Numerical modelling of Phosphorus Advection and Diffusion in Water Bodies (Case study: Sefidrood River)

Shervin Faghihirad [1*], Mahsa Khodayary [2], Fouad Kilanehei [3]

[1] Assistant Professor, Hydro- Environment Department, Water Research Institute, Ministry of Energy
[2] MSc. Civil Engineering Department, Faculty of Engineering, Imam Khomeini International University
[3] Assistant Professor, Civil Engineering Department, Faculty of Engineering, Imam Khomeini International University

ABSTRACT

Phosphorus is one of the vital nutrients for plants and algae growth. Low solubility of phosphorus compared of other nutrients, has caused phosphorus plays key role in algae growth and its often limiting nutrient in most freshwater. So that excessive phosphorus level in water can produce more algae that cannot be consumed by water body creatures and can cause eutrophication, water quality reduction and harmful condition for aquatic ecosystem. Therefore, it is important to identify the main sources of entering into rivers, recognizing the mechanism of transport and its distribution as well as the conditions created in rivers due to the advection and diffusion of phosphorus. For this purpose, in this research, after identifying the main sources of phosphorus entry into the river, it investigates and simulates the advection and dispersion of phosphorus in the Qezel-Ozan, Shahrood and Sefidrood Rivers based on field measuring data and using HEC-RAS software. Five scenarios were designed based on statistics and engineering studies to predict the phosphorus concentration of rivers due to rising temperatures, changes in river discharge due to drought and wet season, human population growth and development of irrigation networks in the region for the future. Then, by numerical simulating using HEC-RAS software, the impacts of phosphorus dispersion have been investigated in the region research area. The result presented that controlling human activities that entering phosphorus to Qezel-Ozan and Shahrood rivers can reduced total phosphorus concentration of Sefidrood river but mass of algae has been increased only by increasing air temperature and discharge of rivers and decreasing by reduced river discharge. Besides, the results showed that maximum total phosphorus concentration of Sefidrood River (downstream river) predicted by the numerical simulation related to the developed scenarios was higher than the maximum desired total phosphorus concentration for warm and cold water fish. For this reason, pay more attention to limit entering phosphorus sources have to be considered for development programme in the upstream rivers (Shahroood and Qezel-Ozan) in the region.

KEYWORDS

Phosphorus, Sefidrood River, HEC-RAS, Numerical Simulation, Eutrophication

[*] Corresponding Author: Email: sh_faghihirad@yahoo.com

Introduction

Rivers are one of the main sources of drinking, agricultural and industrial water supply in the present century due to factors such as; Overgrowth of population, human intervention in the environment, increase in demand for food, development of industries and agricultural products have undergone changes water quality [1]. The excessive entry of pollutants into rivers has adverse effects on aquatic ecosystems and river water quality. Today, one of the most water quality issues in the river environment is the eutrophication [2].

Phosphorus is a key nutrient in the growth of aquatic plants, algae and many microorganisms and is a vital element in producing energy from sunlight that can be used by plants [3]. The uncontrolled increase in the concentration of phosphorus compounds is directly related to the occurrence of the eutrophication in rivers. Many researchers involve to study of advection and diffusion of nutrients, phosphorus compounds in rivers and their accumulation in dam reservoirs by measuring, analytical and numerical modeling [4, 5. 6 and 7].

The present study investigates the advection and diffusion phenomena of phosphorus in Sefidrood River and its upper tributaries (Qezel-Ozan and Shahroud) in exists conditions and future development using numerical tools. Besides, environmental issues of excessive entry of phosphorus on alga and other biological indicators are discussed.

1. The attitudes of study area

Sefidrood Bozorg catchment in the general hydrological division of Iran is part of the Caspian Sea catchment and is located at the confluence of the Alborz, Zagros and Markazi mountains ranges. The area of this basin is equal to 59196 square kilometers, of which 75.4% are mountainous areas and 24.6% are plains and foothills. Parts of 11 provinces of the country are located within Sefidrood Bozorg catchment.

According to studies conducted in 2005-2006, the main sources of phosphorus production in this basin contain wastewater from aquaculture, agriculture (rainfed and irrigated), wastes from urban and rural population centers, livestock activities and industrial slaughterhouses leachate. The studies determine the proportion of activities on entry phosphorous load to Sefidrood, Qezel-Ozan and Shahroud River, 37% for pasture, 22% for livestock and 14% for agriculture and population respectively.

2. Governing Equations

The one-dimensional (1D) HEC-RAS water quality modeling capabilities have been used to support this research. Four water quality modules include the water temperature simulation module, general constituent simulation module (GCSM), and nutrient simulation modules (NSMI and NSMII) have been integrated into HEC-RAS. NSMI simulates aquatic algae, nutrient cycles, DO, CBOD with simplified processes and minimum state variables. The constituent transport model included in 1-D HEC-RAS is based on an advection and dispersion equation with additional terms to account for inflow boundary and kinetics [8]:

$$\frac{\delta(v\phi)}{\delta t} = -\frac{\delta(Q\phi)}{\delta x}\Delta x + \frac{\delta}{\delta x}[\Gamma A \frac{\delta\phi}{\delta x}]\Delta x \pm S \quad (1)$$

where

v = volume of the water quality cell (m3)

ϕ = concentration of a constituent (kg/m3)

Γ =dispersion coefficient (m2/s)

S= sink or source (kg/s)

For reasons of accuracy, efficiency, and stability, the QUICKEST–ULTIMATE explicit numerical scheme has been implemented for solving equation (1). The selection of the time step within the transport model must satisfy Courant and Peclet constraints.

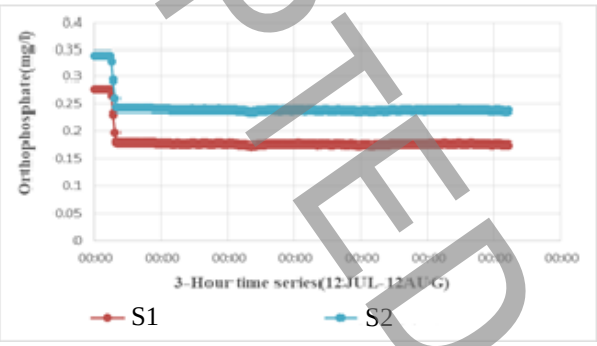
3. Results and Discussion

First, simulation of phosphorus advection and diffusion in these three rivers (Qezel-Ozan, Shahroud and Sefidrood) in a 30-day period from 12 July 2005 to 12 August 2005 was carried out by the numerical model and the results were compared with field measuring at the same time. The results of the mathematical model had good accuracy. Then, the scenario development process was designed based on statistics and engineering studies to predict the phosphorus concentration of rivers due to rising temperatures, changes in river discharge due to drought and wet season, human population growth and development of irrigation networks for the future in 2040.

Results shows that the increase of 1℃ average temperature of Sefidrood catchment in the scenario has caused a slight decrease in the average orthophosphate concentration of Sefidrood River compared to its average orthophosphate concentration in base scenario (12July to 12August 2005). Besides, the average orthophosphate concentration of Sefidrood River is significantly affected by the amount of phosphorus entering its upstream rivers, especially Qezel-Ozan River.

Also, numerical results present that the increase and decrease of discharge of Qezel Ozan and Shahroud

rivers; it is directly related to the concentration of algae mass in Sefidrood River. According to the results obtained from development scenarios of phosphorus advection and diffusion in Sefidrood River for the future (in the year 2040), the most effective way to control the concentration of phosphorus in Sefidrood River is reduction of phosphorus entry sources from the upstream rivers (Qezel-Ozan and Shahroud). Then, a scenario called ideal scenario has been designed based on decreasing the amount of phosphorus into upper tributaries (Qezel-Ozan -58%, and Shahroud, -16%) via implementing more wastewater treatment plant in urban and rural area, reduce chemical fertilizers and control aquaculture in catchments. Figure 1 show the result belongs to ideal scenario.



S1: PO4 in Sefidrood River for 2040-Ideal Scenario
S2: PO4 in Sefidrood River for 2005-Witness Scenario

Figure 1. An example of a figure

As can be seen from figure 1, by controlling the amount of phosphorus entering the Qezel-Ozan and Shahroud rivers considered in the ideal scenario of this research, the orthophosphate concentration of Sefidrood river will be reduced by 18% compared to the orthophosphate concentration of the witness scenario (condition in the year 2005).

4. Conclusion

Sefidrood River and upstream tributaries (Qezel-Ozan and Shahroud Rivers) are one of the main sources of water supply for human communities and fauna in Sefidrood watershed and also the habitat of various aquatic species, but the influx of nutrients, especially phosphorus, into these rivers can reduce the quality of the river. The purpose of this research is to investigate the direct and indirect effects of phosphorus inflow from Sefidrood River and tributaries to Sefidrood dam reservoir.

The results based on the different scenarios in - showed that:

- With decreasing phosphorus entering rivers, increasing air temperature and raise flow discharge by 30%, less dissolved inorganic orthophosphate (mg/l) will remain in rivers and Qezel-Ozan, Shahroud and Sefidrood rivers will meet better quality.

- The maximum phosphorus concentration of Sefidrood River obtained from the simulation results related to the scenario of the year 2005 and the simulation results related to future development was higher than the maximum desired phosphorus concentration for warm and cold water fish.

- The mitigation and control measures for reducing phosphorus sources into rivers needs in the catchment Implementing new wastewater treatment plants in the population area, decrease consuming chemical fertilizer and restrict excessive growth of aquaculture could be considered for and development programme in the area.

- The maximum calculated concentration of phosphorus in Sefidrood River was higher than the amount required creating nutritional conditions in all scenarios.

References

[1] G.M. Filippelli, The Global Phosphorus Cycle, Reviews in Mineralogy and Geochemistry, 48(1) (2002) 391-425.

[2] Z. Zhang, B.E. Johnson, Application and Evaluation of the HEC-RAS-Nutrient Simulation Module (NSM I), US Army Engineer Research and Development Center [Environmental Laboratory], 2014.

[3] Z.-G. Ji, Hydrodynamics and Water Quality: Modeling Rivers, Lakes, and Estuaries, John Wiley & Sons, 2017.

[4] S. Isazadeh, M. Tajrishi, A. Abrishamchi, M. Ahmadi, Application of Phosphorus Simulation Models to Latian Reservoir, Water and Wastewater, 16(2 (54)) (2005).

[5] S.A. Mirbagheri, S. Mahmoodi, S.M. Khezri, Modeling Nitrogen and Phosphorus Chang during Challus River in year 2008-2009 Using Software QUAL2K., Journal of Civil and Environment Engineering, 40(3) (2012).

[6] N. Badrzadeh, J. Mohammad Vali Samani, M. Mazaheri, B. Fakori, Simulation Of Water Level In The Aras River Using One Dimensional Hydrodynamic Model, in: First International Conference Water, Environment and Sustainable Development, University of Mohaghegh Ardabili, 2015. (In Persian)

[7] H. Bakhshi, Simulation Nitrogen Dispersion in River Case-study: Sefidrood River, Amirkabir University of Tehran, 2018. (In Persian)

[8] J.A. Moore, M.J. Gamroth, Calculating the Fertilizer Value of Manure from Livestock Operations, (1991).