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Phytoplankton and Zooplankton Modeling of Pishin Reservoir by Means of an Advection-Diffusion Drought Model

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ABSTRACT: Phytoplankton and zooplankton concentrations in Pishin reservoir are predicted employing a three-dimensional numerical model in this paper. Modeling is performed using a numerical model based on mass transport equation. Advection, diffusion and source/sink processes are considered as separate subroutines for predicting the concentrations of phytoplankton and zooplankton in the reservoir. Finite volume method is used for solving the governing equations of water quality and water flow. The model is adopted for drought periods and dry climates. Water flow in the reservoir is simulated by Fluent software that is a finite volume numerical model. The model also uses a sub-model for compatibility providing of geometry between software and water quality model. A one-year period of experimental works and sampling is done in the study area. Phytoplankton and zooplankton cycles are used to determine the sources and sinks. Standard methods are chosen for experimentation. The concentrations of phytoplankton and zooplankton are calculated and measured in a one-year period. The concentrations of phytoplankton and zooplankton decrease in the depth of water and the decease rate is not linear. Also the concentrations are increase in the times after the maximum floods because of the inflows contain high amounts of nutrients. The calculated values by the model are in good agreement with measured values of laboratory works. It was concluded that the model can be used for water quality prediction in such aquatic environments.

Key words: Aquaculture, Lake, Water Flow, Source/Sink, Water quality

INTRODUCTION

Destroying effects of aquacultures in aquatic environments that are used for water supply of downstream regions are of a big concern. The growth of phytoplankton due to high concentrations of nitrogen and phosphorous and consequently, the growths of zooplankton which most of them are useless, are the most important parameters of water quality evaluation in lakes and reservoirs. A wide variety of bioassays are run by researchers all around the world (Murugan *et al.*, 2009; Shetty and Rajkumar, 2009; Velmurugan *et al.*, 2009; Khanna *et al.*, 2009; Mishra *et al.*, 2009; Banerjee and Srivastava, 2010; Adekunle *et al.*, 2010; Santhanam and Amalraj, 2010; Rajesh Kannan *et al.*, 2010; Jeong *et al.*, 2010) through which Lots of models are developed for phytoplankton and zooplankton modeling in aquatic environments. A simple model is used for nutrient transport modeling in chahnimeh reservoirs by Mirbagheri et al. (2009). The responses of four phytoplankton species of Nigerian coastal water are shown by Adekaunle et al. (2009). The role of phytoplankton in productivity in a seasonally stratified lake was modeled and studied by Hillmer et al. (2008). They developed a 1D and a 3D model for N-P-Z and hydrodynamic and considered non-linear variables in their model. Mieleitner and Reichert (2008) focused on groups of phytoplankton in lakes with different trophic states. They found phosphorous as limiting nutrient in their case. External and internal loads of nutrients on phytoplankton biomass are studied by Burger et al. (2008). Inflows, outflows and sediments were considered as the main source and sink terms for phytoplankton in their study. MCMC methods with a water quality model for algal mass occurrences were applied by malve et al. (2007). They estimated the effect of nutrients on grazing zooplankton and phytoplankton groups. Elliot et al. (2007) linked the models Probe and Protech for Phytoplankton modeling in a lake. They added new cyanobacteria to the model and investigated their growth rate. P-dynamic and algal growth and the role of sediments in a reservoir were specified by Komatsu et al. (2006). They combined three models together and predicted the concentration of phosphorous in

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the reservoirs. Skirlis and Djenidi (2006) chose a submarine canyon and investigated the plankton dynamics. They used a three-dimensional nonlinear hydrodynamic model coupled with a coastal plankton ecosystem. Distribution of phytoplankton in rainy and dry seasons was searched by Zeng et al. (2006). They observed a correlation between phytoplankton abundance and nitrate. The role of zooplankton in C, N and P cycling in lakes studied with a numerical simulation (Bruce *et al.,* 2006). The physical transport of algae to the benthos was studied by Edward et al. (2005). They incorporated the measured parameters in numerical simulations of phytoplankton consumption by benthic zebra mussels. Trancoso et al. (2005) modeled macroalgae using a 3D hydrodynamic-ecological model in a shallow estuary. A statistical prediction and setup of phytoplankton model were developed by Jiao et al. (2004). Shallow and deep lakes chose for the simulation of phytoplankton by Elliot and Thackeray (2004). The eutrophication process and phytoplankton succession were studied by Rukhovets et al. (2003). Pham Thi et al. (2003) simulated 3D phytoplankton dynamics in light-limited environments. Numerical modeling of the planktonic succession in a nutrient-rich reservoir was performed by Bonnet and Paulin (2002). Remote sensing with computational fluid dynamics was coupled for estimating lake chlorophyll-a concentration by Hedger et al. (2002). Protech model with a phytoplankton community model was applied with Lewis et al. (2002). Shallow eutrophic lake selected for modeling mycrophyte-nutrient-phytoplankton interaction in lakes by Asaeda et al. (2001). Walter et al. (2001) predicted the eutrophication effects in a reservoir by means of a deterministic model. The role of top-down effects for fish and zooplankton was studied by Krivtsov et al. (2001). Some other researches in shallow eutrophic lake and warm reservoirs were performed by Xu et al. (1998), Robert et al. (1998) and Jayaweera and Asaeda (1996). Some researches were also performed based on statistical modeling and phytoplankton and zooplankton migration in recent years and last decade (Rose *et al.*, 2007, Freund *et al.*, 2006, Kowe *et al.*, 1998, Megrey *et al.*, 2007). Also a one-dimensional sediment characterization method in a river basin was employed by Mirbagheri et al. (1981). Most of these models did not apply three-dimensinal hydrodynamic models. In many of them only the effects of sources/sinks are considered for variation of concentration of different pollutants or eutriphication in the reservoir. Some of them did not consider water flow models. Advection, diffusion and sources/sinks effects together with a three-dimensional water flow model are applied to simulate water quality parameters in the reservoir in the current model.

MATERIALS & METHODS

Predicting the variations of the concentration of different pollutants in a lake or reservoir needs to calculate the velocity field. When the main river of the reservoir is seasonal, the velocity field varies in each season and affects on the concentration of phytoplankton and zooplankton. The hydrodynamic model simulates the effects on the velocity field. The variations of the velocity field are considered seasonal because the floods of the river are seasonal. Four shots are considered as the representative of seasonal variation of velocity field in the reservoir. The boundary conditions change in different seasons in the input point and output point of the reservoir. Fluent Software that is a numerical finite volume model for water flow equation is applied for this purpose. Modeling of complicated geometries with different turbulent flows is applicable with Fluent Software. This model was used in different case studies in recent years. Governing equations of water flows in Fluent Software are Navier-Stokes equations which are solved with specific algorithms for convergence.

Water quality model considers the effects of advection, diffusion and sources/sinks. Advection is the result of velocity field while, diffusion is molecular and temperature dependent and, sources/sinks are different with the variation in space and time.

The equation used for concentration prediction in the reservoir is advection-diffusion equation (Mohammetoglu *et al.*, 2000):

$$\frac{\partial \phi}{\partial t} = -u\frac{\partial \phi}{\partial x} - v\frac{\partial \phi}{\partial y} - w\frac{\partial \phi}{\partial z} + \frac{\partial}{\partial x}(E_x\frac{\partial \phi}{\partial x}) + \frac{\partial}{\partial y}(E_y\frac{\partial \phi}{\partial y}) + \frac{\partial}{\partial z}(E_z\frac{\partial \phi}{\partial z}) \pm Sources/Sinks \quad (1)$$

where ϕ is the water quality parameter in each stage of transportation in the reservoir

x, y, z : Cartesian directions (m)

u, v, w : Velocity components in directions (m/s)

E_x, E_y, E_z : Diffusion coefficient in dimensions (m^2/s)

t : Time (s)

ϕ : Concentration of each substance (mg/L)

Phytoplankton concentration has a direct effect on water quality. When the concentration of phytoplankton is high, the effects of advection and specially diffusion on concentrations are low. The effect of sources/Sinks in this reservoir is more than others.

Phytoplankton consumes nitrogen, phosphorous and solar radiation. Nitrogen and phosphorous are available in the water flow of the main river of the reservoir. Most additives of agricultural fields have nitrogen and phosphorous complexes that come to reservoir through maximum floods. Solar intensity also is high in the study area.

The source/sink factors that are considered for phytoplankton in the model are listed below (Trancoso *et al.*, 2005):

$$\text{Sources/Sinks} = (\mu_{ph} - r - e_s - S - m)Ph - G \quad (2)$$

where:

μ_{ph} : Impure growth rate for phytoplankton $(1/day)$

r : Respiration rate for phytoplankton $(1/day)$

e_s : Excretion rate $(1/day)$

S : Settling rate

m : Non-predatory mortality rate

ph : Phytoplankton concentration

G : Grazing source reduction rate

Phytoplankton growth is a function of light and nutrients. The main limiting nutrients are phosphorous, nitrogen, carbon and silica. Other nutrients may also limit the phytoplankton growth, but these have been not considered in this model. Phytoplankton growth is calculated as follows:

$$\mu_{ph} = \mu_{\max}(T_{ref})\, f(T)\, f(L, P, N) \quad (3)$$

where:

T : Temperature (°C)

$f(T)$: Temperature (function of growth rate)

$\mu_{\max}(T_{ref})$: Maximum growth rate at reference temperature

$f(L, N, P)$: Limiting growth function for light and nutrients

L : Light intensity

The effects of silica and carbon are not considered due to the low concentration of diatoms in the reservoir. Excretion and respiration, the main components of the nutrient cycle, are modeled by a relation that includes all of the wastes from these processes. Waste process is the difference between pure and impure phytoplankton growth. Therefore,

$$r = r(T_{ref})\, f_r(T) \quad (4)$$

where:

r : Respiration rate plus excretion rate *(1/day)*

$r(T_{ref})$: Respiration rate at reference temperature *(1/day)*

$f_r(T)$: Temperature function for respiration

All of the phytoplanktonic wastes that are not calculated earlier are considered in the non-predatory mortality rate. This rate considers aging, bacterial cell decay and toxic material availability. The non-predatory mortality rate is calculated as follows:

$$m = m(T_{ref})\, f_m(T) \quad (5)$$

where:

m : Non-predatory mortality rate $(1/day)$

$m(T_{ref})$: Non-predatory mortality rate at reference temperature $(1/day)$

$f(T)$: Temperature function for mortality

The settling rate is neglected due to the low turbidity of water in the reservoir.

Zooplankton includes a wide range of different aquaculture. In most of the models a specific group of zooplankton is chose and simulated in the reservoirs. Usually the dominant group of zooplankton is considered in simulation. In this study the small non-predator fishes are not considered as zooplankton.

The source/sink relationship in this model is expressed as follows (Xu *et al.*, 1999; Jayaweera and Asaeda, 1996):

$$\text{Sources/Sinks} = (g_z - r_z - m_z)Z - G_z \quad (6)$$

where:

g_z : Impure growth rate for zooplankton*(1/day)*

r_z : Respiration rate for zooplankton *(1/day)*

m_z : Non-predatory mortality rate for zooplankton *(1/day)*

Z : Zooplankton concentration *(mg/L)*

G_z : Reduction rate due to predation *(mg/L/day)*

Zooplankton growth is due to reproduction and depends on the content of absorbed nutrients. Some of the absorbed nutrients supplies are consumed for reproduction and the residual are accounted in metabolic losses. The zooplankton growth rate is calculated as follows:

$$g_z = C_g E \quad (7)$$

where:

g_z: Impure growth rate $(1/day)$

C_g : Absorption rate (mass of nutrient/ (mass of zooplankton. day))

E : Absorption efficiency

As for phytoplankton, zooplankton respiration is modeled by a general formulation and is a function of temperature.The predatory mortality rate of zooplankton is considered constant, and this rate includes predation by fishes.

Phishin reservoir is located in south-east of Iran in Sistan& Baluchstan province near Pakistan border. The main river of the reservoir called Sarbaz that is a seasonal river. The water of the river is consumed with rural residents of the region and therefore, pollutants are added in to the water as point sources. About ten years ago the reservoir became empty due to incorrect policies and totally changed the environment of the reservoir. The effect of winds on flow turbulence is low because of surrounding mountains around the reservoir. Input discharge data of the river and reservoir are collected from ten-year flood measurements in the study area. The reservoir is located upstream of a clay core earth dam. The depth of the reservoir is 30m in deepest points in full volume seasons. The data used for model verification and calibration are measured by the hydrological station near the reservoir. No fishery activity is done in the reservoir in recent years. Outflow water of the reservoir is consumed for agricultural purposes. Marash crocodile lives in the reservoir and affects on water quality and is not considered in the modeling process. Fig. 1 shows the location of study area.

The model uses Fluent Software for determining the velocity field in the reservoir. Fluent is a numerical water flow model with finite volume numerical method that solves three-dimensional unsteady and turbulent flows. Mesh generating, geometry and defining boundary conditions in Fluent Software are performed through Gambit. Totally, 73 vertices were applied for the surface and the same number for the bottom of the reservoir. The wall slopes of the reservoir were considered to be 1:3 because they had been experimentally measured for many faces in the field, and it is assumed that reservoir had a shape proportional to the surface in the water depth. The mesh was generated with 10 m spacing and tetrahedral elements. The applied boundaries were velocity inlet, walls, surface as symmetry and outlets. Therefore, the adopted model for water flow modeling consists of 9,623 tetrahedral cells, 22,018 triangular velocity inlet faces and 23,411 wall faces. The velocities in the entering face were measured during each new flood of the river and applied to the model. The Quick method is considered for solving the water flow equation. This process is done for four seasons and four different velocity fields are determined. An integrated seasonal separate advection diffusion model (ISSADM) is used for obtaining phytoplankton and zooplankton concentration in the reservoir. ISSADM is a finite volume numerical model for predicting water quality parameters in water. Advection, diffusion and source/sink effects are simulated through three different subroutines in this model. ISSADM uses quick method for numerical solution of the transport equations. LOD method is applied for sweeping all cells of the body volume in this model. The user can choose the rank of each subroutine in ISSADM. The effect of all subroutines is considered as the transport. ISSADM was employed to study Chahnimeh man-made reservoir before (under publiucation). ISSADM is developed by visual FORTRAN and is an open source model that is available in the library of K.N.Toosi University of Technology. This model is now under development for predicting eutrophication in lakes and reservoirs by the authors. Fig.s 2 and 3 show the flowchart of the ISSADM model and the phytoplankton and zooplankton sub-model.

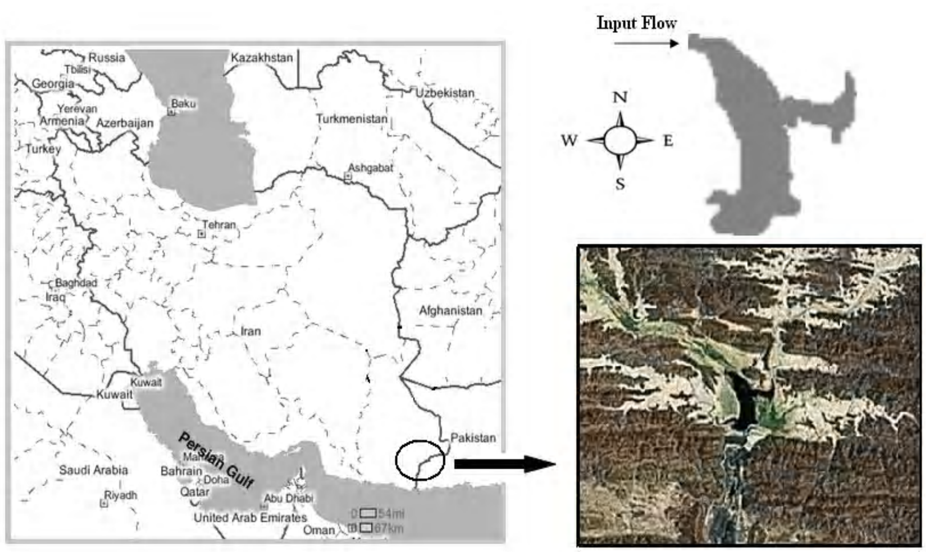

Fig. 1. Location of the study area

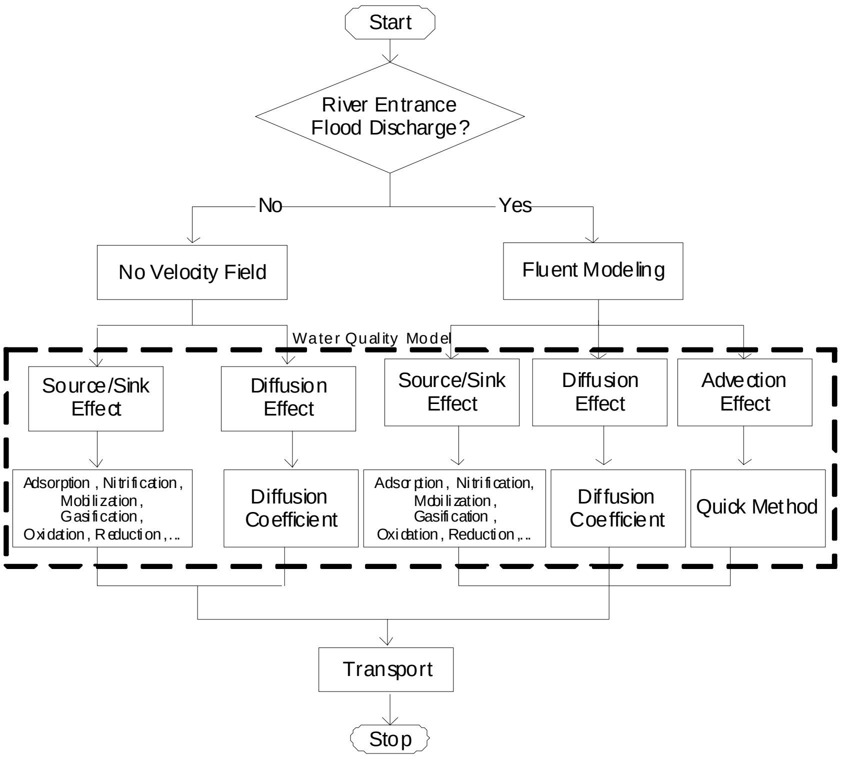

Fig. 2. Flowchart of ISSADM water quality model

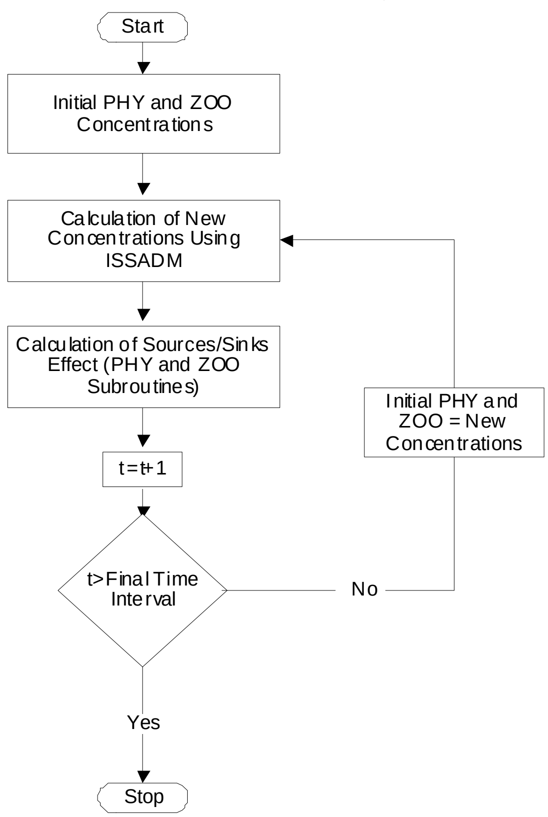

Fig. 3. Flowchart of phytoplankton and zooplankton model

Sampling processes were done in different seasons in the reservoir. Three different points are selected as the representative of changing in concentration in the reservoir. The coordination of these three points, determined by a GPS instrument, is shown in Table 1.

Table 1. The coordination of sampling points

Sampling Point	1	2	3
Latitude	26.0336N	26.0295N	26.0282N
Longitude	61.6890E	61.6887E	61.6896E

A one-liter water sampler was applied for sampling from different depths of water. A small boat was used in order to minimize turbulence during sampling procedure. Samples were collected in specified bottles and were transferred to the rural water& wastewater laboratory of Zahedan that is about 500 kilometer far from the reservoir. A spectrophotometer is used for water quality test and filtering for phytoplankton and zooplankton concentration. The data of a one-year seasonally measurements were employed for verification of the model. Seasonal time intervals are selected for sampling and laboratory works in the reservoir. This is because of large changes that are due to maximum floods in different seasons on the study area.

The Blue - Green algae that is the dominant specie of phytoplankton in the reservoir is considered as the representative type of phytoplankton. Four groups of zooplankton are found in the samples of water. The types of zooplankton and their average growth rate are shown in Table 2.

Table 2. The types of zooplankton that is considered in model

Zooplankton	Growth Rate(1/day)
Cladocerans	0.35-0.5
Copepods	0.5
Rotifers	0.44-0.45
Mysids	0.14

RESULTS & DISCUSSION

A three-dimensional numerical model that is linked to Fluent Software is used for predicting water quality in the reservoir. Phytoplankton and zooplankton parameters are used for this purpose. The concentration of these two parameters are calculated by the model and compared with measurements carried out in this study. The variations in the concentration of phytoplankton and zooplankton are shown in the figures. At Point 1, the concentration of phytoplankton at the surface of the water is 0.13 mg/L in autumn and reaches to 0.021 mg/L at the bottom of the reservoir. In summer at Sampling Point 2, the concentration of phytoplankton is 0.17 mg/L at the surface of the water and varies rapidly to 0.22 mg/L at the bottom. At Sampling Point 3, the concentration of phytoplankton is 0.16 mg/L during spring at the surface of the water as shown in Fig. 4. Phytoplankton concentration at summer is more than other seasons. The growth rate of phytoplankton is temperature dependent and solar radiation effect on the concentrations of

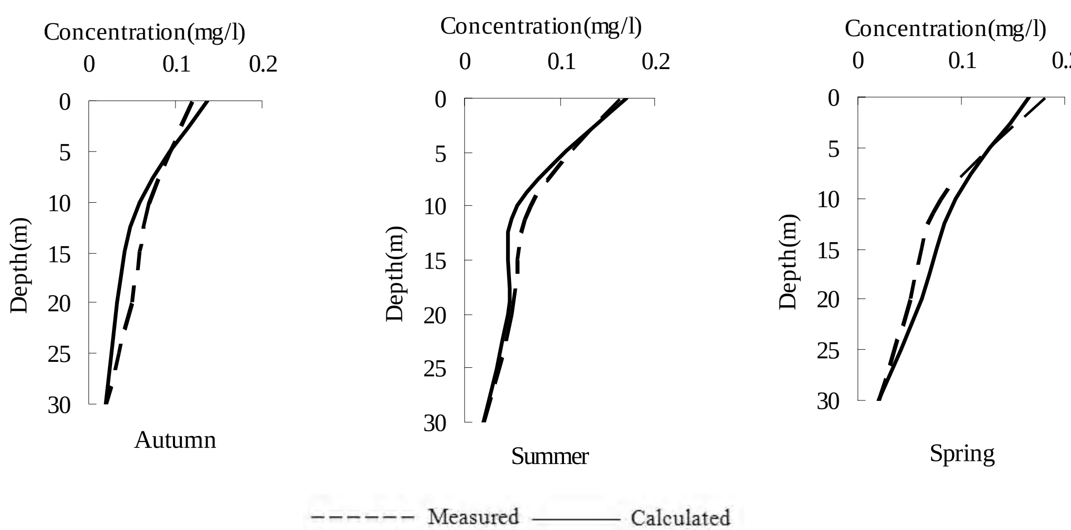

Fig. 4. Phytoplankton concentrations at different sampling points

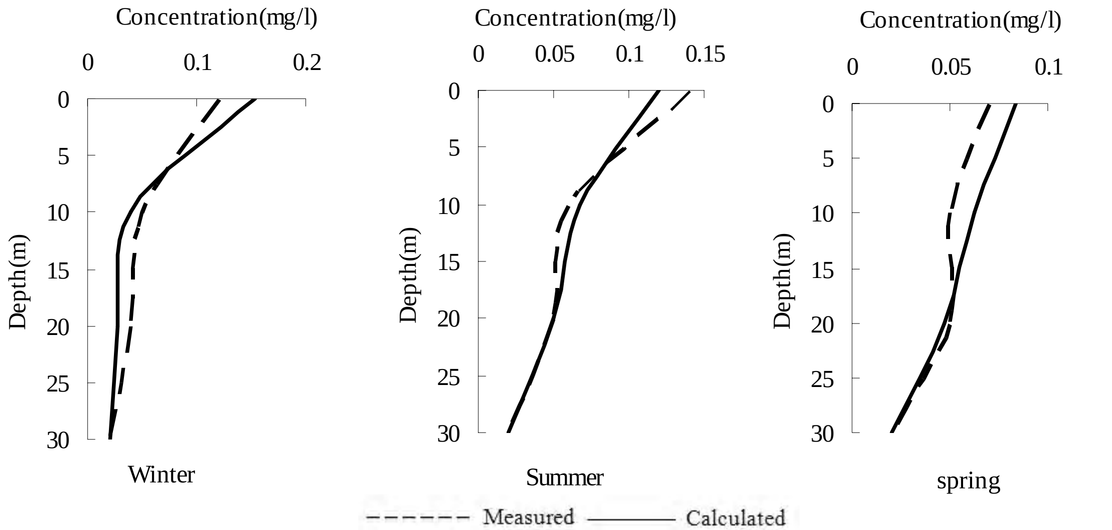

Fig. 5. Zooplankton concentrations at different sampling points

Table 3. The concentration of phytoplankton in different points and seasons (mg/L)

Sampling Point	**Point 1**				**Point 2**				**Point 3**			
Depth(m)	0	10	20	30	0	10	20	30	0	10	20	30
Spring	0.11	0.815	0.0892	0.021	0.1362	0.1155	0.0892	0.021	0.1662	0.0937	0.0612	0.021
Summer	0.1053	0.0427	0.0322	0.022	0.1697	0.0546	0.0456	0.022	0.1053	0.0475	0.0325	0.022
Autumn	0.1368	0.058875	0.03231	0.021	0.1503	0.0288	0.0223	0.021	0.1081	0.0234	0.0207	0.021
Winter	0.1046	0.01334	0.01006	0.01	0.1090	0.0144	0.0111	0.01	0.1065	0.0167	0.0109	0.01

Table 4. The concentration of zooplankton in different points and seasons (mg/L)

Sampling Point	**Point 1**				**Point 2**				**Point 3**			
Depth(m)	0	10	20	30	0	10	20	30	0	10	20	30
Spring	0.0835	0.061	0.046	0.0209	0.0975	0.066	0.051	0.0209	0.0835	0.0625	0.0475	0.0209
Summer	0.1196	0.0571	0.0506	0.0219	0.1188	0.0671	0.0506	0.0219	0.1115	0.0675	0.0522	0.0219
Autumn	0.0828	0.0475	0.0388	0.0221	0.0828	0.0475	0.0388	0.0221	0.0587	0.0475	0.0370	0.0221
Winter	0.1531	0.0399	0.0271	0.0221	0.0663	0.0359	0.0270	0.0221	0.0538	0.0368	0.0280	0.0221

phytoplankton and zooplankton is very evident. Moreover, water stagnancy raises the concentrations. The variation in concentration of zooplankton in the water column is nearly similar to phytoplankton. The concentration of zooplankton in Sampling Point 1 is 0.15 mg/L in winter at the surface of water and reaches to 0.22 mg/L at the bottom of the reservoir. During summer time in Sampling Point2 the concentration of zooplankton is 0.11 mg/L at the surface of the water. In Sampling Point3 the concentration of zooplankton at the surface of the water is 0.08mg/L in spring and reaches to 0.02 mg/L at the bottom of the reservoir as shown in Fig. 5. The concentration of zooplankton in winter is more than other seasons in the reservoir. The content of concentrations for phytoplankton and zooplankton are shown in Tables 3 and 4.

CONCLUSION

A numerical finite volume model is adopted to predict water quality parameters in Pishin reservoir. Phytoplankton and zooplankton are considered as water quality parameters and the concentrations are calculated by the model. One-year experimental works and laboratory activities with seasonal time intervals were performed in the study area and used for water flow and water quality modeling. Results show that the concentrations of phytoplankton and zooplankton increase where the volume of water is stagnant. Moreover, the concentrations increase in the seasons after the maximum floods when reservoir spends a shock of water entrances. The water body of the reservoir is stationary in this time and a large amount of nutrients is available in the reservoir. This condition increases the growth rate of phytoplankton and therefore the population of phytoplankton and zooplankton increases. In both cases, the concentrations decrease in depth of the water column. The decrease rate is not linear in most of the time. Velocity field also affects on the concentration of phytoplankton and zooplankton. The growth rates of phytoplankton and zooplankton are measured for different seasons. The variations in the growth rates are affected on the concentrations of phytoplankton and zooplankton in different seasons.

The concentrations of phytoplankton and zooplankton increase in edges and the regions of low velocities. The standard error and correlation of each diagram are shown that the model calculated values are in good agreement with measured values of laboratory works.

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