



# Dissolved oxygen concentration and eutrophication evaluation in Yamchi dam reservoir, Ardabil, Iran

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## Abstract

One of the essential issues in the quality management of water resources is the determination of the level of eutrophication and dissolved oxygen in dam reservoirs and other water bodies. It is possible to study changes in dissolved oxygen concentration using qualitative models. In this study, CE-QUAL-W2, a two-dimensional model of hydrodynamics and water quality capable of predicting the behavior of aquatic ecosystems, has been used to simulate dissolved oxygen concentration and eutrophication. As a case study, the water quality of the Yamchi dam reservoir, located in Ardabil Province, has been qualitatively investigated using the CE-QUAL-W2 model. Based on the geographical location of the Yamchi dam reservoir, it includes warm monomictic basins. According to the results, the dissolved oxygen concentration in the simulation period varied between 0 and 12 mg/L. In autumn and winter, this concentration was almost uniform at various depths. However, in summer, a sharp decrease in dissolved oxygen concentration, to less than 2 mg/L in the bottom layers, was observed, which is due to the presence of nutrients. Regarding eutrophication, the Yamchi dam reservoir is one of the eutrophic reservoirs, and practical strategies should be employed to improve these conditions. Recommended strategies include reducing the retention time of water in the reservoir, dewatering from the underlying layers during the thermal stratification period, and preventing the entry of agricultural drains into the inlet tributaries of the reservoir.

**Keywords** Yamchi dam · CE-QUAL-W2 Software · Dissolved oxygen · Eutrophication

## Introduction

Due to the economic, social, and industrial growth of societies, the water in rivers, estuaries, and natural lakes, in terms of quantity, quality, and geographical distribution, no longer meets human needs. In order to overcome this problem, several dams were constructed all over the world. The construction and operation of dams have physical, chemical, and biological effects on the rivers. These effects have both positive and negative aspects, such as flood control, hydro-power generation, water supply for agricultural and drinking sectors, as well as profound influences on the aquatic

environment, including changes in the qualitative structure of outgoing water (Yigzaw et al. 2019; Khonok et al. 2021). One of the critical issues related to the operation and environment of dam reservoirs is the prediction of the quality of reservoir water and its outflow during operation. Increased water nutrients, i.e., eutrophication, in reservoirs results in a sharp drop in dissolved oxygen concentration, water quality, and its inability to meet the various environmental needs that endanger the aquatic life of the river downstream ecosystem. This phenomenon decreases the water quality and increases sedimentation in the reservoir by increasing the growth of algae and aquatic plants in reservoirs, thus reducing the amount of dissolved oxygen in water (Sun et al. 2022; Oliveira et al. 2020; and Yigzaw et al. 2019). Ma et al. (2008) examined the thermal stratification in the Kouris dam reservoir in Cyprus using the CE-QUAL-W2 qualitative two-dimensional model. They showed that this reservoir has thermal stratification most of the year, while a mixing occurs in the reservoir in early February. Meteorological parameters are the crucial parameters that affect this phenomenon in the reservoir. They then investigated the

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effect of selective dewatering on thermal stratification in the dam reservoir by defining water withdrawal scenarios from various water elevations and concluded that water withdrawal scenarios did not affect the reservoir stratification pattern during the year. The reason was the relatively small volume of water withdrawal from the dam. However, the outflow of water from the deeper layers was able to facilitate the heat transfer from the surface to the depth (Ma et al. 2008). Chai et al. (2014) studied the simulation of the Heihe reservoir in Xian city, China, in terms of pollution characteristics due to thermal stratification and found that this reservoir has a stable thermal stratification, and the lower layers lack oxygen in summer. The main qualitative problem of the reservoir is the release of pollutants from sediments. Therefore, to disrupt the stratification, aeration of the bed has been suggested to improve water quality (Chai et al. 2014). Ebrahimi et al. (2015) studied the simulation of thermal and salinity stratification in the Baft dam reservoir, Iran, using the CE-QUAL-W2 software. They showed that thermal stratification occurs in nine months of the year, starting in April and peaks in August and September, and there is a correlation between salinity and thermal stratifications. The maximum salinity is 307 mg/L, indicating a favorable condition of the Baft dam reservoir in terms of drinking and agricultural water compared to the optimum salinity threshold (500 mg/L) (Ebrahimi et al. 2015). Sabeti et al. (2017) simulated the thermal and salinity stratification of the Mamloo dam using the CE-QUAL-W2 model. The results showed that the reservoir experiences a vertical mixing in summer and a radiant slope in winter. Also, thermal and salinity stratification prevail at the same time. Moreover, the thermal stratification decreases, and the temperature intensity increases in summer (Sabeti et al. 2017). Rahimi Movaghar et al. (2019) modeled the temperature conditions, dissolved oxygen concentration, and total dissolved solids (TDS) in the Shahid Rajaei dam reservoir, Mazandaran Province. They studied the effects of reducing the input TDS to the reservoir under two scenarios: a 20% reduction in the input TDS in both input branches (Scenario 1) and a 20% reduction in the input TDS in the main input branch (Scenario 2). They investigated the quality conditions of the reservoir according to IRWQI<sub>SC</sub>. The results showed the optimal modeling with acceptable performance. The simulations indicated that TDS in the first and second scenarios was reduced by 20.0 and 14.2% in the maximum TDS conditions and 19.4 and 13.4% in the minimum TDS conditions, respectively. Subsequently, IRWQI<sub>SC</sub> values showed that the water quality of the Rajaei dam reservoir is in relatively good condition (Rahimi Movaghar et al. 2019). Shabani et al. (2019) used the CE-QUAL-W2 model to investigate the thermal stratification of the Seymareh dam in Ilam Province, Iran. The modeling results determined that the dam has a period of thermal stratification, which causes

the organic matter and sediment deposited in the bottom to increase gradually. Moreover, the mixing of the reservoir causes the spread of the eutrophication phenomenon. This phenomenon lasts from March to December and reaches its peak in autumn. The thickness of the surface layer of water, called epilimnion, varies from month to month. Besides, this difference in the middle layer, called the thermocline, is also seen in various months. The thickness of the epilimnion in December is more than in other months (Shabani et al. 2019). Salehi et al. (2019) investigated the water quality of the Mahabad dam reservoir located in West Azerbaijan Province using the CE-QUAL-W2 model as an efficient software for water quality analysis in reservoirs and lakes. According to the results, the Mahabad dam reservoir has a relatively strong stratification in summer that starts in late April and reaches its peak in August. With the beginning of autumn and at the same time with the decrease in radiation entering the reservoir, stratification changes into mixing in such a way that complete mixing occurs in the reservoir in December. The changes in TDS have an upward trend by increasing the depth so that the maximum concentration is at the bottom of the reservoir throughout the year. In contrast, dissolved oxygen concentration decreases by increasing the depth of the reservoir. The changes in dissolved oxygen concentration begin in June and continue until late summer, so that at this time of year, the dissolved oxygen concentration in the hypolimnion reaches zero, eventually leading to the production of unpleasant color and odor in the reservoir (Salehi et al. 2019). Talakesh et al. (2019) investigated the water quality of the Karun 3 dam reservoir, Khuzestan Province, using the CE-QUAL-W2 model. The results showed that this reservoir had only one period of thermal stratification, starting from the end of April and reaching its peak in the middle of summer. Passing through this peak and entering the cold seasons of the year, the formed stratification gradually disappears so that in March, complete mixing occurs in the reservoir. Changes in dissolved oxygen concentration also show a downward trend by increasing the depth so that its amount decreases from 7.07 to 4.37 mg/L in September. This downward trend starts in April and intensifies with the warming of the weather. This condition eventually produces an unpleasant color and odor in the reservoir (Talakesh et al. 2019). Mercy and Kioko (2021) evaluated the water quality of two Maruba and Kyai earth dam in Machakos Municipality, Kenya, based on variables including pH, chlorides, EC, turbidity, nitrites, nitrates, sulfates, phosphates and TDS. The results showed that the amount of all mentioned parameters were within WHO set standard except turbidity for domestic water in both dams which was due to poor farming practices causing soil erosion and accumulation of silt within the two dam reservoirs (Mercy and Kioko. 2021).

Rezaei Barandagh et al. (2018) investigated the thermal and qualitative stratification of the Taham dam reservoir, Zanjan Province, Iran, using the CE-QUAL-W2 model. The results indicated the existence of a period of thermal stratification in the reservoir that lasts about eight months of the year. This phenomenon starts at the end of April and reaches its peak in August and September, with a 20 °C difference between the epilimnion and hypolimnion. Also, mixing was observed from January to April. In autumn, with decreasing the difference in water temperature in the upper and lower layers, the thermal stratification in the reservoir weakened and completely disappeared in winter. The results also indicated the presence of salinity stratification at the same time as thermal stratification in the reservoir (Rezaei Barandagh et al. 2018). Beiramipoor et al. (2018) conducted a qualitative study of the Baft dam constructed on the Baft River in Kerman Province, Iran, with the help of CE-QUAL-W2. Their studies showed that thermal stratification begins in late May with the onset of the heating season and peaks in August and September. This stratification continues until October, and mixing occurs in the reservoir in November and March, with decreasing water temperature (Beiramipoor et al. 2018). Kaveh et al. (2015) used the CE-QUAL-W2 model to investigate the thermal stratification and eutrophication conditions of the Ilam dam, Iran. The results indicated the presence of stratification in summer. This stratification begins with the warming of the air in the spring and reaches its most stable state in July. With the decreasing trend of temperature in the reservoir in autumn, a mixing is observed in winter, and also, the reservoir is in the mesotrophic and eutrophic state according to the Vollenweider and Kress, as well as the Newton and Ulm criteria (Kaveh et al. 2015). Kiani Sadr (2017) simulated thermal stratification and dissolved oxygen concentration of the Garsha dam reservoir, Kermanshah Province, Iran, using the CE-QUAL-W2 model. The results showed that thermal stratification occurs in summer and the reservoir is almost completely mixed in terms of changes in dissolved oxygen in December. The concentration of dissolved oxygen in the water surface increases sharply in spring, which is due to the photosynthesis of algae in these months. The lowest dissolved oxygen concentration (0 mg/L) occurs in January and December and in the hypolimnion, while the highest concentration (10.2 mg/L) is observed at the water surface in May (Kiani Sadr 2017). Since the Yamchi dam reservoir, Ardabil, Iran, is used for drinking and agricultural purposes, it is necessary to investigate its qualitative parameters, the timing of thermal stratification, eutrophication,

and their effect on the water dissolved oxygen concentration. Therefore, in this study, in order to identify the water quality status of Yamchi Dam, thermal stratification and dissolved oxygen concentration were simulated using the CE-QUAL-W2 model, and the eutrophication conditions of the dam reservoir have also been investigated which these evaluations are beneficial to ensure the safety of the water for not only drinking and agricultural purposes but also for the environment by controlling the phenomenons like eutrophication and thermal stratification affecting water quality parameters.

## Material and methods

### Study area

Constructed in 2005, the Yamchi dam (38°2'–38°4' N, 48°2'–48°5' E) is located on Bakhlichai River ca. 25 km away from west of Ardabil (Fig. 1). Considering the altitude and geographical location of the reservoir, it is classified as a warm monomictic reservoir. The dam was constructed for drinking water supply and irrigation purposes with the capacity of 82 MCM: 80 MCM useful storage and 2 MCM dead storage.

### CE-QUAL-W2 model

In this study, the CE-QUAL-W2 model was used to simulate the thermal stratification and its effects on dissolved oxygen concentration. This is a two-dimensional, longitudinal/vertical, hydrodynamic model to study water quality, and it is best suited for relatively long and narrow water bodies, such as rivers, lakes, reservoirs, estuaries, as well as entire river basins with multiple reservoirs and river segments, exhibiting longitudinal and vertical water quality gradients. Geometric data, initial conditions, boundary conditions, hydraulic parameters, kinetic parameters, and calibration data are required for the CE-QUAL-W2 model (Wells 2020a, b).

### Governing equations of the CE-QUAL-W2 model

The CE-QUAL-W2 model solves the mean transverse equations using the finite difference method. These equations include momentum in the x-direction (Eq. 1), momentum in the z-direction (Eq. 2), continuity equation (Eq. 3), state equations (Eq. 4), and water surface elevation equation (Eq. 5)

$$\frac{\partial UB}{\partial t} + \frac{\partial UUB}{\partial x} + \frac{\partial WUB}{\partial z} = gB \sin \alpha + g \cos \alpha B \frac{\partial \eta}{\partial x} - \frac{g \cos \alpha B}{\rho} \int_{\eta}^z \frac{\partial \rho}{\partial x} dz + \frac{1}{\rho} \frac{\partial B \tau_{xx}}{\partial x} + \frac{1}{\rho} \frac{\partial B \tau_{xz}}{\partial z} + qBU_x \quad (1)$$

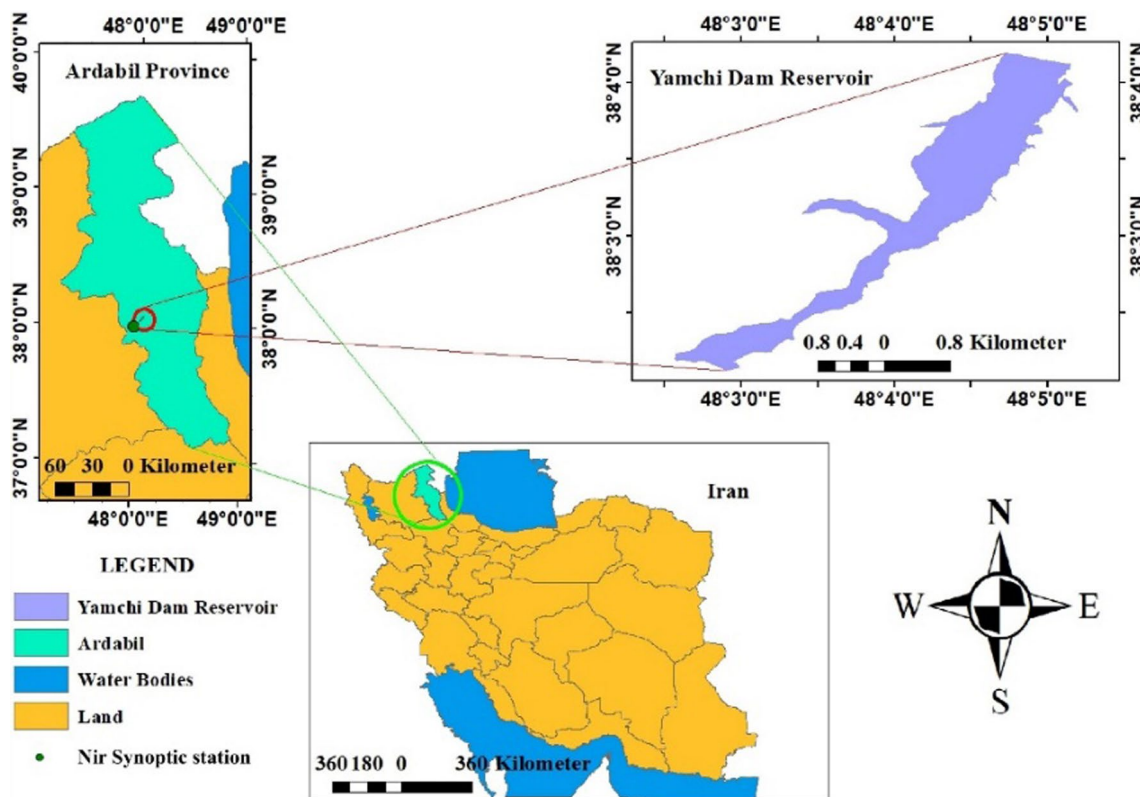


Fig. 1 Location of Yamchi dam reservoir

$$\frac{\partial P}{\partial z} = \rho g \cos \alpha \tag{2}$$

$$\frac{\partial UB}{\partial x} + \frac{\partial WB}{\partial z} = qB \tag{3}$$

$$\rho = f(T_w, \theta_{TDS}, \theta_{SS}) \tag{4}$$

$$\frac{\partial B_\eta \eta}{\partial t} = \frac{\partial}{\partial x} \int_\eta^h UB dz - \int_\eta^h qB dz \tag{5}$$

where  $x$  and  $z$  are horizontal and vertical coordinates,  $B$  is the width of the waterbody,  $U$  is the horizontal mean transverse velocity,  $W$  is the vertical mean transverse velocity,  $\rho$  is water density,  $t$  is time,  $p$  is pressure,  $g$  is the gravitational acceleration,  $q$  is the inlet and outlet flow rate,  $\alpha$  is the slope of waterbody bed,  $dz$  and  $dx$  are the thermal elements in  $x$  and  $z$  directions,  $\tau_{xx}$  and  $\tau_{xz}$  are turbulent shear stress in  $x$  and  $z$  directions,  $\beta_\eta$  is water surface width that varies with time and location,  $\eta$  is the water surface elevation, and  $h$  is depth. In the state equation, the density is a function of water temperature ( $T_w$ ), total dissolved solids concentration

( $\theta_{TDS}$ ), and suspended solids concentration ( $\theta_{SS}$ ) (Wells 2020a, b).

**Model calibration**

Model calibration was performed in three steps, the calibration of reservoir geometry, the calibration of water surface elevation, and the calibration of temperature and quality (concentration of qualitative parameters). After calibrating the model, Absolute Mean Error (AME) (Eq. 6) and Root-Mean-Square error (RMSE) (Eq. 7) were used to measure the error between the observed and predicted data

$$AME = \frac{\sum_{i=1}^n |x_p^i - x_o^i|}{n} \tag{6}$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^n (x_p^i - x_o^i)^2}{n}} \tag{7}$$

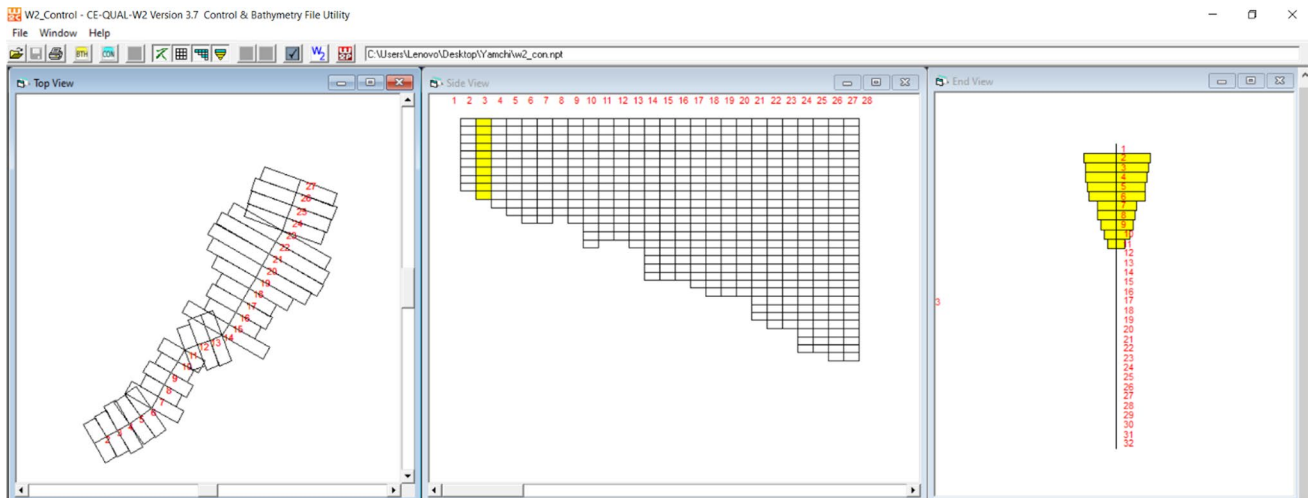


Fig. 2 A view of the reservoir geometry in the CE-QUAL-W2 software

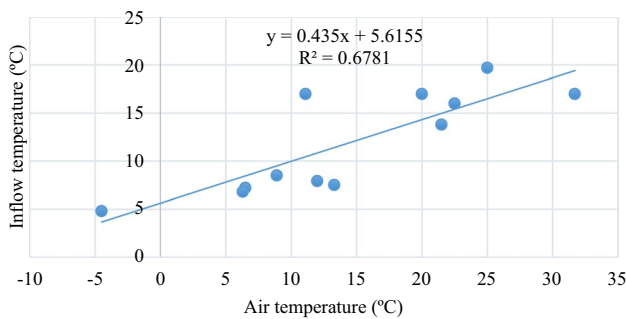


Fig. 3 The air temperature in Nir synoptic station versus inflow temperature

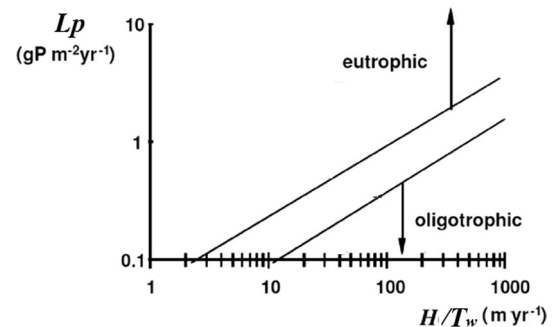


Fig. 4 Vollenweider trophic graph

where  $n$  is the total number of data and  $x_p^i$  and  $x_o^i$  are the predicted and observational data, respectively (Wells 2020a, b).

### Simulation duration and geometry

The Yamchi dam reservoir was simulated for a one-year period from May 2015 to April 2016. The waterbody of the reservoir was divided into a primary branch with 28 longitudinal segments, each having a 200 m length. Reservoir depth was also divided into 32 elements with a 2 m depth. Figure 2 depicts a view of the geometrical model of the Yamchi dam reservoir.

### Inflow temperature

Due to the lack of sufficient data on the temperature of inlet water to the reservoir and the existence of a significant

relationship between this parameter and air temperature (Fig. 3), the temperature of the inlet to the reservoir was extracted using the Nir synoptic station data for the simulation period. In this research, the existing inlet water temperatures and the meteorological data were obtained from Iran Water Resources Management Company and Iran Meteorological Organization.

### Eutrophication

Eutrophication is the process in which a water body becomes overly enriched with nutrients like Nitrogen and Phosphorus, leading to dramatic growth of algae and simple plant life which leads to the deterioration of water quality and the depletion of dissolved oxygen in water bodies which threaten the survival of organisms (Sun et al. 2022 and Olivera et al. 2020).



**Table 1** Eutrophication level according to Carlson index (TSI)

Carlson TSI	Eutrophication level
TSI < 25	Oligotrophic
TSI = 25–45	Mesotrophic
TSI > 45	Eutrophic

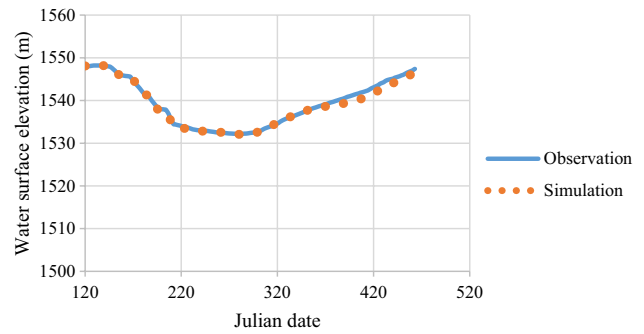
**Vollenweider trophic graph**

Vollenweider provided the graph shown in Fig. 4 to diagnose eutrophication in dam reservoirs. In this diagram,  $H$  is the average depth of the reservoir (m),  $T_w$  is the water retention time in the reservoir (year), and  $L_p$  is the amount of entrance of phosphorus into the dam reservoir, which is obtained by dividing the amount of input phosphorus in the reservoir per year by lake area (Parchami et al. 2016).

**Carlson trophic state index**

Carlson trophic state index (TSI) uses three water quality parameters, namely, Secchi depth (SD), chlorophyll-a (CHL), and total phosphorous (TP), to determine the eutrophication level of the dam reservoirs.

$$2TSI(SD) = 10 \left( 6 - \frac{\ln(SD)}{\ln_2} \right) \tag{8}$$



**Fig. 7** The observed and simulated water surface elevation of the Yamchi dam reservoir

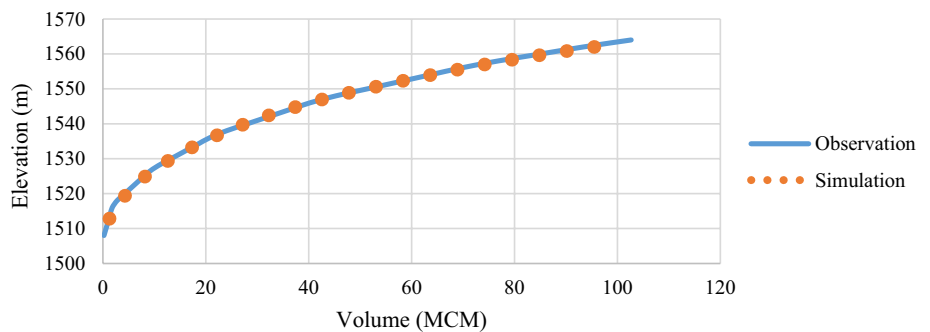
**Table 2** Calculated errors for the simulation of water surface elevation

Mean Error	AME (°C)	RMSE (°C)
-0.36	0.41	0.63

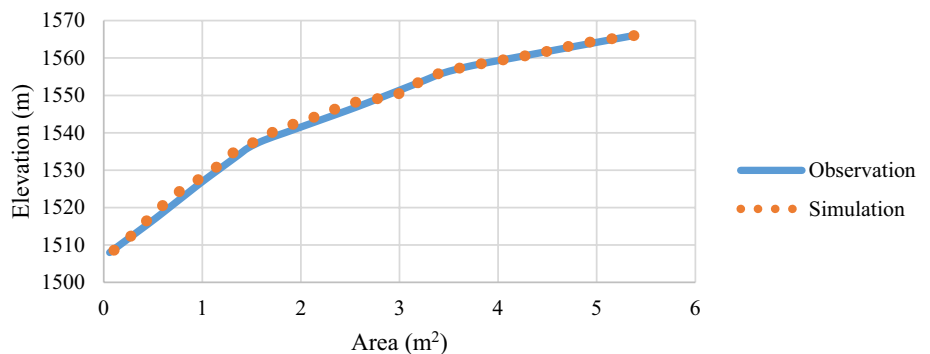
$$TSI(CHL) = 10 \left[ 6 - \frac{(2.04 - 0.68 \ln(chl))}{\ln_2} \right] \tag{9}$$

$$2TSI(TP) = 10 \left[ 6 - \frac{48}{TP(\ln_2)} \right] \tag{10}$$

**Fig. 5** The observed and simulated elevation versus volume of the Yamchi dam reservoir



**Fig. 6** The observed and simulated elevation versus area of the Yamchi dam reservoir



**Table 3** Calculated AME in two calibration and validation periods for temperature

Period	AME (°C)
Calibration	0.458
Validation	0.905

**Table 4** Calculated AME in calibration and validation periods for DO concentration

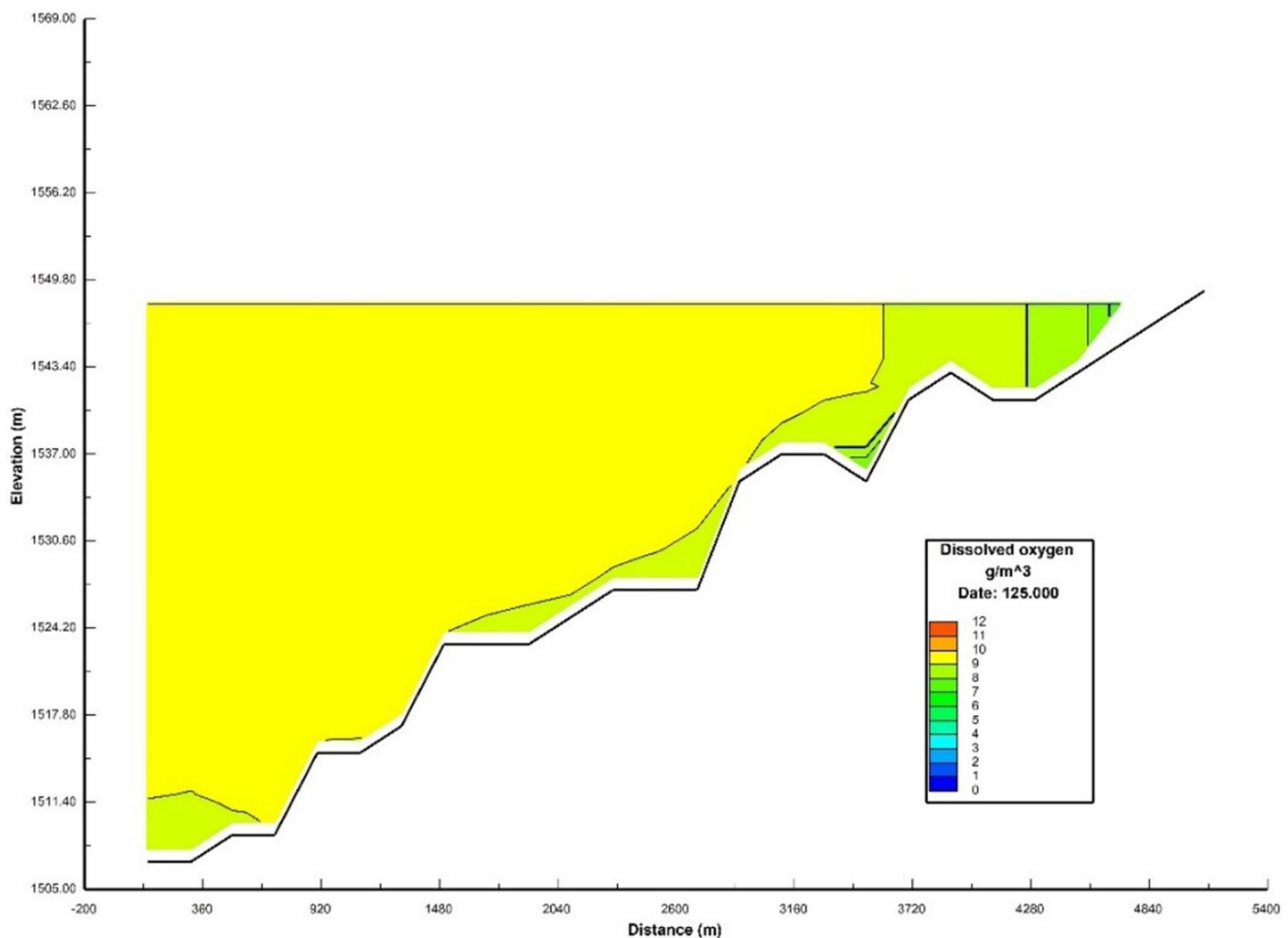
Period	AME (°C)
Calibration	1.762
Validation	1.389

In using this index, it should be noted that these three water quality parameters can vary from one reservoir to another and from one season to another. TSI (SD) might be associated with the error, as opacity might not be due to the presence of algae alone, and the TSI (CHL) can be more reliable overall. Therefore, the TSI (CHL) was used in this study. Table 1 shows the eutrophication level of dam reservoirs according to Carlson TSI (Vice Presidency for Strategic Planning and Supervision 2011).

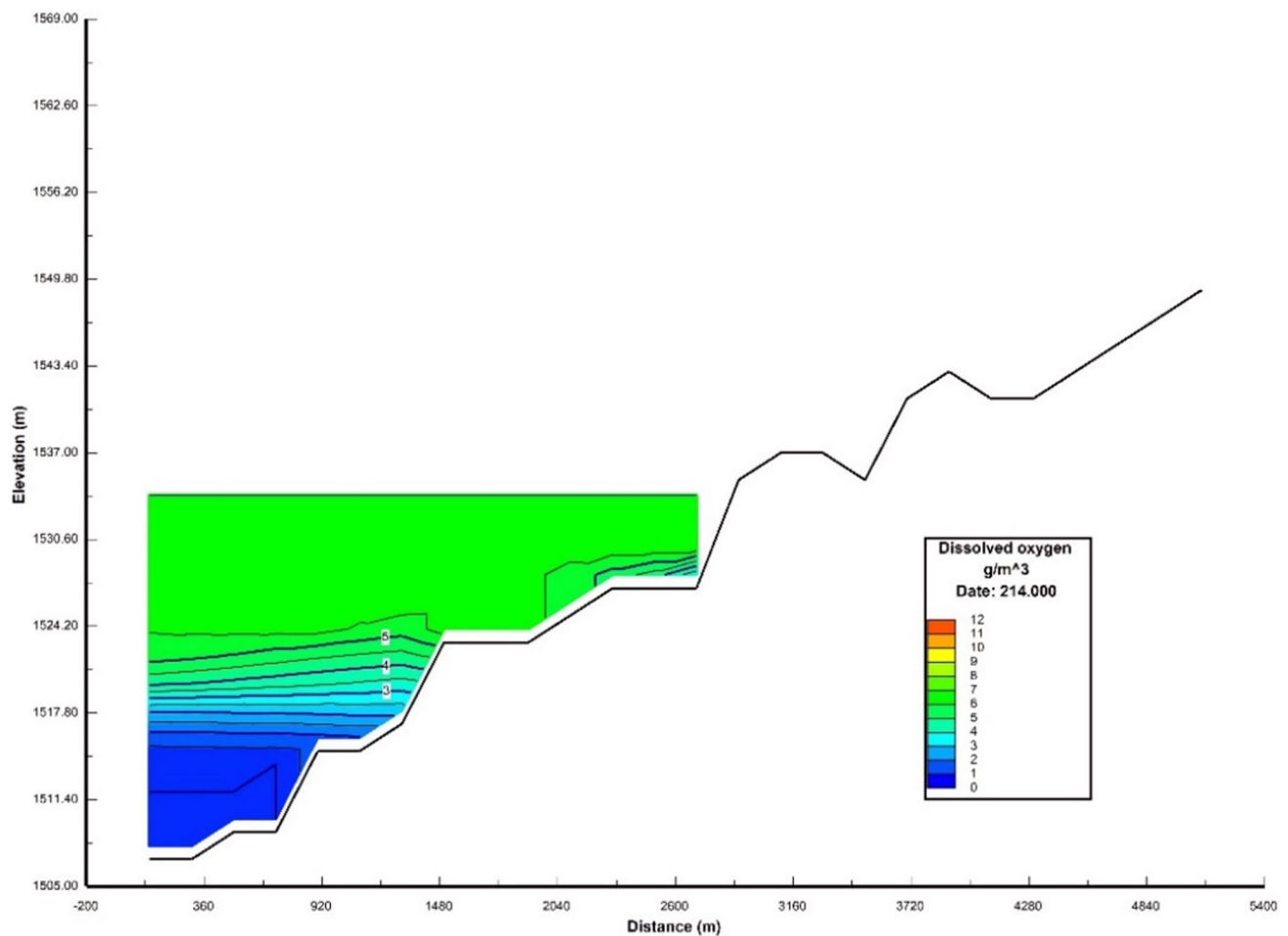
## Results and discussion

### Model calibration

For geometric calibration of the reservoir, according to the observational and simulated data of volume-area-elevation, the observational volume and area were compared with predicted data by the model at various elevations. To do this, the observational and simulated data were refined by changing the width of the segments. Figures 5 and 6 show these comparisons. As can be seen, there is a good agreement between observational and simulation data. The second step was to calibrate the water surface elevation. The simulated water surface elevation during the simulation period should be similar to the observed data. A program (waterbal-ivf37.exe) was used to calibrate the water surface elevation. Figure 7 depicts a comparison of observational and simulated data, while Table 2 shows the error calculated by the program. According to the results of other researches including Talakesh et al. 2019 with the calculated AME and RMSE of 0.74 and 0.84, respectively, calibration has been appropriately conducted in this research



**Fig. 8** The pattern of dissolved oxygen concentration in mid-May (Date: 5/15/2015)



**Fig. 9** The pattern of dissolved oxygen concentration in mid-August (Date: 8/15/2015)

(Talakesh et al. 2019). The third step was the calibration of temperature and quality. According to the comparison of observational data and the simulation results of the model, the trend of changes in temperature and dissolved oxygen parameters has been simulated with acceptable performance (Tables 3 and 4). According to the results conducted in other researches shown in the user manual of the CE-QUAL-W2 model, calibration has been done properly. Furthermore, as can be seen, during the validation process for temperature parameter, the AME calculated for two months were higher than one which led to a higher amount for AME calculated for validation period. This could be due to human Error or not calibrated devices (Table 3).

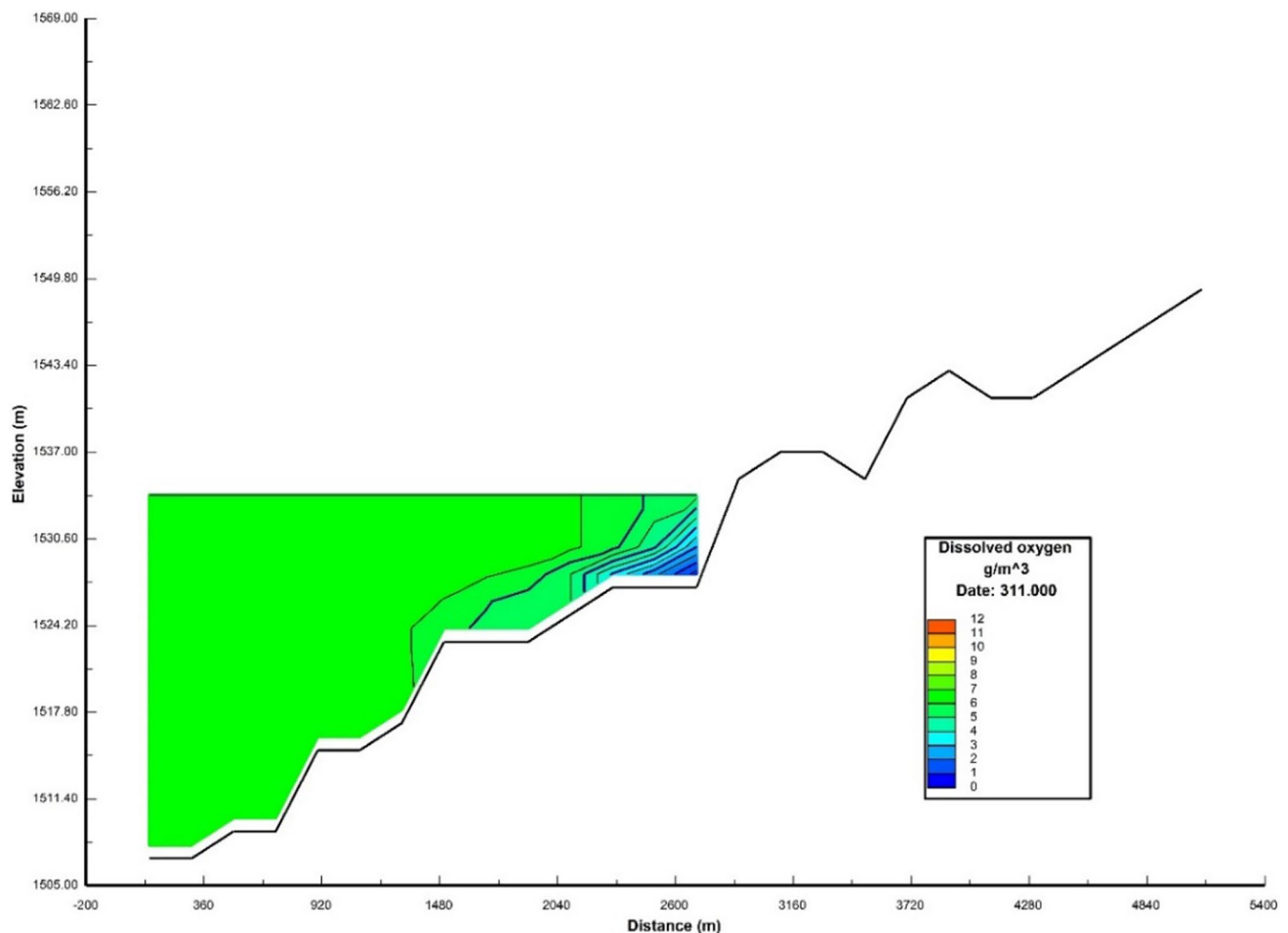
### Thermal stratification

Thermal stratification, refers to the uneven variation of water temperature in vertical profiles of a water body (in our case Yamchi Dam Reservoir). In a stratified reservoir three layers

are formed: an upper layer called (Epilimnion), which is well-mixed and a bottom layer called (hypolimnion), which is disconnected from the former layer by a third layer called thermocline (Yuanning et al. 2022; Yigzaw et al. 2019).

The effects of the thermal stratification of reservoirs on changes in dissolved oxygen concentration are undeniable (Yuanning et al. 2022). The Yamchi dam reservoir has a four-month stratification period, starting in June and reaching its peak in August, resulting in a temperature difference of up to 6 °C between the epilimnion and hypolimnion. It is possible to observe more temperature differences if the depth of stored water exceeds its value during the simulated period in this study. With the beginning of September and the decrease in air temperature, the temperature difference between the epilimnion and hypolimnion decreases to the point that the mixing process begins in mid-September, and complete mixing is observed in the coming months of autumn and winter due to decreasing the temperature of the reservoir water. The reservoir temperature varies between 0 and 2 °C in





**Fig. 10** The pattern of dissolved oxygen concentration in mid-November (Date: 11/15/2015)

January and February. Also, the mixing process continues in April and May, and the epilimnion begins to form in early June, and the reservoir enters the period of thermal stratification.

### Dissolved oxygen concentration

The importance of monitoring the Dissolved oxygen concentration in water bodies is inevitable as this parameter is vital to support aquatic life. In this regard, the distribution of the dissolved oxygen in Yamchi dam has been modeled (Kiani Sadr 2017). Figures 8, 9, 10 and 11 show the dissolved oxygen concentration in the simulation period in the Yamchi dam reservoir. According to these figures, from mid-October to May, the reservoir becomes fully mixed in terms of changes in dissolved oxygen concentration. From September, with the decrease in water temperature, as it is predicted, the concentration of dissolved oxygen starts

to increase so that the concentration reaches its maximum amount (more than 12 mg/L) in January and February. However, with the onset of temperature increase which leads to less gas being soluble in the water body from March to June, when the reservoir is still in the mixing condition, the dissolved oxygen concentration decreases to about 9 mg/L. In the following months, with the beginning of the thermal stratification period in summer and its intensification in July and August, the amount of dissolved oxygen starts to decrease dramatically, Specifically in the hypolimnion the amount of DO becomes equal to 0 mg/L, which is due to high presence of nutrients and eutrophic condition of the Yamchi dam reservoir leading to the high oxygen consumption in this layer. During this period, the reduction in oxygen dissolution causes the anaerobic decomposition of some compounds in water, resulting in an unpleasant odor, color, and taste.

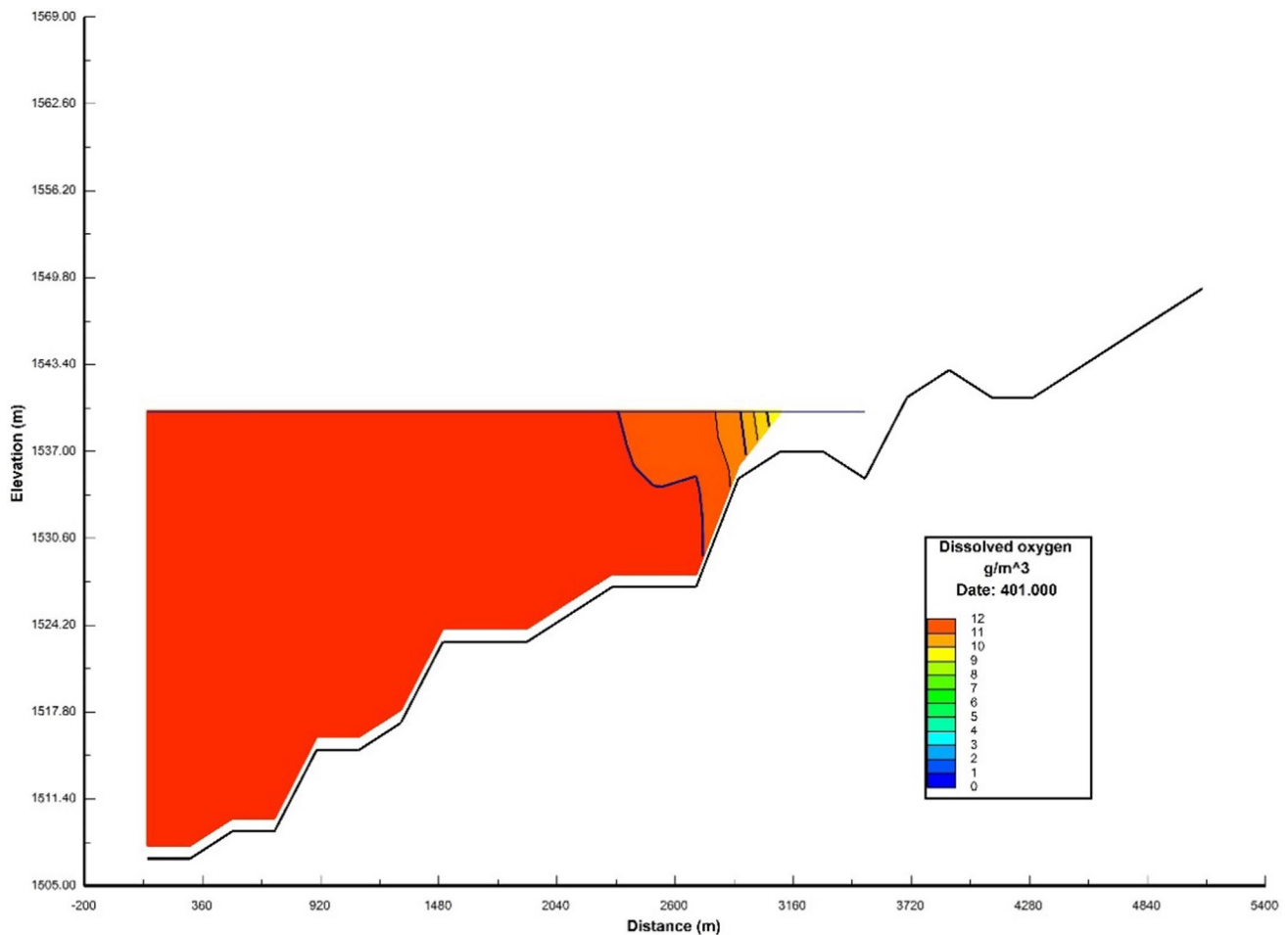


Fig. 11 The pattern of dissolved oxygen concentration in mid-February (Date: 2/15/2016)

**Vollenweider graph**

According to the graph and method provided by Vollenweider, in the Yamchi dam reservoir, the value of  $H/T_w$ , which is equal to the  $Q/A$  ratio, is equal to:

$$\frac{64.9 \times 10^6}{4 \times 10^6} = 16.225$$

The average annual flow rate to the Yamchi dam reservoir is 64.9 MCM and the total phosphorus concentration entering the Yamchi dam reservoir is 0.33 mg/L. Therefore, the amount of phosphorus entering the reservoir per year in terms of grams is equal to:

$$64.9 \times 10^6 \times 0.3 = 19.47 \times 10^6$$

The resulting  $L_p$  is equal to:

$$L_p = \frac{19.47 \times 10^6}{4 \times 10^6} = 4.86$$

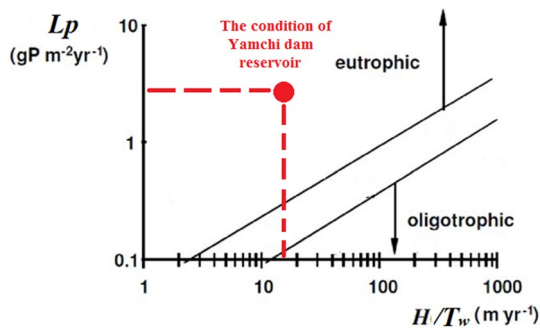
According to the Vollenweider graph (Fig. 12), the condition of the Yamchi dam reservoir is in the eutrophic zone.

**Carlson trophic state index**

The average values of TSI (chl) in the reservoir in the four seasons of spring, summer, autumn, and winter are 47.97, 46.07, 42.02, and 44.06, respectively. As a result, according to the calculations and Table 1, the Yamchi dam reservoir is in the eutrophic condition in spring and summer and in the mesotrophic condition in winter and autumn.

**Conclusion**

In this study, thermal stratification, eutrophication, and dissolved oxygen concentration in the Yamchi dam reservoir have been studied using the CE-QUAL-W2 two-dimensional hydrodynamic model for a one-year period



**Fig. 12** The status of the Yamchi dam reservoir in the modified Vollenweider graph

(2015–2016). Due to the importance of the study reservoir in supplying the drinking and agricultural water in the region, the necessity of this study was apparent. The results show a four-month period of thermal stratification, beginning in June and reaching its peak in August. A temperature difference of about 6 °C is observed between the epilimnion and hypolimnion in the vicinity of the dam axis. This stratification continues until the middle of September, and the reservoir is witnessing a mixing process in other months. Therefore, the Yamchi dam reservoir has a thermal stratification of summer type and experiences a mixing in autumn and winter seasons. The eutrophication was investigated according to the amount of total phosphorus entering the reservoir and chlorophyll-a concentration using Carlson TSI and Vollenweider graph, which according to the results, the reservoir is in eutrophic and mesotrophic conditions. Also, although the dissolved oxygen concentration in the epilimnion during the whole simulation period is more than 6 mg/L, in the lower layers, its concentration has decreased sharply from June to September and even decreased to nearly 0 mg/L. After summer, with decreasing temperature and the beginning of mixing, the concentration of dissolved oxygen increases and reaches more than 11 mg/L in winter.

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**Author contribution** All authors had equal contribution in writing, review, and final approval of the paper.

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**Data availability** Data used in this research were obtained from Iran Water Resources Management Company and Iran Meteorological Organisation; therefore the data are not available to share.

## Declarations

**Conflict of interest** The author declares that there is no conflict of interest.

**Ethical approval** The present study and ethical aspect was approved by Department of Water Engineering and Sciences, Faculty of Agricultural Sciences and Food Industries, Science and Research Branch, Islamic Azad University (SRBIAU), Tehran, Iran.

**Consent to participate** All authors designed the study, collected data, wrote the manuscript and revised it.

**Consent to publish** All authors agree to publish this manuscript. There is no conflict of interest.

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