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Assessment of Ilam Reservoir Eutrophication Response in Controlling Water Inflow

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ABSTRACT: In this research, a 2D laterally averaged model of hydrodynamics and water quality, CE-QUAL-W2, was applied to simulate water quality parameters in the Ilam reservoir. The water quality of Ilam reservoir was obtained between mesotrophic and eutrophic based on the measured data including chlorophyll a, total phosphorus and subsurface oxygen saturation. The CE-QUAL-W2 model was calibrated and verified by using the data of the year 2009 and 2010, respectively. Nutrients, chlorophyll a and dissolved oxygen were the water quality constituents simulated by the CE-QUAL-W2 model. The comparison of the simulated water surface elevation with the measurement records indicated that the flow was fully balanced in the numerical model. There was a good agreement between the simulated and measured results of the hydrodynamics and water quality constituents in the calibration and verification periods. Some scenarios have been made base on decreasing in water quantity and nutrient inputs of reservoir inflows. The results have shown that the water quality improvements of the Ilam reservoir will not be achieved by reducing a portion of the reservoir inflow. The retention time of water in reservoir would be changed by decreasing of inflows and it made of the negative effects on the chlorophyll-a concentration by reduction of nutrient inputs and keeping constant of discharge inflow to reservoir, the concentration of total phosphorus would be significantly changed and also the concentration of chlorophyll-a was constant approximately. Thus, the effects of control in nutrient inputs are much more than control in discharge inflows in the Ilam reservoir.

Keywords: CE-QUAL-W2, Ilam Reservoir, Eutrophication, Retention Time, Water Quality.

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INTRODUCTION

Eutrophication is the enrichment of an aquatic ecosystem with additional nutrients from different pollution sources such as point and nonpoint sources. Some quality problems like diurnal variations in dissolved oxygen concentration and pH, hypoxic condition and etc. in the bottom are caused by an overabundance of algae biomass. The mass transport formula including the advection and dispersion equations, exogenous environmental factors (e.g., water temperature, riverine nutrient loads) and interactive biochemical kinetics are effective factors on phytoplankton dynamics (Karamouz and karachian, 2011; Kuo et al., 2006; Liu et al., 2009). Various management techniques such as reducing external nutrient source, hypolimnetic aeration, hypolimnetic withdrawal, artificial circulation, nutrient diversion, dilution and etc. are selected to manage and maintain water quality in lakes and reservoirs (Kuo et al., 2006; Liu et al., 2009; Garrell et al., 1977; Irianto et al., 2012). To improve the eutrophication in the reservoir, much effort has been made to reduce the external loading of phosphorus. Some reservoirs rapidly respond to such reductions (Kuo et al., 2006; Liu et al., 2009) but a delay in reservoir recovery is often seen (Messer et al., 1983; Dodds, 1992; Dzialowski et al., 2007). Water quality models are one of the best available tools used to determine the quantitative relationship between pollutant loads and water quality responses in water bodies. In the last decade, the CE-QUAL-W2 model has been widely used for modeling reservoirs in around the world (Gelda et al., 1998; Chung and Oh, 2006; Kim and Kim, 2006; Fang et al., 2007; Ma et al., 2008; Chung and Lee, 2009; Lee et al., 2010; Dai et al., 2012; Amarala et al., 2013). Wu et al. (2004) simulated the eutrophication in the Shihmen reservoir by the CE-QUAL-W2 model. The calibrated and verified model was used for simulation of chlorophyll a concentration under various reduction scenarios. Kuo et al. (2006) modeled the Tseng-Wen and Te-Chi reservoirs in Taiwan by the CE-QUAL-W2 model. They applied the calibrated model to simulate several scenarios with the reduced nutrient load and found that a substantial reduction (30-55%) of the phosphorus loading would change the trophic status from eutrophic/mesotrophic to oligotrophic in the Te-Chi Reservoir. Diogo et al. (2008) investigated the strategies to improve eutrophication in the Alqueva reservoir in Portugal. Their results showed that even a reduction of the total pollutant loads would not improve water quality in this reservoir. Ha and Lee (2008) modeled the Daecheong reservoir and investigated turbidity effects on the eutrophication in this reservoir. They showed that the CE-QUAL-W2 model can simulate seasonal changes and good agreement exists between the simulated and measurement results. The numerical simulation result was relatively poor for predicting the seasonal change of Chlorophyll a and total phosphorus. Debele et al. (2008) used SWAT and CE-QUAL-W2 models to simulate the combined processes of water quantity and quality both in the upland watershed and downstream water body in the Cedar Creek reservoir. Their results showed that these models can be used to assess and manage water resources in complex watersheds. Afshar and Saadatpour (2009) applied the CE-QUAL-W2 model to simulate water temperature and quality parameters including total phosphorus, nitrate, Chlorophyll a, dissolve oxygen and ammonium in the Kharkheh reservoir in Iran. After calibrating the model, a sensitivity analysis has been performed to determine the effective of the significant parameters in the numerical modeling. Liu et al. (2009) used the CE-UAL-W2 model for eutrophication management in the Mingder reservoir. They showed that load reduction will change the water quality in this reservoir. Etemad-Shahidi et al. (2009) applied the CE-QUAL-W2 model to determine total maximum daily load (TMDL) of total dissolved solids during a two years' period in the Karkheh reservoir. Yu et al (2010) described the influence of a diffuse pollution on a natural organic matter (NOM) in the Daecheong reservoir by using the CE-QUAL-W2 model. Liu and Chen (2013) assessed the effect of the withdrawal level on stratification patterns and suspended solids concentration in the Shihmen reservoir by the CE-QUAL-W2 model. Deus et al. (2013) simulated the eutrophication in the Tucurui reservoir by this model and investigated various management scenarios to improve the eutrophication of the Tucurui reservoir. Park et al (2014) applied the CE-QUAL-W2 model to predict the pollutant load released from each reservoir in response to different flow scenarios. Zouabi-aloui et al. (2015) used the CE-QUAL-W2 model to simulate the impact of various water withdrawal scenarios in thermal stratification and water quality in the Sejnane reservoir.

The Ilam reservoir with a capacity of 71 million cubic meters is one of the two main sources of drinking water in Ilam city. The water taste and odor problems of the Ilam reservoir interested us to model the eutrophication in this reservoir. In this study, the laterally averaged two-dimensional CE-QUAL-W2 model was calibrated and verified by existing observation data in the Ilam reservoir. Then the calibrated model was used to evaluate the effect of using different management scenarios on chlorophyll a and total phosphorus concentrations.

STUDY AREA

The Ilam dam basin (Figure 1) is located at the southeastern of the Ilam city in the Ilam province. The study area lies from 46° 20' to 48° 36' E longitude and from 33° 23' to 33° 38' N latitude and covers an area about 462 km^2. This basin has been made by three sub basins named the Golgol, Chaviz and Ema sub-basin. The annual average of discharge, temperature and rainfall respectively are 106 m^3/s, 16 °C and 616 mm at the upstream watershed of the Ilam reservoir. The main uses of land in this watershed are forest by 60.2%, agriculture 38% and residential 0.5%. The Ilam dam watershed is drained by three rivers (Golgol, Chaviz and Ema). The inflow of the Ilam dam is included by sum of the Golgol, Chaviz and Ema rivers discharge. This dam was designed for water supply, irrigation, ecological environment improvement and flood control uses. The physical characteristics of Ilam dam are 65 m height above the foundation and 162 m the crest length with a capacity of 71 million cubic meters. The major sources of pollution into the Ilam reservoir are upstream villages' sewage, agricultural drainage waters, animal breeding activities and severe erosion in this catchment (Mahab Qods, 2010). The Chapra's classification was used to specify the trophic state of the dam. The measured data was fitted with this classification to determine the eutrophication condition. Table 1 shows the depth-averaged total phosphorus concentration, chlorophyll a and subsurface oxygen saturation in the different sampling month at the dam station. Also, the trophic state of different months on the basis of the Chapra's classification has been given in Table 1. Results of comparison between Chapra's classification and the measured data showed that the water quality condition of Ilam reservoir was mesotrophic to eutrophic.

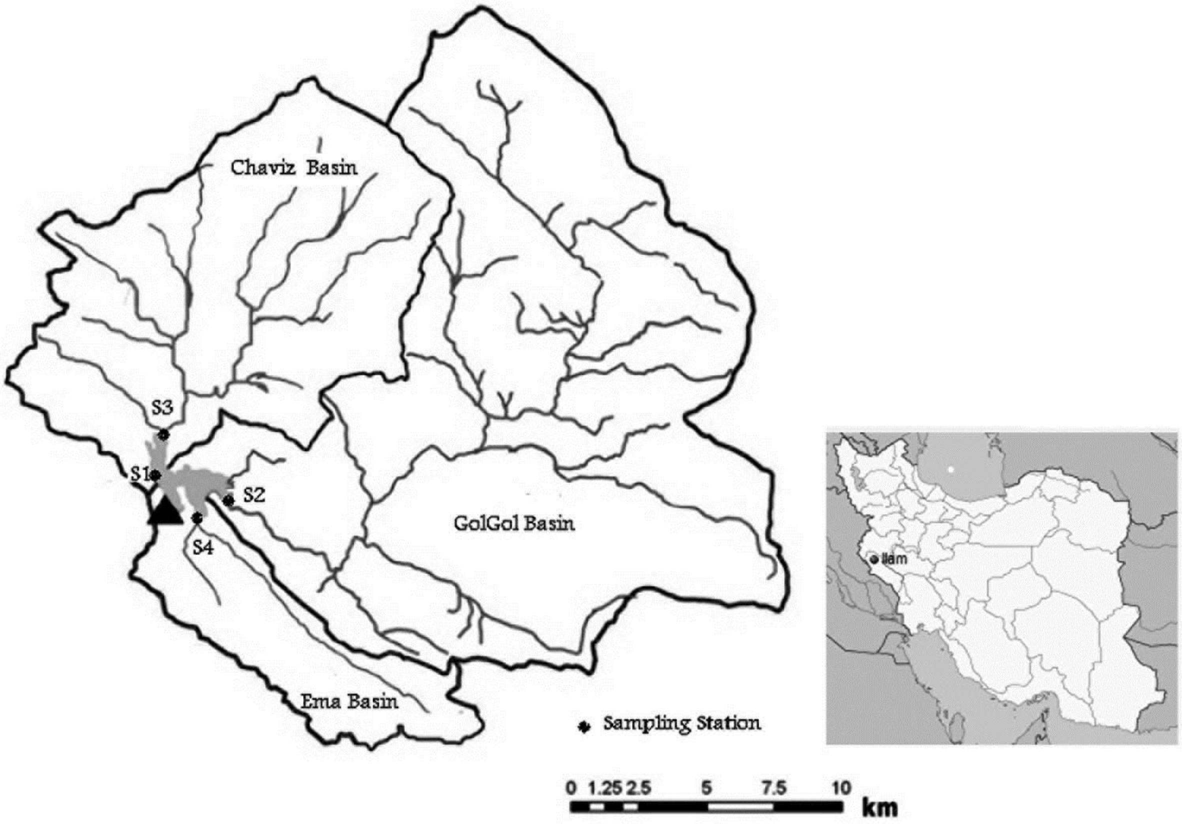


Fig. 1. Location of Ilam reservoir and the sampling point

Table 1. The trophic state of the reservoir in the various month at the dam station (S1)

Month	TP (mg/l)	Trophic State	chlorophyll-a (μg/l)	Trophic State	Subsurface Oxygen Saturation (%)	Trophic State
July	943	Eutrophic	7.7	Mesotrophic	16	Mesotrophic
August	48	Eutrophic	-	-	14	Mesotrophic
September	195	Eutrophic	0.036	Oligotrophic	16	Mesotrophic
October	217	Eutrophic	1.17	Oligotrophic	16	Mesotrophic
November	100	Eutrophic	0.35	Oligotrophic	37	Mesotrophic
December	205	Eutrophic	0.4	Oligotrophic	59	Mesotrophic
April	72	Eutrophic	0.16	Oligotrophic	42	Mesotrophic
May	82	Eutrophic	0.36	Oligotrophic	52	Mesotrophic
June	118	Eutrophic	0.16	Oligotrophic	43	Mesotrophic

Model Description

In this study, the CE-QUAL-W2 model was selected to simulate the eutrophication process in the Ilam reservoir. This numerical model is a finite difference, laterally averaged, 2D hydrodynamics. It has been improved for the last three decades and also is supported by the US Army Corps of Engineers Waterways Experiment Station. This numerical model was originally known as LARM (laterally averaged reservoir model) developed by Edinger and Buchak in 1975. The CE-QUAL-W2 model can be applied to rivers, estuaries, lakes, reservoirs and river basin systems. Water quality parameters such as dissolved oxygen (DO), nutrients, algal groups and organic matter can be simulated by the CE-QUAL-W2 model. Any combination of water quality parameters can be included or excluded from the numerical simulation. Due to assume lateral mixing, the CE-QUAL-W2 model is suited for relatively long and narrow water body that water quality gradient is in the longitudinal and vertical direction. In this model, the governing equations are the horizontal momentum equation, the continuity equation, the constituent–heat transport equation, the free water surface elevation equation, the hydrostatic-pressure equation and the state equation (Cole and Wells, 2008).

Model Inputs

In the CE-QUAL-W2 model, the reservoir is divided into a number of segments linked together to form the system. Four branches water body of the Ilam reservoir was divided into sixteen segments with a length of 500 m to 700 m and layers with a depth of 1 m. Figure 2 shows the numerical model grids for the Ilam Reservoir. In addition to the Golgol, Chaviz and Ema rivers, a part of the reservoir water body located near the dam is also considered as a branch.

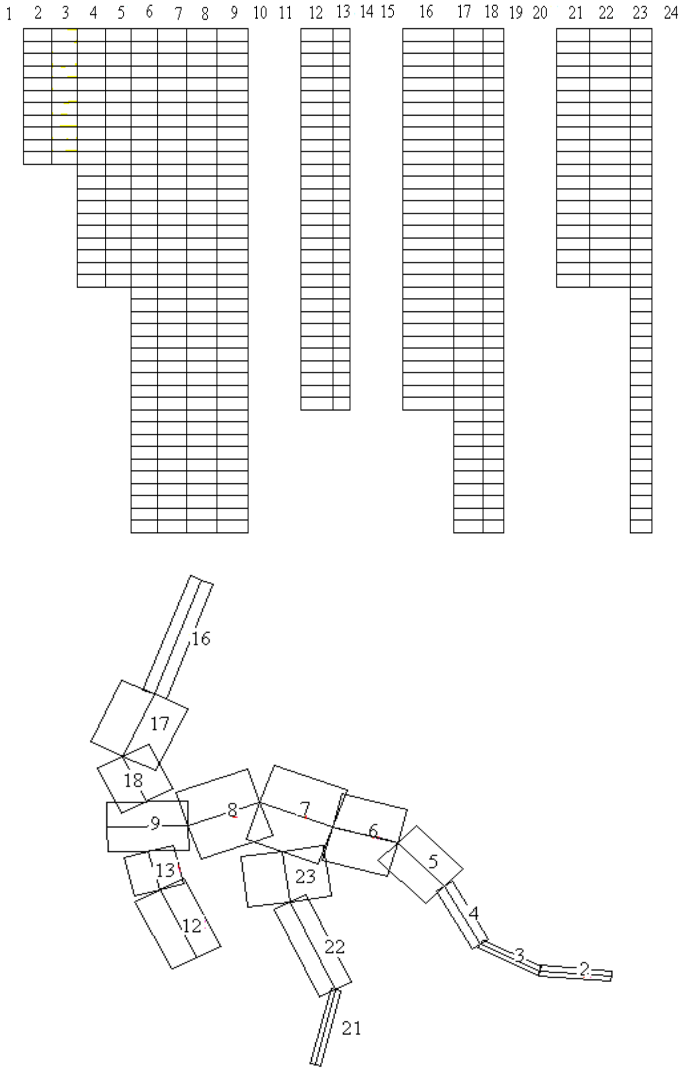
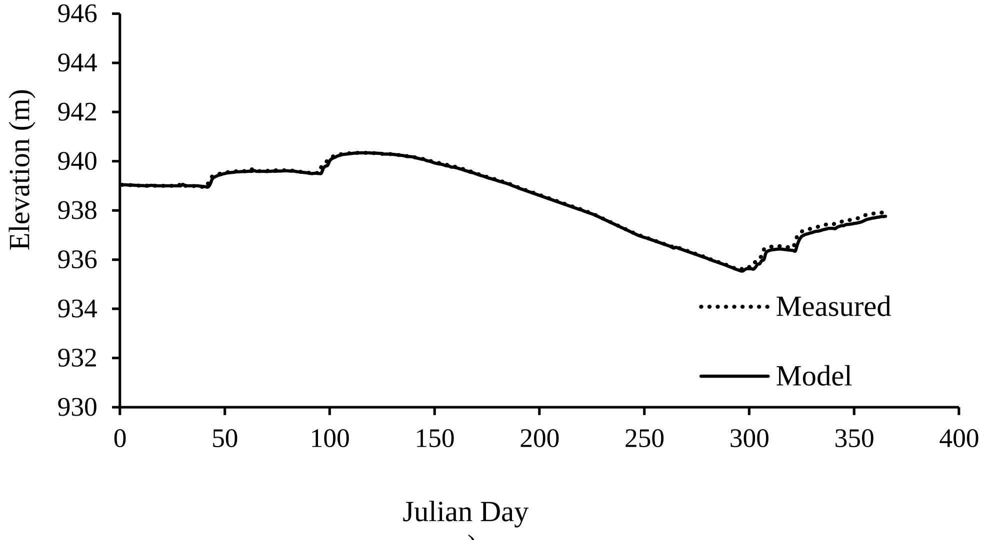


Fig. 2. Location of Ilam reservoir and the sampling point

The CE-QUAL-W2 hydrodynamic model was calibrated using the year 2009 data and the year 2010 data were used for the numerical model validation. The modeling period was from July 27 2009 to June 14 2010 and the modeling start time was at 24:00 o'clock on January 1 2009. The maximum time step and time step fraction were selected 1 hour and 0.8 in the simulation, respectively. The inputs of the numerical model were reservoir bathymetry, branches discharge, temperature and water quality, meteorological parameters and reservoir outflows. The grid dimensions were specified by three parameters: the length of each segment, the thickness of each layer and the width of the segment at each layer. The meteorological data generally are air temperature, dew point temperature, cloud coverage and wind speed and direction. The surface boundary conditions of the CE-QUAL-W2 model were constituted with these meteorological data. The required meteorological data has been extracted from the Ilam synoptic stations. In this numerical simulation, the daily hydrology data and three-hourly meteorology data were entered into the CE-QUAL-W2 model. Numerical simulations of the Ilam reservoir were divided into two main phases. The hydrodynamics and temperature at the first phase and then water quality constituents including ammonium, nitrate, phosphate, dissolve oxygen, silica and chlorophyll a have been simulated.

Hydrodynamics Results

In the Ilam reservoir simulation, the calibration process was begun with the water balance. The water level was calibrated and verified using the daily data. Figure 3 shows the comparison of the simulated and measured water level. The mean absolute error (MAE) of the simulated water level was respectively 0.05 and 0.04 m for the year 2009 and 2010 therefore the flow balance was ensured in the model. The simulation and measurement results indicate that the water surface elevation gradually decreases and reaches the lowest level in the late autumn of 2009 and then gradually increases and reaches a peak level in the late spring of 2010.



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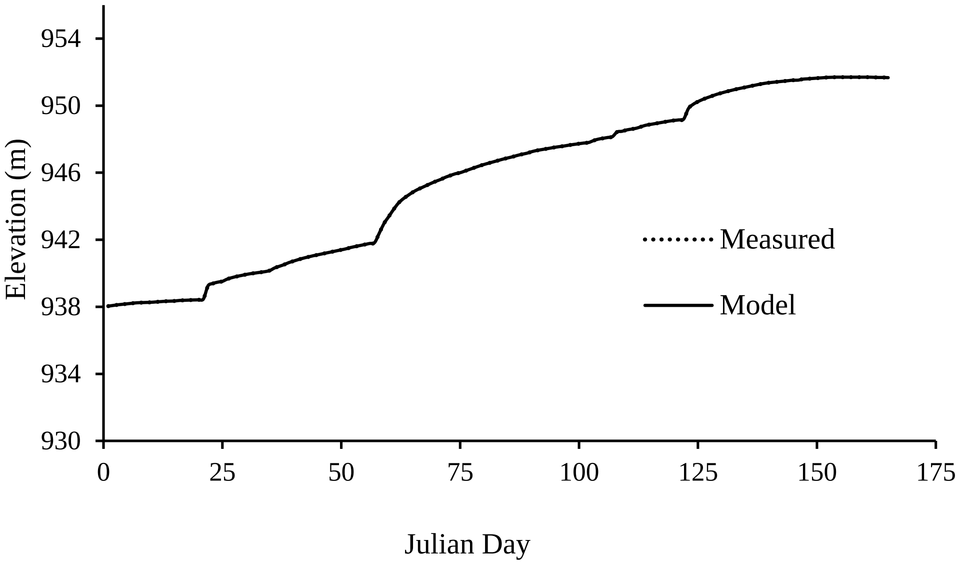


b)

Fig. 3. Comparison of the simulated and measured water surface elevation, a) the calibration period, b) the verification period

The water temperature data was used to evaluate the hydrodynamics results of the numerical model. The temperature profiles were calibrated and verified using monthly data collected in 2009 (July to December) and 2010 (March to May), respectively. The light extinction coefficient is one of the key parameters in the modeling of the temperature distribution. Before simulating the reservoir temperature, this coefficient was determined from the measured Secchi Disk depth using the following relationship (Etemad-shahidi et al., 2009)

$$\lambda = 1.11\, Z_s^{-0.73} \tag{1}$$

where λ and Z_s: are light extinction coefficient (m^{-1}) and depth of Secchi disk (m), respectively. After performing numerous runs of the model for calibrating the temperature distributions, the appropriate values of the coefficients such as horizontal eddy viscosity and diffusivity, sediment heat exchange coefficient, bottom frictional resistance, wind sheltering coefficient, maximum vertical eddy viscosity and evaporation coefficients were determined and listed in Table 2. Figures 4 and 5 show the calibration and verification results for the temperature profile, respectively. As seen, the numerical model has successfully simulated the variations of the water column temperature in both stratified and well-mixed conditions. The MAE and maximum error of the simulated temperature were respectively 0.72 °C and 1.18 °C. Figure 6 shows that the simulated temperatures are within ±15% of the measured ones. In the Ilam reservoir, thermal stratification has started at the beginning of the spring (early April) and reached its maximum during the summer. The maximum temperature difference between the upper and lower layers is about 13 °C and the thermocline layer with a thickness of about 5 m is formed in the reservoir in the summer. The surface cooling and wind mixing induce the fall overturn of the water column in the late October. A complete vertical mixing has been observed in the late November and the reservoir has remained well-mixed during the winter (Figure 4).

Table 2. The parameters' values used in the temperature calibration

Parameter	Description	Units	Value
AX	Horizontal eddy viscosity	m^2/s	1
DX	Horizontal eddy diffusivity	m^2/s	1
CBHE	Coefficient of bottom heat exchange	$W/m^2/s$	0.5
CHEZY	Bottom frictional resistance	m^2/s	70
TSED	Sediment temperature	°C	14
AZMAX	MAX Vertical Eddy Visc	m^2/s	0.001
WSC	Wind sheltering coefficient	-	0.5-0.95
AFW	Evaporation Coefficient	-	4.3
BFW	Evaporation Coefficient	-	1.7
CFW	Evaporation Coefficient	-	2

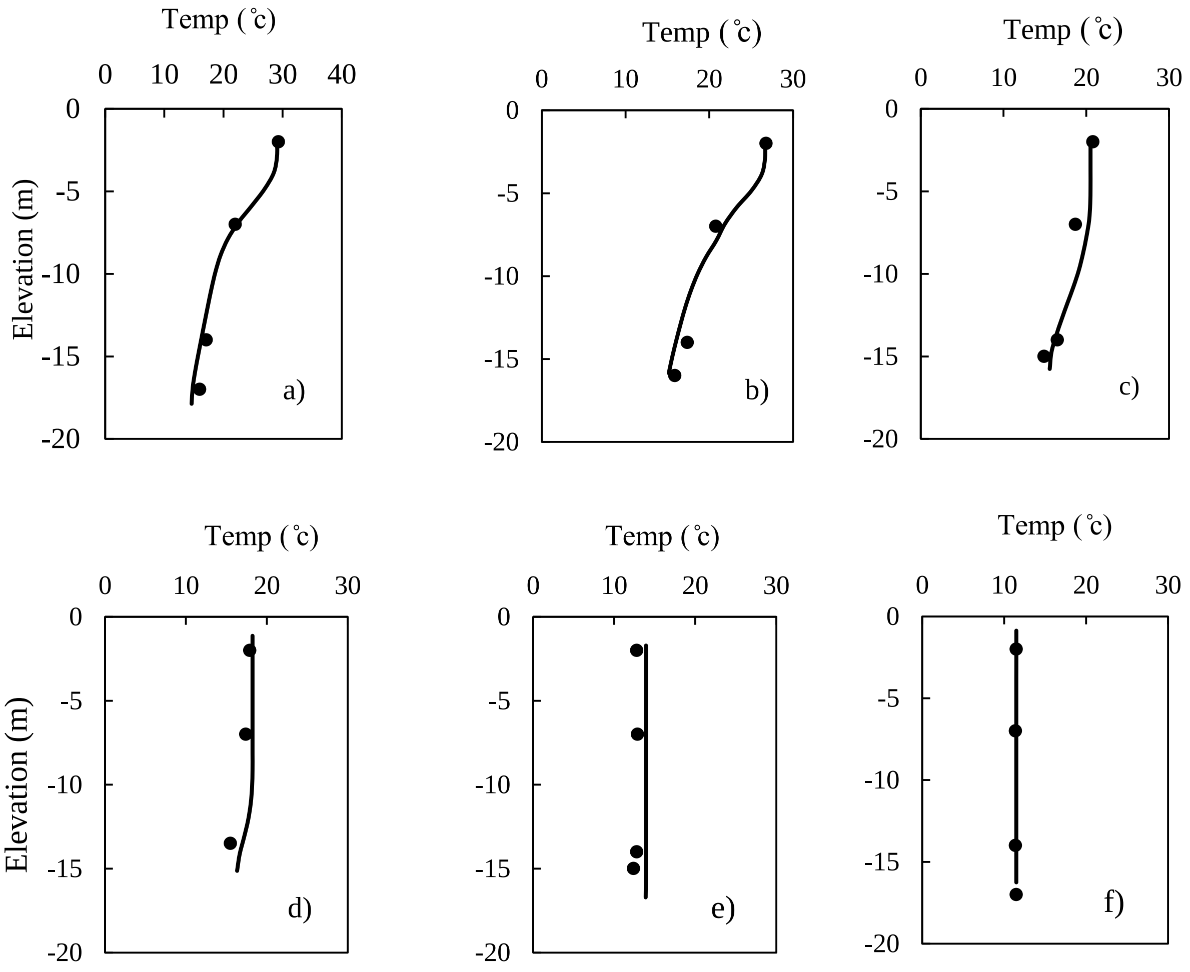


Fig. 4. Comparison of measured and simulated temperature profiles in the calibration period, a) Julian day = 208, b) Julian day = 238, c) Julian day = 273, d) Julian day = 299, e) Julian day = 335 and f) Julian day = 364

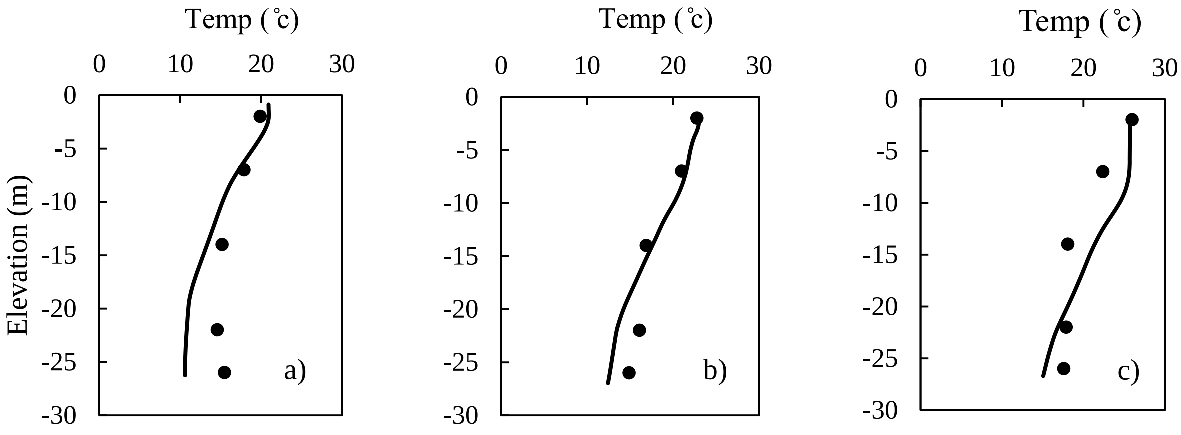


Fig. 5. Comparison of measured and simulated temperature profiles in the verification period, a) Julian day = 105, b) Julian day = 133 and c) Julian day = 165

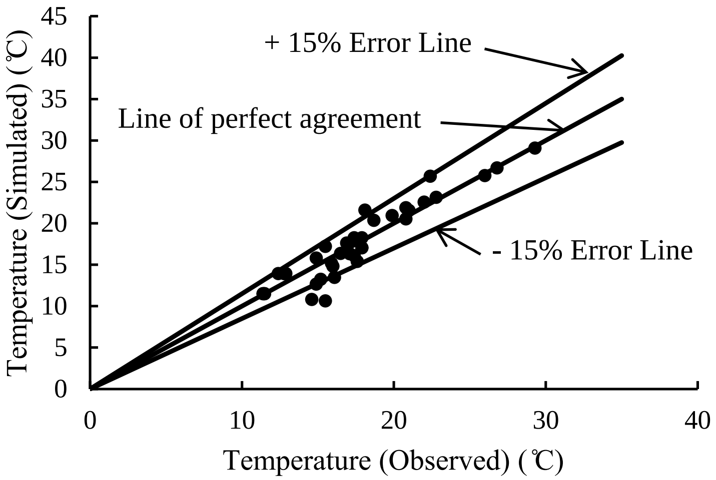
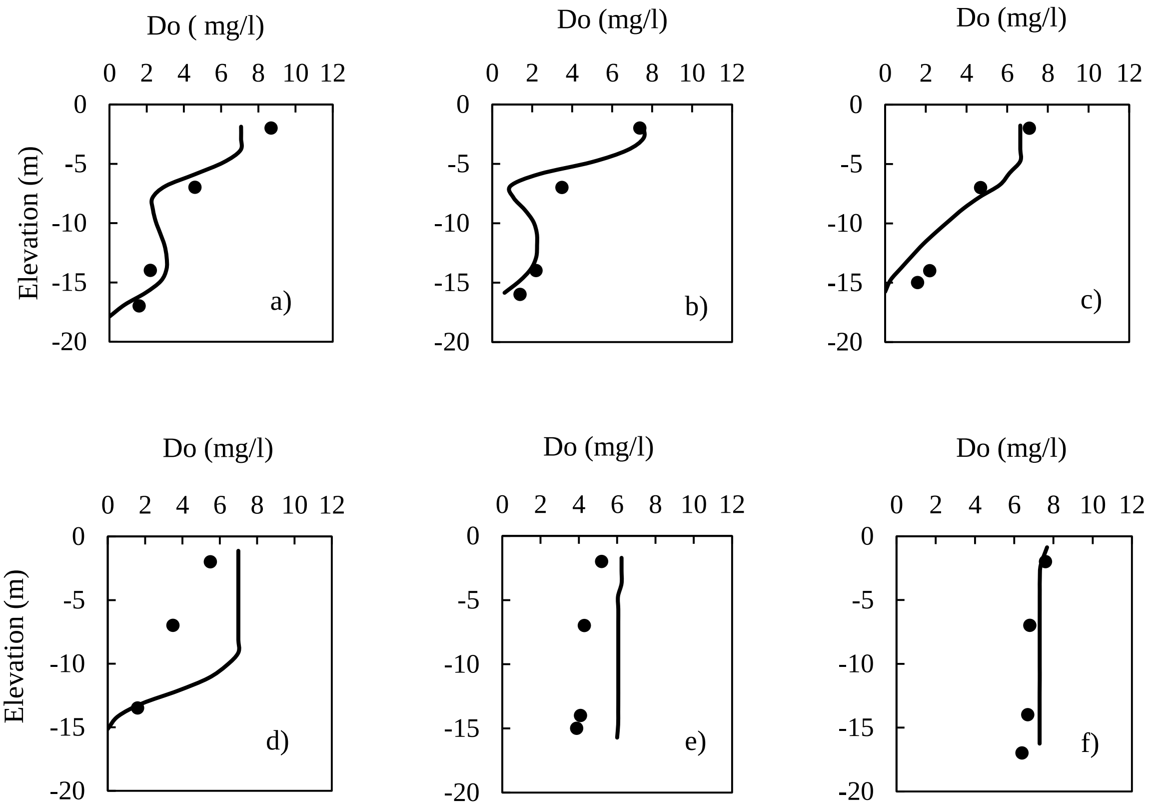


Fig. 6. Comparison of the measured and simulated temperature data

Water Quality Results

For simulating the water quality of the Ilam reservoir, the dissolved oxygen, chlorophyll a and nutrient concentrations at the Golgol, Chaviz and Ema rivers confluence with the reservoir were entered as inlet boundary conditions. In Figures 7 and 8, the simulated water quality results including DO, phosphate, ammonium, silica, nitrate and chlorophyll a are compared with the measured data at the dam site in 2009. After numerous runs of the CE-QUAL-W2 model, the calibrated kinetic coefficients and constants for the water quality simulation were determined and listed in Table 3. In general, they are consistent with literature values (Afshar and Saadatpour, 2009, Cole and Wells, 2008). Several statistical methods including mean absolute error (MAE) and root-mean-square error (RMSE) were used to compare the simulated and measured results in the calibration and verification periods.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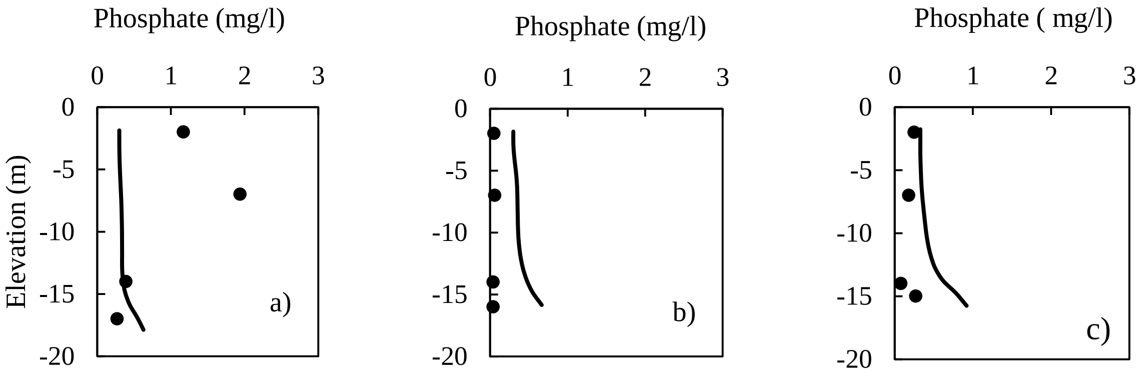
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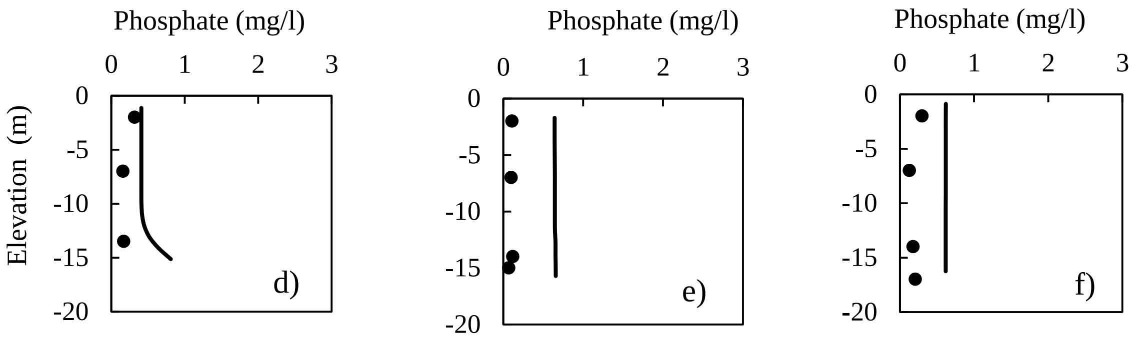
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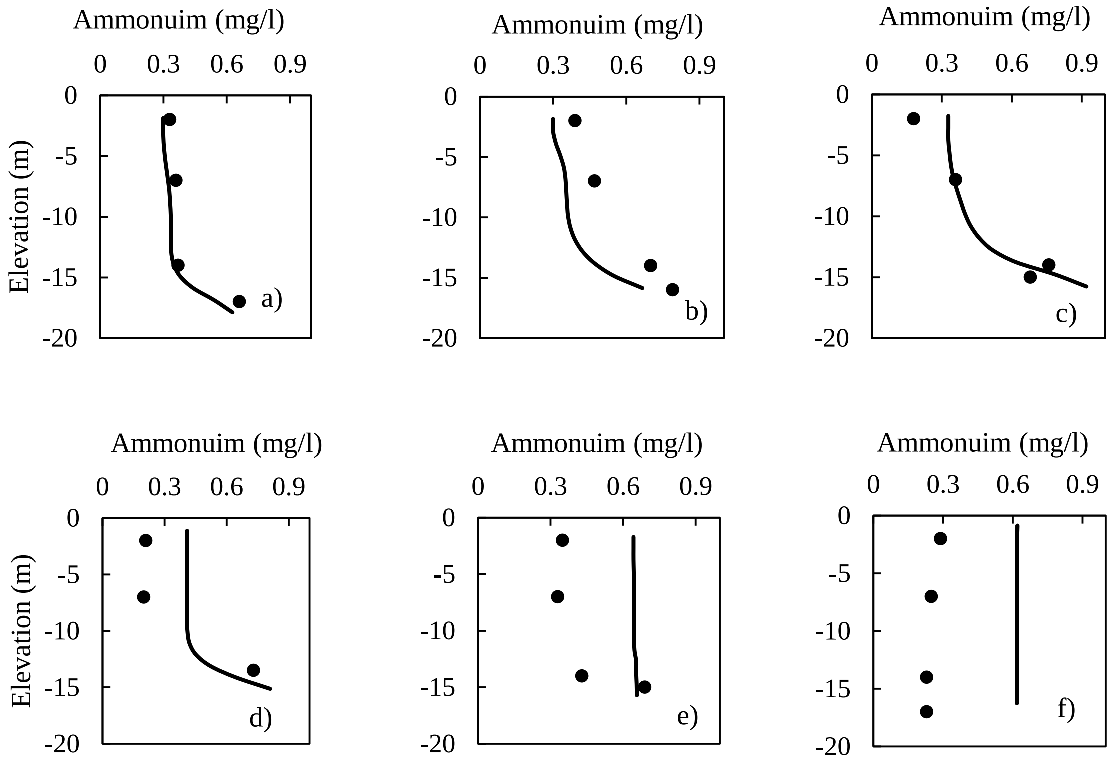
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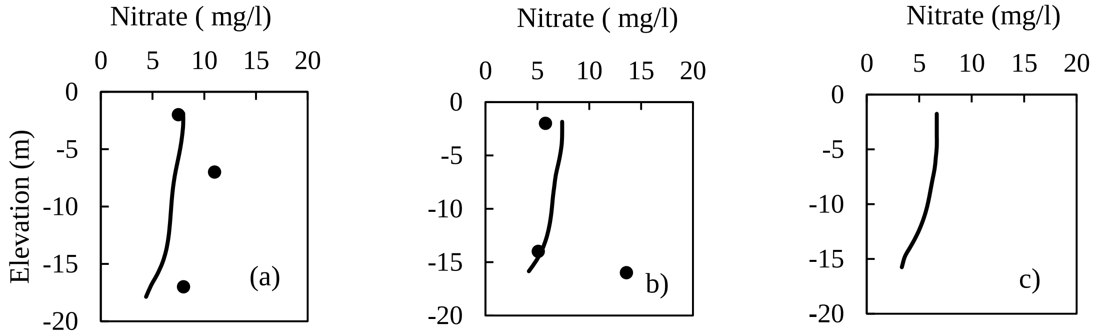
Nitrate (mg/l)
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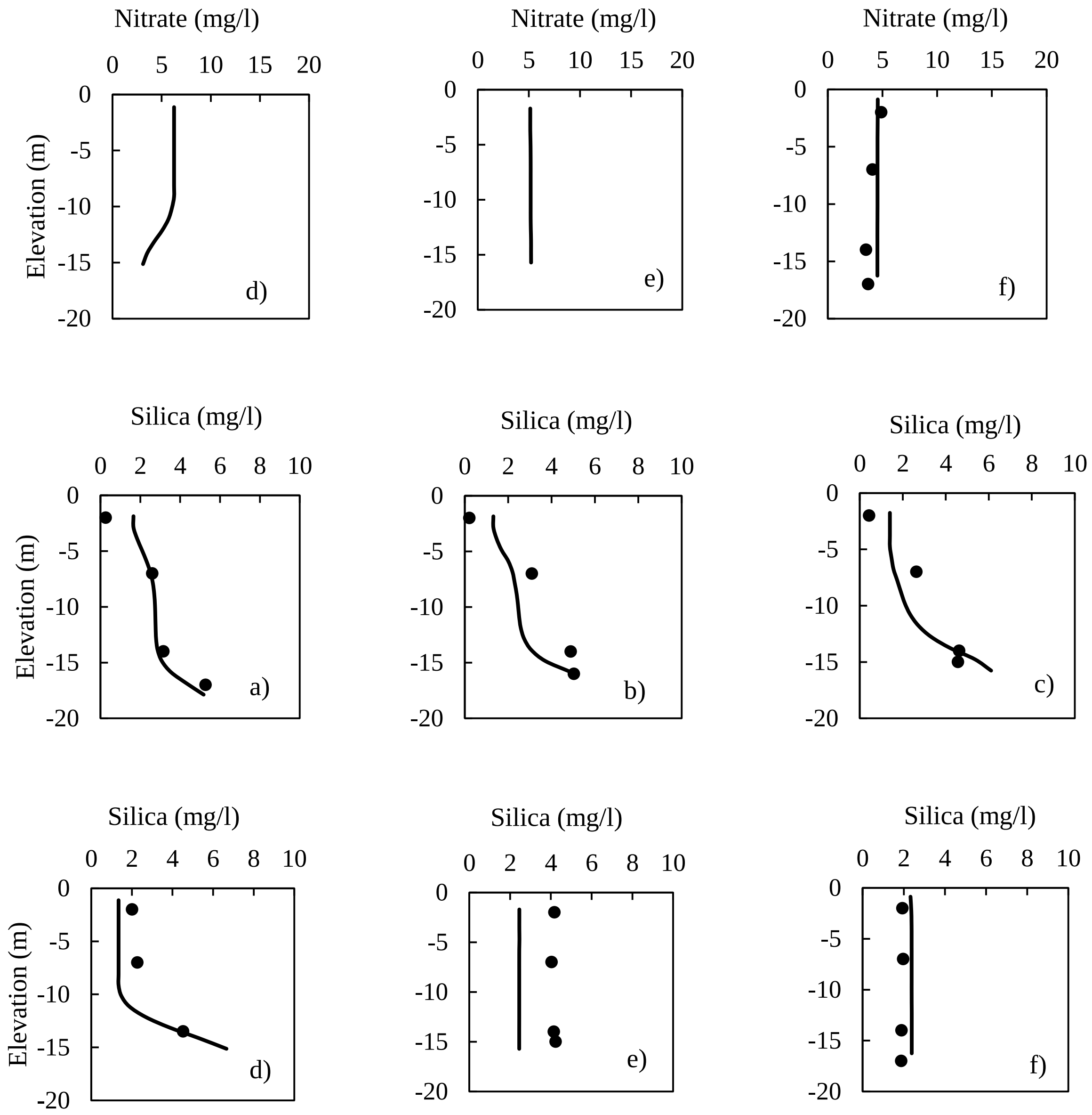
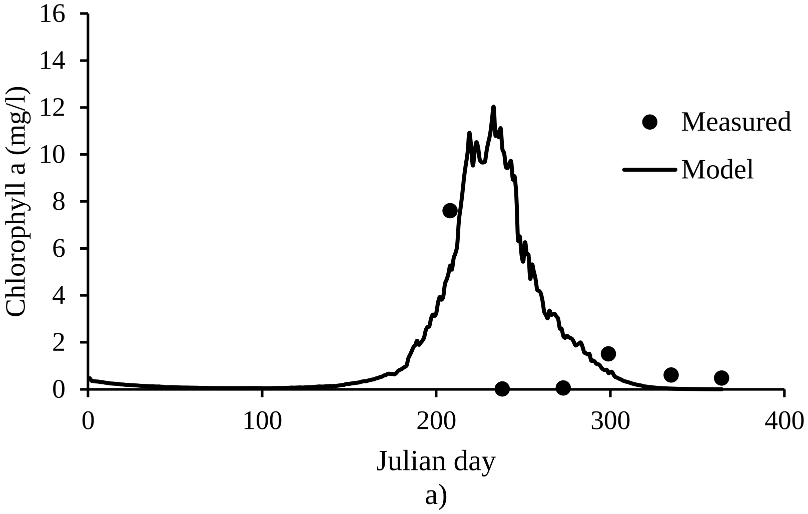


Fig. 7. Comparison of the simulated and measured water quality profiles in the calibration period ((-) Modeled, (•) Measured), a) Julian day = 208, b) Julian day = 238, c) Julian day = 273, d) Julian day = 299, e) Julian day = 335 and f) Julian day = 364



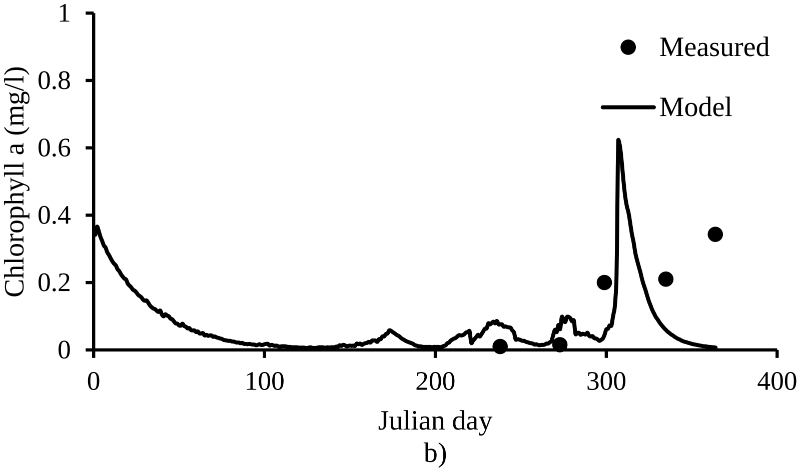


Fig. 8. Comparison of the simulated and measured chlorophyll a concentration in the calibration period, a) Top layer b) Bottom layer

Table 3. Coefficients and constants used in the calibrated model of the water quality

Parameter	Description	Units	Value
AG	Algal grow rate (20 °C)	day^{-1}	0.66
AM	Algal mortality rate for algal	day^{-1}	0.1
AS	Algal settling rate	day^{-1}	0.1
AE	Algal excretion rate for algal	day^{-1}	0.04
AR	Algal dark respiration rate	day^{-1}	0.04
ASAT	Algal light saturation	W/m^2	50
AHSP	Algal half-saturation P	g/m^3	0.003
AHSN	Algal half-saturation N	g/m^3	0.014
ASAT	Saturation light intensity	W/m^2	50
NH4DK	Ammonia decay rate	day^{-1}	0.001
NO3DK	Nitrate decay rate	day^{-1}	0.03
PSIS	Particulate silica settling velocity	m/day	0.05
PSIDK	Particulate silica decay	1/day	0.003
SOD	Sediment oxygen demand	$g\ o_2\ m^{-2}\ day^{-1}$	0.7

Calibration Period

Oxygen is an essential element for all organisms into aquatic ecosystems. According to Environment Protection Agency (EPA), larval life stages of many fish and shellfish species can be compromised when dissolved oxygen is less 5 mg/l for long periods. In a reservoir, the dissolved oxygen calibration is an important step for obtaining a useful model (Nielsen, 2005). The basic parameter influencing the modeling results of the dissolved oxygen is the sediment oxygen demand (SOD) (Chen et al., 2012). The parameter value of the sediment oxygen demand was determined so that a good agreement between the simulated and measured dissolved oxygen concentrations had been achieved. By the CE-QUAL-W2 model, the seasonal variations of the DO were well simulated in the reservoir and the simulated results were reasonably matched with the measured ones (Figure 7). At the surface layer of the Ilam reservoir, the DO concentration ranges are from 5.2 to 9 mg/L. During the summer and autumn seasons, the DO concentration is below the water quality criteria provided by EPA (Figure 7). The EPA water quality criteria states that phosphates concentration should not exceed 0.025 mg/l within a lake or reservoir. According to the measured data, the phosphate concentration of the Ilam reservoir is higher than drinking water standards during all months in which the measurements have been performed. Because of releasing phosphorus from the bottom sediments into water column under anoxic conditions, the available phosphorus has been increased within the reservoir water. The ammonium concentration is generally lower at the water surface due to algal uptake and higher at the bottom where the phytoplankton growth is dependent to the light limitation (Figure 7). The ammonium concentration is too higher than drinking water standards (0.5 mg/l) at the lower layers from August to December. After carbon, nitrogen is the second important component in the phytoplankton feeding processes. In this study, the nitrate decay rate was determined 0.03 day^{-1}. A good agreement between the simulations and measurements of the ammonium and nitrate is observed (Figure 7 and Table 4). Silica is a limiting factor for diatoms and silica seasonal variations affect the diatoms growth. Diatoms are a major group of algae and second group of algae in the Ilam reservoir (Mahab Qods, 2010). The simulated and measured silica concentrations are compared with together in Figure 7 which indicates a good agreement between them. During the summer, when the stratification is evident, the simulations and measurements indicate that the silica concentration is higher at the bottom than the surface.

In the aquatic ecosystem, one of the most important kinds of living organisms is phytoplankton. The algae growth is clearly a function of residence time and reservoir hydrodynamics (Afshar and Saadatpour, 2009). In this study, the algae maximum growth rate and maximum light saturation coefficient were calibrated to 0.66 day^{-1} and 50 W/m^{2}, respectively. The mean absolute errors between the simulation and measurement results of the Chlorophyll a concentration were respectively 1.08 and 0.15µg/l at the top and bottom layers. According to the measurement and simulation results, the chlorophyll a concentration is low in the winter, increases in the spring, reaches its maximum in the summer and decreases in the autumn (Figure 8).

Table 4. Mean absolute and root mean square errors of the water quality parameters in the calibration period

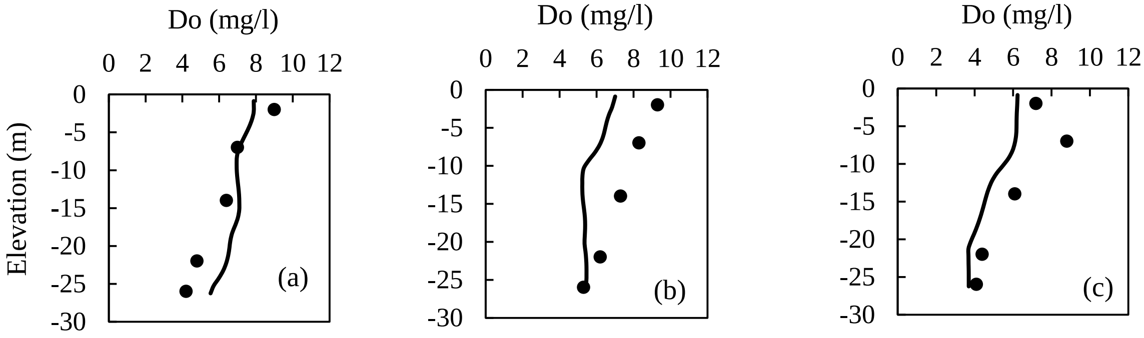
Julian Date	Dissolve Oxygen		Phosphate		Ammonium		Nitrate		Silica	
	MAE (mg/l)	**RMSE (mg/l)**	**MAE (mg/l)**	**RMSE (mg/l)**	**MAE (mg/l)**	**RMSE (mg/l)**	**MAE (mg/l)**	**RMSE (mg/l)**	**MAE (mg/l)**	**RMSE (mg/l)**
208	1.25	1.31	0.92	1.14	0.08	0.09	2.48	2.87	0.64	0.82
238	0.96	1.35	0.30	0.44	0.16	0.18	3.75	5.51	0.96	1.11
273	1.00	1.09	0.24	0.57	0.09	0.10	-	-	0.73	0.80
299	1.81	1.20	0.91	1.16	0.11	0.13	-	-	0.60	0.67
335	1.71	1.77	0.37	0.52	0.11	0.14	-	-	1.70	1.70
364	0.54	0.60	0.33	0.72	0.19	0.19	0.66	0.72	0.45	0.45

Verification Period

Model validation is possibly the most important step in the model building. There are many techniques including, comparison to other models, face validity, historical data validation, parameter variability – sensitivity analysis, predictive validation that can be utilized to verify a model. In this study, the historical data validation is selected for verifying the model. In this method, the parts of the data are used to build the model and the remaining data are used to test validity of the previously evaluated coefficients. For verification of the model, data from year 2010 were used. Verification results of the numerical model are presented in Figure 9. Table 5 presents the verification results of MAE and RMSE between model results and observations. The means absolute errors are 1.21 mg/l, 0.19 mg/l, 2.85 mg/l, 0.1 mg/l, and 0.46 mg/l for DO, total phosphorus, nitrate, ammonium, and silica, respectively. The corresponding RMSE values are 1.43 mg/l, 0.21 mg/l, 4.31 mg/l, 0.12 mg/l and 0.57 mg/l, respectively. In Figure 9 and Table 5, a reasonable agreement between the model results and field measurements is observed. Therefore, this numerical model is appropriate for evaluation future management strategies.

Table 5. Mean absolute and root mean square errors of the water quality parameters in the verification period

Julian Date	Dissolve Oxygen		Total Phosphorus		Ammonium		Nitrate		Silica	
	MAE (mg/l)	**RMSE (mg/l)**	**MAE (mg/l)**	**RMSE (mg/l)**	**MAE (mg/l)**	**RMSE (mg/l)**	**MAE (mg/l)**	**RMSE (mg/l)**	**MAE (mg/l)**	**MAE (mg/l)**
105	0.96	1.10	0.22	0.25	0.10	0.11	3.36	4.91	0.59	0.73
133	1.45	1.68	0.20	0.21	0.05	0.07	3.78	5.38	0.20	0.26
165	1.23	1.46	0.16	0.17	0.15	0.16	1.41	1.61	0.60	0.61



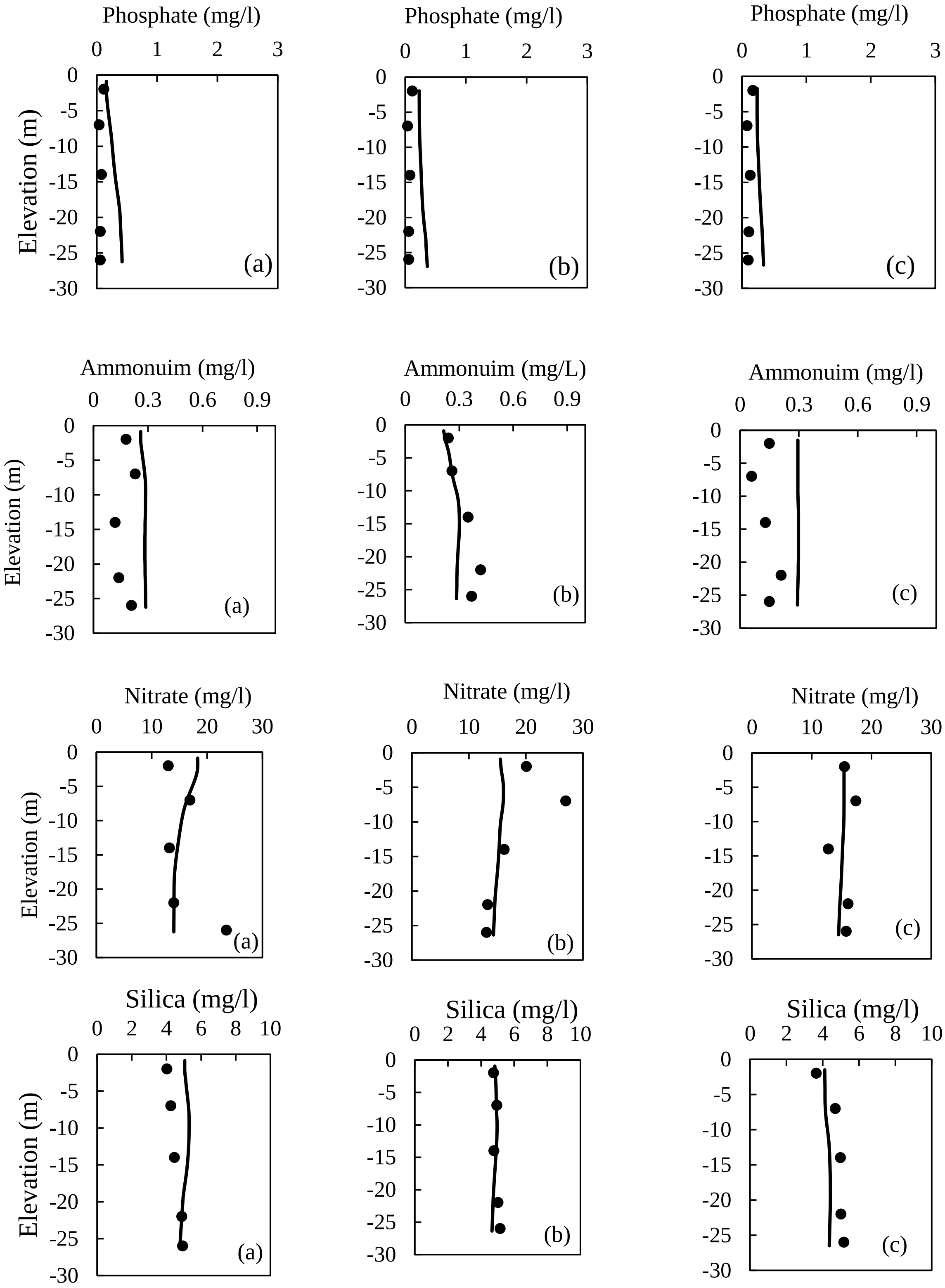


Fig. 9. Comparison of the simulated and measured water quality profiles in the verification period ((-) Modeled, (•) Measured), a) Julian day = 105, b) Julian day = 133 and c) Julian day = 165

MODEL APPLICATION

As mentioned earlier, the Ilam reservoir inflow is the discharge sum of Golgol, Chaviz and Ema rivers at the confluence with the reservoir. Based on the hydrological data, Golgol, Chaviz and Ema rivers respectively supply 68%, 23% and 9 % of the total annual inflow of the Ilam reservoir. The effects of various management scenarios on the chlorophyll a and total phosphorus concentrations were investigated. Simulations were executed for fifth scenarios: reference scenario (first scenario), the Ema river diversion (second scenario), the Ema and Chaviz rivers diversion (third scenario), total reduction of nutrient loads derived from the Ema river (fourth scenario) and total reduction of nutrient loads derived from Chaviz and Ema rivers (fifth scenario). The reference scenario corresponds to the actual situation and the results of the calibrated model used for this scenario. For the second and third scenarios, it was assumed that a diversion weir is constructed in the confluence of rivers with the reservoir and thus prevents the entering water from these rivers to the reservoir. Therefore, about 9% of the total annual inflow of the Ilam reservoir is diverted in the Ema river diversion (second scenario) and about 32% of the total annual inflow of the Ilam reservoir is diverted in the Chaviz and Ema rivers (third scenario). For the fourth and fifth scenarios, it was assumed that the best management approach in the watershed was applied to achieve nutrient load reduction from rivers. For this purpose, the concentration of nutrients including phosphate, ammonium, Silica and nitrate in rivers was reduced. All other reservoir condition was kept identical. Concentration duration curves of chlorophyll a and depth-averaged total phosphorus yielded by the numerical simulation of these scenarios are illustrated in Figures 10 and 11, respectively. The Ema river diversion (second scenario) reduces 3% depth-averaged total phosphorus concentration in 17% of the time and increases 44% chlorophyll a concentration in 44% of the time. The 9% reduction of the inflow to the Ilam reservoir (second scenario) leads to increase the water retention time which has a considerable effect on the chlorophyll a concentration. The inflow variations to the reservoir have little effect on the thermal stratification. The Ema and Chaviz rivers diversion (third scenario) decreases 23% depth-averaged total phosphorus concentration. The chlorophyll a concentration is increased 200 percent at the third scenario (32% reduction of the inflow). The water retention time affects the chlorophyll a concentration with inflow reduction (2nd and 3rd scenario). Hence, the chlorophyll a concentration within the reservoir approximately is independent of the nutrient loads input changes. On the other, it significantly affects the phosphors concentration of the reservoir. The total reduction of the nutrient loads entered by Chaviz and Ema rivers decreases 30% depth-averaged total phosphorus concentration in 17% of the time.

With considering the numerical simulation results of the hypothetical scenarios, the water quality improvement of the Ilam reservoir will not be achieved by the Ema and Chaviz rivers diversion at the inlet sections. The water retention time is a limiting factor of chlorophyll a concentration in the reservoir. The inflow water purification should be considered in the Ilam reservoir management.

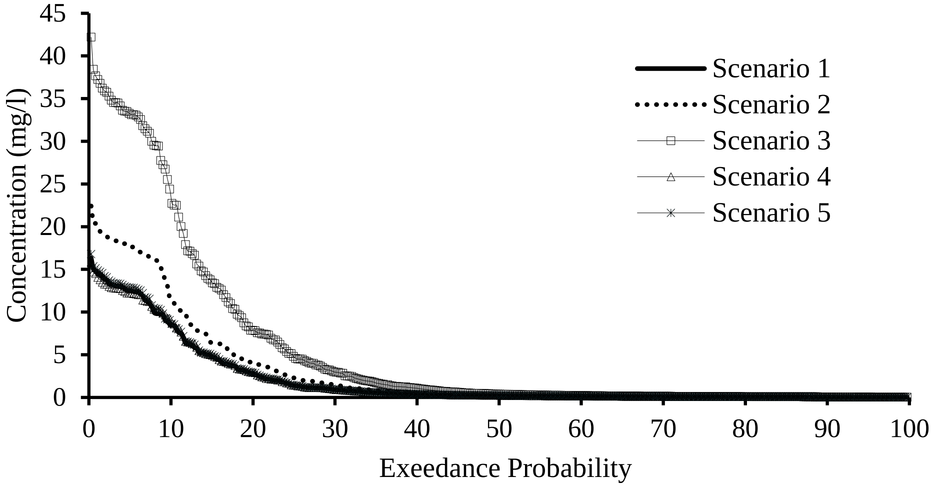


Fig. 10. Duration curves of chlorophyll a concentration at the top layer of the reservoir in the various scenarios

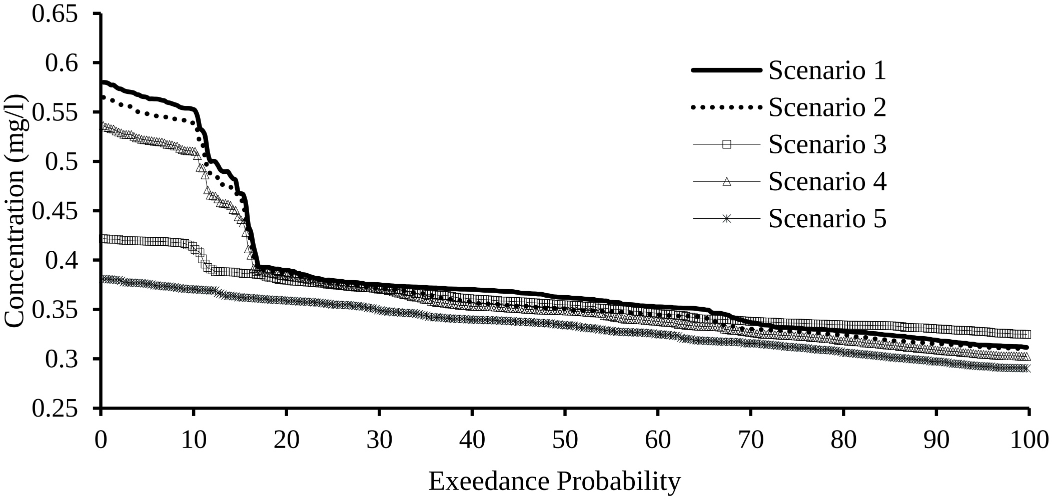


Fig. 11. Duration curves of total phosphorus depth-averaged concentration in the various scenarios

CONCLUSIONS

In this research, a 2D laterally averaged model of hydrodynamics and water quality, CE-QUAL-W2, was applied to simulate variations in the water quality parameters of the Ilam reservoir. The water quality of Ilam reservoir was obtained between mesotrophic and eutrophic based on the measured data including chlorophyll a, total phosphorus and subsurface oxygen saturation. The CE-QUAL-W2 model was calibrated using the year 2009 data and the year 2010 data were used for the numerical model validation. The comparison of the water surface elevation with the measurements indicated that the flow was fully balanced in the numerical model. The numerical model has successfully simulated the variations of the water column temperature in both stratified and well-mixed conditions. Several water quality parameters such as DO, phosphate, ammonium, chlorophyll a, silica and nitrate that measured were considered for the model calibration and verification. A reasonably agreement between the simulated and measured results of the water quality constituents was observed in the calibration and verification periods. The numerical model successfully simulated the variations of the water column temperature in both stratified and well-mixed conditions. In the summer, the concentration of the chlorophyll a is higher and anoxic conditions happen in the bottom of the reservoir. During the summer and autumn seasons, the DO concentration is below the water quality criteria provided by EPA. Large quantities of phosphorus are also released from the bottom sediments when dissolve oxygen levels decrease in the lower layers. The phosphate concentration is higher than drinking water standards during all months in which the measurements have been performed. The ammonium concentration is too higher than drinking water standards at the lower layers from August to December.

According to results obtained by the scenarios analyze, the partial diversion of the total annual inflow of the Ilam reservoir significantly increases the chlorophyll a concentration at the top layer and this inflow diversion slightly affects the depth-averaged total phosphorus concentration. The depth-averaged total phosphorus concentration was significantly reduced and the chlorophyll a concentration at the top layer approximately was constant by the nutrient loads input variations of the Ilam reservoir.

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