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Measurement and simulation of dissolved oxygen in Zayandehrood river

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ABSTRACT

Aims: This study aims to simulate dissolved oxygen of Zayandehrood river from regulating dam to Polle-Kalleh bridge using MIKE11 software that is a hydrodynamics and water quality model.

Materials and Methods: During 5 months the samples were taken from four hydrometric stations and water quality parameters such as dissolved oxygen, pH, BOD (1 day, 3 days, 5 days, and 7 days), NH_4, NO_3^- phosphate (PO_4^{3-}), and temperature were measured. Morphological and hydrological data were provided and introduced into the model. The model was calibrated and its accuracy was investigated.

Results: The results indicated that concentration of PO_4^{3-}, BOD_5, COD, NH_4, and NO_3^- exceeded surface water standards from regulating dam to Pole-Kalleh bridge. The results of the prediction for the next 25 years indicated that due to growth of population and industries along the river, concentration of some pollutants will be increased.

Conclusions: The results indicated that although the current DO level is suitable for aquatic environment, this is not adequate for fish reproduction and migration. Prediction of the river water quality parameters for the future conditions showed that discharge of urban and rural wastewater to river should be avoided. In situations where release of effluent into the river is inevitable, nitrification process should be added to wastewater treatment processes.

Key words: Dissolved oxygen, MIKE11, Zayandehrood river

INTRODUCTION

In recent decades, qualititative and quantitative simulation of water resources has been developed to manage water resources and assess the effects of discharging wastewater effluent into receiving waters. Many mathematical and numerical equations have been used which leads to improvement of simulation of water resources.[1,2] Computer models that have been used to simulate water quality are a combination of the equations that are sitting well beside each other to assess the system behavior clearly and predict the system future in a simple way.[1] Qualitative models of water resources are capable to assess the water quality behavior of various sources ranging from simple pollutants to more toxic pollutants both as one- or multidimensional flows.[3] In modeling water quality in rivers, the main aim is to determine the relation between hydraulic, chemical, and biological characteristics of river system.

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Simulation of dissolved oxygen in a river system is important. Various processes that affect dissolved oxygen simulation include dispersion, solar radiation, saturation of dissolved oxygen, biochemical oxygen demand of carbon materials, nitrogenous oxygen demand, the effect of phosphor compounds, photosynthesis, respiration, and reaeration. Various computer models are available for qualitative and quantitative simulation of water resources. Each of these models has special capability that depending upon the existing demands and facilities, a suitable model is selected.[4] This study aims to simulate dissolved oxygen in Zayandehrood river (from regulating dam to Pole-Kalleh bridge using MIKE11 a one-dimensional computer model. In this study, the study area—the main branch of Zayandehrood—is located between longitude of 50°, 3′ to 50°, 37′ and latitude of 32°, 17′ to 32°, 43′.

Great part of this basin is covered by rocky mountains.[5] Zayandehrood river water is a source of water for agriculture, industry, municipal (drinking), recreational, and recharging groundwater. In this study, the upstream part of the Zayandehrood river, the distance between regulating dam to Kalleh Bridge that is about 120 km, was investigated [Figure 1]. Near Pole-Kalleh bridge about 10 m^3/s of flowing water is diverted to Isfahan water treatment plant.

MATERIALS AND METHODS

MIKE 11 model is a dynamic, one-dimensional modeling tool for the design, management, and operation of complex river systems. This software has four editors including simulation, river network, cross sections, and boundary conditions and various modules including hydrodynamic (HD), the advection dispersion, water quality (WQ), runoff and rainfall, sediment transfer, and flood forecasting.[6] Flow equations in hydrodynamic module of MIKE11 are continuity and momentum equations. These are written as follows[6]:

$$\frac{\partial Q}{\partial x}+\frac{\partial A}{\partial t}=q \qquad (1)$$

$$\frac{\partial Q}{\partial x}+\frac{\partial\left(\alpha Q^2/A\right)}{\partial x}+gA\frac{\partial A}{\partial x}+\frac{gQ|Q|}{C^2AR}=0 \qquad (2)$$

where Q is discharge, A is the cross-sectional area, q is lateral inflow, C is Chezy roughness coefficient, R is hydraulic radius, and QUOTE α is momentum correction coefficient. Based on differential equations and finite difference method, flow depth (h-points) and flow discharge (Q-points) at nodes are calculated [Figure 2].

The advection–dispersion equation in MIKE11 model is as follows. This equation considers two transport mechanisms of advective and dispersive transports.[6]

$$\frac{\partial AC}{\partial C}+\frac{\partial QC}{\partial x}+\frac{\partial}{\partial x}\left(AD\frac{\partial C}{\partial x}\right)=-AKC+C_2q \qquad (3)$$

where C is the concentration, D is the dispersion coefficient, A is the cross-sectional area, K is the linear decay coefficient, C_2 is the source/sink concentration, q is the lateral inflow discharge, x is the space coordinate, and t is the time coordinate.

The mathematical equations used in water quality module of MIKE11 software use specific forms for simulation of water quality in rivers. These include the investigation of bacteria in sewage effluent and other sources of pollutants in water resources; bacteria survival under the influence of different environmental conditions; changes of dissolved oxygen that is affected by organic matter, ammonia, and other oxygen demand substances; dispersion, degradation, and internal reactions between nutrient materials such as ammonia, nitrite, nitrate, and phosphate; evaluation of eutrophication in water resources as a result of different levels of nutrient materials; chlorophyll a and chemical degradation of substances; and the assessment of their effects for different concentrations.[6] Based on mass balance, the model assesses changes in dissolved oxygen at four different levels. The first assessment level is simple definition of oxygen; second level assessment is slightly developed and BOD degradation as solute, suspended, and sediment or one of them is considered; third level of assessment considers oxygen and nutrient processes (BOD degradation as solute, suspended and sediment or one of these processes with nitrification); and fourth level assessment considers oxygen, nutrients, and chlorophyll

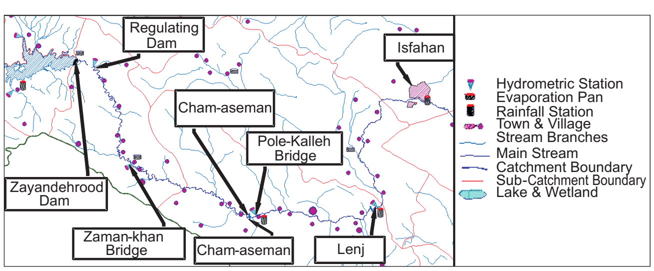

Figure 1: The study area

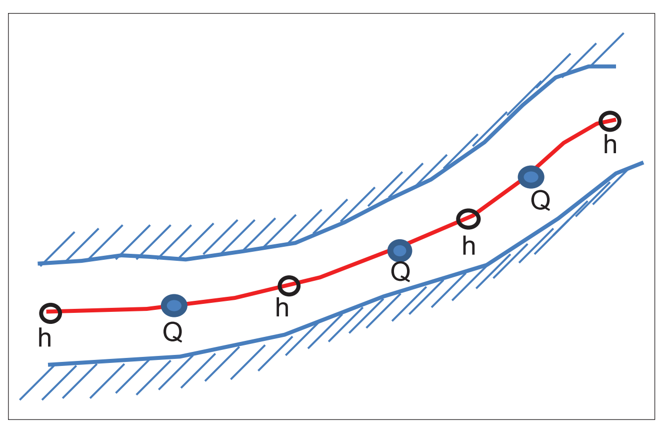

Figure 2: Schematic nodding of h-points and Q-points for a river section in MIKE11 model[7]

processes together with nitrification. For each of these elements, the related mathematical relations including reaeration, nitrification, photosynthesis, respiration, BOD degradation, required oxygen for sediment, potential of limitation of nutrients in photosynthesis, and oxygen saturation have been used in the model. A MIKE 11 model of Zayandehrood was prepared by introducing 302 sections to the model. Outflow from regulating dam was introduced as the upstream boundary and stage–discharge curve of hydrometric station at Pole-Kalleh bridge was introduced as the downstream boundary. The model was hydraulically calibrated based on the measured water levels by adjusting roughness coefficient at some cross sections. The model was also calibrated against BOD concentration (1 day, 3 days, 5 days, and 7 days), ammonium, nitrate, phosphate, and dissolved oxygen measured along Zayandehrood river at regulating dam, Zaman-khan bridge, Cham-aseman, and Pole-Kalleh bridge. The model parameters were adjusted such that the results of model prediction were compatible well with the measured values. A sensitivity analysis on the model results was carried on and the predicted values were compared with the measured values at two middle stations. Since Zayandehrood river is a narrow and low depth river, samples can be taken by hand.[7] The samples were taken from December 2007 to April 2008 on a monthly basis. Physico-chemical indicators including temperature, electrical conductivity, dissolved oxygen, nitrate, phosphate, pH, NH_4, and biochemical oxygen (1 day, 3 days, 5 days, and 7 days) were measured to determine K_{BOD} coefficient. In this study, dissolved oxygen was measured at site using DO meter (YSI55). BOD measurement was performed in accordance with standard method for examining water and wastewater. Dissolved oxygen was measured using both Winkler method and portable DO meter and similar results were obtained.[8] PH was measured at sampling site by portable d evice. Phosphate, NH_4, and NO_3^- were measured using DR5000 (HACH Company). All methods used to measure water quality parameters in this study were conformed to USEPA and were in accordance with standard method. Electrical conductivity and temperature were measured using Hach Model 44600 conductivity meter at site. The flow discharge was estimated from the measured water depth and from stage–discharge curves available at hydrometry stations. The coefficients of nitrification (1.088), nitrification reaction rate (0.1), reaeration coefficient (1.08), and respiration temperature ratio (1.06) were determined from model calibration.[9] To determine organic matter degradation velocity (K_{BOD}), BOD values of first, third, fifth, and seventh days were measured and estimated by Thomas graphical method. Then, final BOD was determined for each station and was introduced to the model. The population growth of villages along Zayandehrood river was estimated for the next 25 years. Two different scenarios were considered to assess the future conditions of the river. In the first scenario, it was assumed that 50,000 people will be added to the current population of villages surrounding Zayandehrood river and as a consequence run-off and wastewater was estimated. In the second scenario, it was assumed that wastewater produced by Saman city and the villages were collected and transferred to a wastewater treatment plant and treated before released to river in a concentrated form. The base information for both scenarios was introduced to the model, and the future water quality conditions of the river were predicted.

RESULTS

During the period of sampling in Zayandehrood river, flow discharge at regulating dam increased from 14.4 m^3/s in March to 56.49 m^3/s in April. The water temperature in February at regulating dam was lowest (3°C) and was the highest in March at Cham-aseman dam (14.1°C). Concentration of dissolved oxygen at Pole-Kalleh bridge in December was 7.5 mg/L. While, at Cham-aseman Dam and Zaman-Khan bridge the highest value occurred in January as 10.2 mg/L. The lowest concentration for ammonium occurred at Pole-Kalleh bridge in December was 0.04 mg/L and the highest value was recorded in March at regulating dam as 0.35 mg/L. The lowest BOD_5 concentration was dedicated to December at regulating dam as 2.2 mg/L and the highest value was dedicated to Pole-Kalleh bridge as 8.8 mg/L.

DISCUSSION

The variation of dissolved oxygen along the river is shown in Figure 3. The correlation coefficient of simulated and measured dissolved oxygen was 0.94. At Cham-aseman dam, this coefficient was 0.87. The dissolved oxygen of Zayandehrood river shows that due to pollutants entering the river, dissolved oxygen has dropped to below 8.5 mg/L. This can endanger migration and spawning fresh and cold water species. This amount of dissolved oxygen is adequate to maintain the life of aquatic species.

Concentration of BOD_5 in all stations in March was more than other months. This was also proved by analysis of variance and Duncan test (P value = 000). The experimental results showed that in February and March, BOD_5 was more than 5 mg/L. In this regard, the pollution level of water in Zayandehrood river along the length considered in this study can be considered as average. The correlation coefficient between model and field measurement for ammonium, BOD, and nitrate at Zaman-khan station and Cham-aseman stations were more than 0.9. Analysis of variance showed that there is significant difference in average of ammonium for at least 2 months over the period that measurements was conducted ($P_{value} < 0.001$). Duncan test showed that average of ammonium in March was different compared to other months. Ammonium level downstream of regulating dam indicated that polluted water enter the river from the upstream sections. Phosphate concentration in

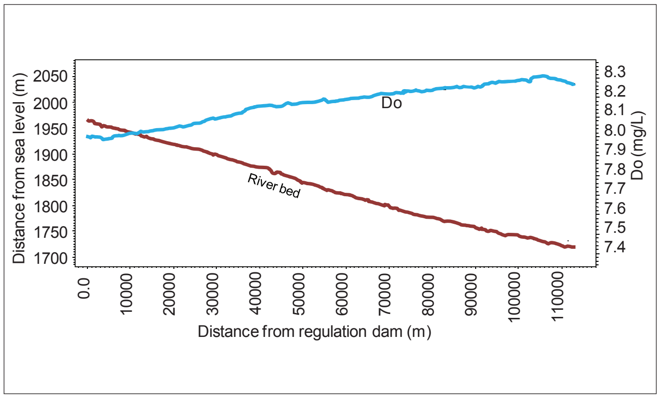

Figure 3: Dissolved oxygen changes along Zayandehrood river from regulating dam to Pole-Kalleh bridge in December 2008 (model results)

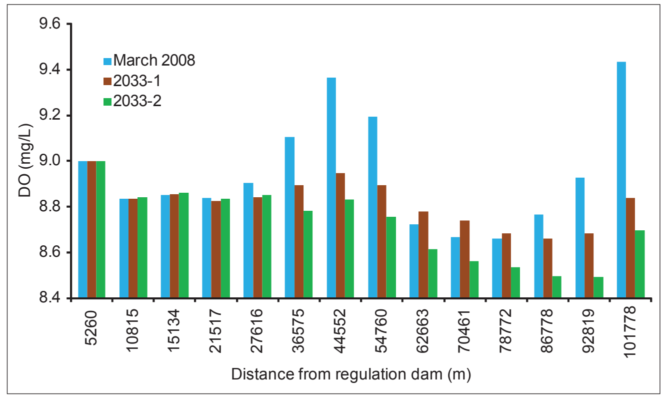

Figure 4: Dissolved oxygen concentration in March 2008 and prediction in 2033. 2033: (1) Pollutant increase as nonpoint source. 2033: (2) Include release of wastewater effluent from Saman wastewater treatment plant and the related villages starting from 35 km)

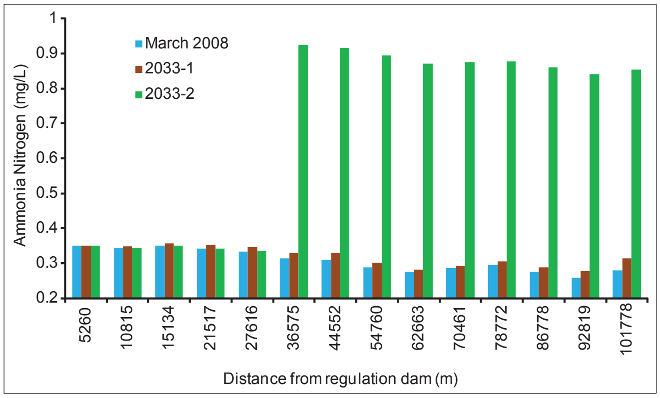

Figure 5: Ammonia nitrogen in March 2008 and prediction in 2033. 2033: (1) Pollutant increase as nonpoint source. 2033: (2) Include release of wastewater effluent from Saman wastewater treatment plant and the related villages starting from 35 km)

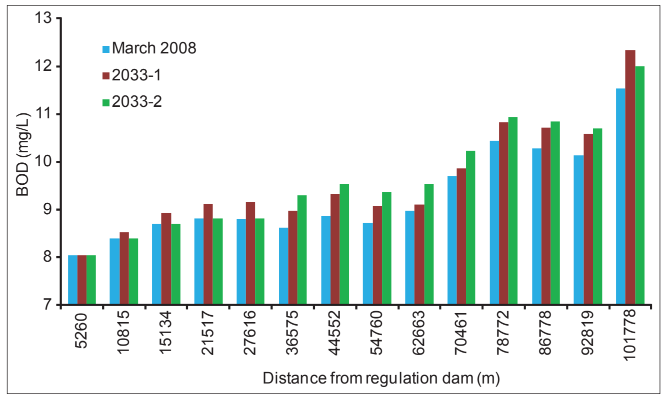

Figure 6: BOD concentration in March 2008 and prediction in 2033. 2033: (1) Pollutant increase as nonpoint source. 2033: (2) Include release of wastewater effluent from Saman wastewater treatment plant and the related villages starting from 35 km)

terms of phosphor ratio in unpolluted rivers has been reported to be 0.01 mg/L (0.03 mg/L based on phosphate).[10] In Zayandehrood river from regulating dam to Pole-Kalleh bridge, phosphate concentration exceeded 0.2 mg/L in most cases and this indicates that the river is polluted. Phosphate with this level of concentration can disturb chemical coagulation of turbidity in water treatment plant.[11] Figures 4 to 6 show the current and future conditions of the river for both scenarios. Figure 4 shows that for both scenarios dissolved oxygen are decreasing toward the downstream direction; however, the impact of second scenarios is more pronounced. In first scenario as indicated in Figure 5, ammonium changed slightly but when it was assumed that wastewater enter the river at 35 km speed, ammonium concentration increased assuming that the hypothetical wastewater treatment plant does not have nitrification process unit. The modeling results indicate that self-purification process in the river for ammonium was slow. This is an alarming situation and suggesting that construction of any wastewater treatment plant along the river that may discharge effluent into the river should include nitrification unit as part of its design. As indicated in Figure 6, BOD variation was the same in all scenarios and this level of BOD would be sufficient to classify Zayandehrood river as polluted river. Zayandehrood river may be a treat to Isfahan drinking water as Isfahan water treatment plant may not be able to fulfill treatment process. Using a robust model such as MIKE 11 to predict the future condition of Zayandehrood river that is endangered by various industries and developments, and some other activities such as aqua culture, etc., is important. The results of the model suggested that release the wastewater from urban and rural treatment plants into the river should be avoided. In situation that this is not avoidable, nitrification process should be added to wastewater treatment processes.

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