to the increase in the concentration of input arsenic and, as a result, its increase in the dam reservoir in August, which caused a decrease in the quality class of the epilimnion. The changing trend of the index in the epilimnion increased from August to September, so that the index in the epilimnion reached its maximum value of 50.2 in September, and the epilimnion lied in the medium class in this month. The improvement in the water quality of the reservoir and the increase in the index value in September were related to the decrease in the concentration of arsenic in the dam reservoir in this month. With the decrease in the index from September to October, the quality class of the epilimnion lied in the relatively bad class. From October to November, the index increased slightly and the quality class of the epilimnion did not change (Table 1 and Fig. 11a). In the hypolimnion, at the beginning of the thermal stratification period, the IRWQI$_{ST}$ index with a value of 45.9 lied in the average class.



(a)

(b)

Fig. 11. Time series of the IRWQI$_{ST}$ at St1 of the Talvar Dam reservoir.

The index value in the hypolimnion decreased slightly from June to July that did not change the quality class of the hypolimnion, but with the continuation of the decreasing trend, the quality class of the hypolimnion changed into relatively bad in August. From August to September, the index increased slightly, and from September to October, the index in the hypolimnion, similar to the epilimnion, decreased significantly that continued with a gentler slope until November. These increases and decreases, due to the limited range of fluctuations, did not change the quality class of the hypolimnion, and water quality of the hypolimnion remained in the relatively bad class. In summary, it can be said that at the beginning of the thermal stratification period (June and July), the quality class of the hypolimnion and the epilimnion, and in September the quality class of the epilimnion of the dam reservoir based on toxic parameters was average. This classification changed to relatively bad in the other months of the thermal stratification period (August, October and November) in the hypolimnion and the epilimnion, and in September in the hypolimnion (Table 1 and Fig. 11a). The changing trend of the water quality index for toxic parameters during the stratification period can be considered consistent with changes in arsenic concentration.

At the beginning of the mixing period in December, the IRWQI$_{ST}$ with a value of 39 lied in the relatively bad class. From December to February, the index changes were relatively stable. From February to March, it decreased significantly, reaching its minimum value of 30.2 in March. The decrease in the IRWQI$_{ST}$ in March and November can be attributed to the increase in arsenic concentration in this month (Table 1 and Fig. 11b). From March to May, the index increased with an almost constant slope. However, this increase was not enough to change the quality class of the reservoir, and throughout the mixing period, the quality class of the dam reservoir was relatively bad based on the toxic parameters (Table 1 and Fig. 11b). It should be noted that, except for arsenic, other heavy metals studied in the Talvar dam reservoir had lower concentrations, so they also had less effect on the IRWQI$_{ST}$.

Therefore, the changing trend of the water quality index of the toxic parameters during the mixing period can be considered consistent with the changing trend of arsenic concentration. Sudden decreases in the IRWQI$_{ST}$ of the Talvar Dam occurred in October and March, which can be attributed to the periodic use of the arsenic-containing pesticides in October and the arsenic-containing chemical fertilizers in March in upstream agricultural farms.

4. Conclusions

In the present study, by simulating the temperature profile in the Talvar Dam reservoir, the summer thermal and qualitative stratification period (June to November) and the winter mixing period (December to May) were first determined. Then, the Iranian Water Quality Index was used to study the water quality of the reservoir, and considering the significant changes in the quality parameters influencing the determination of the aforementioned index at different depths of the reservoir and at different times, this index was calculated separately for the hypolimnion and the epilimnion during the thermal stratification period, and in the mixing period, considering the minor changes in the above-mentioned quality parameters at different depths of the reservoir, the value of this index was obtained for the entire reservoir. The results showed that during thermal stratification period, water quality of the epilimnion was generally better than that of the hypolimnion. In addition, the dam reservoir water quality index in terms of the value of the common parameters lied in the relatively good class in all months in the hypolimnion and from June to August in the epilimnion, and from September to November in the epilimnion. In addition, the dam reservoir water quality index in terms of the common parameters in the mixing period lied in the good class from December and January and in the relatively good class from February to May. The dam reservoir water quality index in terms of the toxic parameters in the thermal stratification period lied in the average class in June and July in the hypolimnion and epilimnion, and in September in the epilimnion, and in August, October and November in the hypolimnion and epilimnion, and in September in the hypolimnion. In addition, the water quality index of the dam reservoir lied in the relatively bad class in terms of the value of the toxic parameters during the mixing period in all months. Among the parameters affecting the IRWQISC of the Talvar Dam, the dissolved oxygen and fecal coliform had a greater effect on the index changes, with the effect of the fecal coliform being more evident in the stratification period, and the dissolved oxygen being effective in both the stratification and the mixing periods. Arsenic, among the parameters affecting the IRWQI$_{ST}$ in the Talvar Dam, had the maximum direct effect on changes in this index in both the stratification and the mixing periods.

Author Contributions

Sina Pakmanesh: Study conception and design, data collection, data analysis, writing the original draft.
Seyyed Mohammad Shoaei: Study conception and design, data collection, review & editing of the manuscript.
All authors read and approved the final manuscript.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflict of Interest

The authors declare that they have no conflict of interest.

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