The effect of aquaculture effluents on water quality parameters of Haraz River

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Abstract

In this study, a water quality model of Haraz basin was used as an evaluative tool to estimate the spatial distribution of variables that are related to water quality and nutrient loads of the Haraz River. Previous studies performed in this river indicate that trout culture activity along the Haraz River have led to various changes in the water quality parameters. In the present work, the possible effects of two additional fish farms with a production capacity of 50 tons, located on the Haraz within 1 km distance from each other were evaluated in terms of their effects on the streams water quality. A water quality model was developed in order to investigate the spatial distribution of water quality variables. The model also used to estimate the dissolved oxygen (DO), biological oxygen demand (BOD_5) and nutrients along the stream.

Keywords: Mathematical modeling, BOD_5, Streeter-Phelps, Haraz River

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Introduction

Because of the limitation in capture fisheries production, aquaculture has been developed worldwide through the recent years in order to satisfy the increasing demand for food supply. Although aquaculture is able to solve many food problems but its dependence on limited natural resources presents various challenges for sustainability. Aquaculture has significant impacts on the environment and natural resources, and a number of concerns have been expressed by environmental activists and scientists (Dierberg and Kiattisimukul, 1996; Goldburg and Triplett, 1997; Naylor et al., 1998; Boyd, 2003).

The environmental impact of aquaculture is observed in many ways including user conflicts, change of ecosystems, water pollution and etc. Of these possible negative impacts, water pollution of water resources is the most common complaint and has attracted the greatest attention through the nations (Tookwinas, 1996; Boyd and Tucker, 2000; Cripps and Bergheim, 2000). Discharges from flow-through aquaculture systems such as raceways, tanks contain organic matter, nutrients, and suspended solids which directly impacts on oxygen depletion, eutrophication, and turbidity in receiving waters. Such effluents may have a serious negative impact on the quality of the receiving water when discharged untreated (Forenshell, 2001; Miller and Semmens, 2002; Schulz et al., 2003).

In recent years, interests in applying environmentally friendly and sustainable aquaculture techniques through waste management have been increased. Mathematical modeling of water quality forms an integral part of the decision-making process for water resources management and has been used since 1960s as a tool in environmental sciences. Models and simulations allow the rapid evaluation of pollution in terms of cause and effect relationships. The main advantage is that modeling enables analyses of different future scenarios in present time (Erturk, 2005). So, model results can be applied in decision-making process, because they provide the possibility to forecast the environmental effects of future investments and to optimize the environmental effects.

Haraz River basin area is located in the Mazandaran province, in north of Iran. It lies between longitude of 35° 52′E and 45° 05′E and latitude of 35° 45′N and 36° 15′N, and has a length of 185 km with a discharge of 940 × 106 m^3/y (in 2009). The width of river ranges from 50 to 500 m at different locations. The catchments area of river is about 4,060 km^2 with average precipitation of 832 mm/y. Haraz River originates from Alborz mountain ranges and flows into the southern coast of the Caspian Sea (Amirkolaie, 2008). Haraz River is an important habitat which has been highly considered for construction of trout fish farms. There are more than 27 farms with minimum production of 50 tons and maximum production of 185 tons. The water right system is applied in this river. Based on the present contract for trout culture, the amount of water for 27 farms with net area of 80000 m2 is about 8 m^3. There is an increasing rate of trout farm construction around the border of Haraz River. According to Varedi (2007) due to closeness of farms and discharge of their effluents to river, trout culture effluent has negative impact on Haraz ecosystem. Taking into consideration the potential negative effects of these construction sites on the surrounding environmental ecosystem, the possible effects of additional fish farms should be investigated.

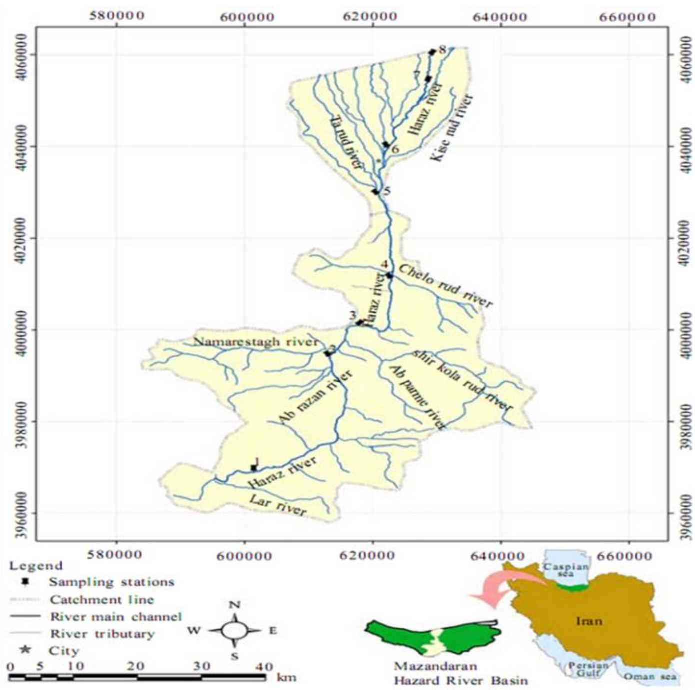

Figure 1: Map of the study area and surface water quality sampling stations in Haraz River basin

Materials and methods

Data Analysis

The average monthly flow rates, which were used for the simulations were calculated using the daily flow gauging data from Tamab. During the spring and summer season, high precipitation combined with snow melts results in maximum flow rate as given in Table 1.

Table 1: Monthly flow rate of Stations in Haraz River basin

Rivers	Haraz	Haraz	Lar
station	Kore sang	Sorkhrood	Polor
Oct	19.4	6.4	3.7
Nov	19.6	7.0	3.4
Dec	17.6	7.3	2.9
Jan	16.2	6.7	2.9
Feb	15.9	6.1	3.1
Mar	18.5	6.6	2.7
Apr	33.1	6.3	9.3
May	71.8	10.4	32.2
Jun	72.9	6.8	33.1
July	40.1	3.4	15.8
Agu	26.6	3.3	7.7
Sept	21.4	7.2	4.7
yearly	31.1	6.3	10.1

Water quality model

Water quality models have been developed during the past three decades. According to Jorgensen (1999), more than 4000 ecological models have been used in aquatic ecosystem research and environmental management. Water quality modeling in a river is based on Streeter and Phelps (1925) model that is developed based on a mass balance which is affected by two processes. One is that oxygen is removed from water by the degradation of organic materials. In other words, the biochemical oxygen demand of an organic waste is satisfied by oxygen taken from the water. The second process is "re-aeration" by oxygen transfer into the water from the atmosphere. In this model the biochemical oxygen demand (BOD) de-oxygenation rate was expressed as an empirical first order reaction, producing the classic dissolved oxygen sag (DO) model. Considering the dispersion process, the governing equation becomes a partial differential equation. DO is one of the most important constituents of natural water bodies; as fish and other aquatic animal species require oxygen. Stream must have a minimum of 2 mg/l DO to maintain higher life forms; while most fish require 4 mg/l (trout require at least 6 mg/l). Oxygen is also important to maintain an aerobic state as the end products of chemical and biochemical reactions in anaerobic systems produce aesthetically displeasing odors, colors and taste. When biodegradable organics are discharged into a stream, microorganisms convert the organics into new cells and oxidized waste components. During this process, DO is consumed. The rate and quantity of DO consumption is dependent on the quantity of organics and the dilution capacity of the stream.

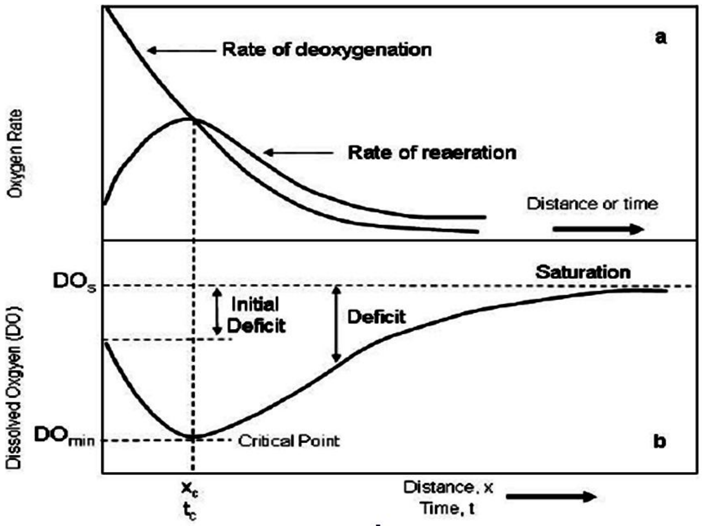

Figure 1: (a) Deoxygenation and reaeration responses to the organic material, and (b) the DO sag curve, which is characteristic of change of DO concentration in a river after the introduction of organic material.

Applying a mass balance to Figure 2 for the oxygen concentration in the stream, relating oxygen consumption to BOD and re-oxygenation to natural re-aeration, and neglecting hydrodynamic dispersion:

Accumulation = Inflow - Outflow + De-oxygenation + Re-oxygenation

$$\partial C/\partial t(\Delta V) = QC_x - QC_{x+\Delta x} - r_{BOD}(\Delta V) + r_R(\Delta V)$$

Where C is the O_2 concentration

Substituting for r_{BOD} and r_R and taking the limit as Δx approaches zero

$$\partial C/\partial t = Q\partial C/\partial t - kL - k_2(C_s - C)$$

Where: L is organic matter present at any time, (equal to BODu(t))

Assuming steady state conditions, $\partial C/\partial t$ = 0, Eq. 2 becomes,

$$QdC/dv = -kL + k_2(C_s - C)$$

Assuming that the stream has a constant cross-sectional area, volume of reach is:

$$V = Ax$$

Where: x is the distance downstream, giving

$$dV = Adx$$

Since,

$$dx = udt$$

$$dV = Audt$$

Substituting Eq. 7 into Eq. 3 and rearranging gives or

$$Q\frac{dC}{Audt} = -kL + k_2(C_s - C)$$

$$\frac{dC}{dt} = -kL + k_2(C_s - C)$$

$$D_{(t)} = C_s - C_{(t)} \qquad 1$$

The change in oxygen deficit with residence time is:

$$dD/dt = -dC/dt$$

Knowing that

$$dC/dt = -kL + k_2(C_s - C)$$

Gives

$$dD/dt + k_2 D = kL$$

Or

$$\frac{dD}{dt} + k_2 D = kBOD_{u(0)} e^{-kt}$$

Comparison of Eq. 14 to a first order differential equation of the form dy/dx + Py = Q, where P and Q are functions of x, shows similarity. The use of an integrating factor is necessary.

For the oxygen deficit equation, the integrating factor is:

$$e^{\int Pdx} \Rightarrow e^{\int k_2 dt} \Rightarrow e^{k_2 t}$$

Thus multiplying both sides of the oxygen deficit equation (14) with the integrating factor (15) gives:

$$e^{k_2 t}\frac{dD}{dt} + k_2 D e^{\int k_2 dt} = kBOD_{u(o)} e^{(k_2 - k)t}$$

Since the left side of Eq. 16 can be factored as:

$$e^{k_2 t}\frac{dD}{dt} + k_2 D e^{k_2 t} = \frac{d}{dt} D e^{k_2 t}$$

This leads to:

$$\frac{d}{dt} D e^{k_2 t} = kBOD_{u(o)} e^{(k_2 - k)t}$$

Separating variables and integrating gives

$$D e^{k_2 t} = \left(\frac{kBOD_{u(o)}}{k_2 - k}\right) e^{(k_2 - k)t} + K$$

The constant of integration is determined from known boundary conditions, that is D = Di at t=0. Thus,

$$K = D_i - \frac{kBOD_{u(o)}}{k_2 - k}$$

$$D_{(t)} = \left(\frac{kBOD_{u(o)}}{k_2 - k}\right)\left(e^{-kt} - e^{-k_2 t}\right) + D_i e^{-k_2 t}$$

Where: D (t) is the oxygen deficit at any place along the stream

By considering the effects of sedimentation and photosynthetic production of oxygen the Streeter and Phelps equation was modified and applied as the basis of a water quality model.

The software for modeling the water quality has been developed in Visual basic environment. This software can be easily used for water quality analyzing and simulating in one-dimensional steady water and also for assessing the possible effects of various scenarios.

Results

Model Inputs

The model inputs include the model network, geographic features of the basin, meteorological information, hydraulic and geometric properties of channels in the model network and the model coefficients. The model network composed of the main branch of the Haraz basin consisting of three reaches (5 km each). Geographical features of the watershed were obtained from the existing physical maps and existing meteorological stations.

Due to high volume of runoff in spring and maximum agricultural load to the river in this season, the model was calibrated for winter season and verified for spring. The results of model calibration for the winter are illustrated in Figures 3and 4. The results of model calibration indicate that the model reproduced the spatial distribution of the related water quality variables successfully. It is known that there are several fish farming facilities within Haraz basin. There have been lots of inquiries about establishing fish farms within 1 km distance from each other. In order to evaluate the possible effect of establishing more fish farms, modeling scenarios were created based on 180-230 tons of feed and capacity of 100 tons.

According to the modified model, variation of DO, BOD_5, temperature and nutrients are illustrated.

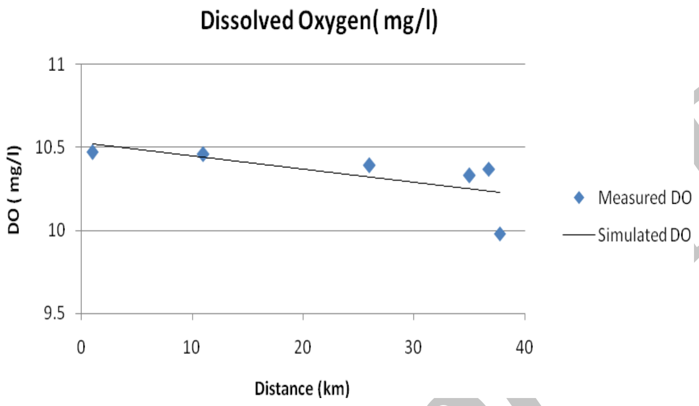

Figure 2: Model calibration for dissolved oxygen

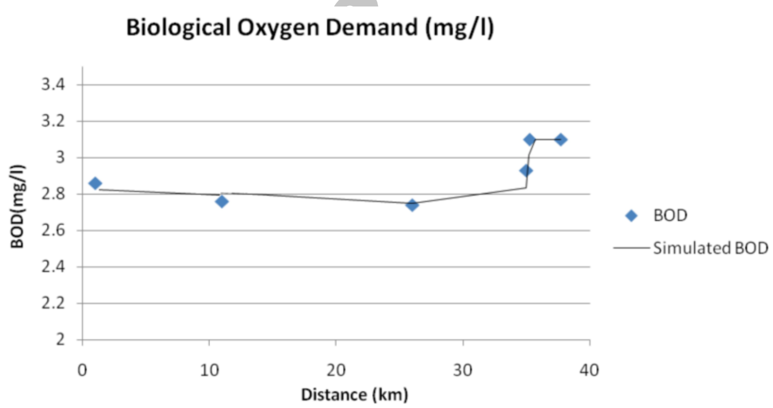

Figure 3: Model calibration for ultimate biological oxygen demand

Haraz River area is an important place for trout production and more than 27 trout farms are active. This river can be as model for aquaculture development in other rivers such as Dohezar and Sehezar in Tonkabon, Charmahal Bakhtiary, Isfehan, Fars and other provinces.

The distance between two farms and construction of farm is an important result for modeling and oxygen is most important indicator for modeling.

The results obtained from the steady-state simulation indicate that additional fish farms of large capacities may have apparent effects on the Haraz basin, especially in decreased DO and increased BOD and nutrient concentrations.

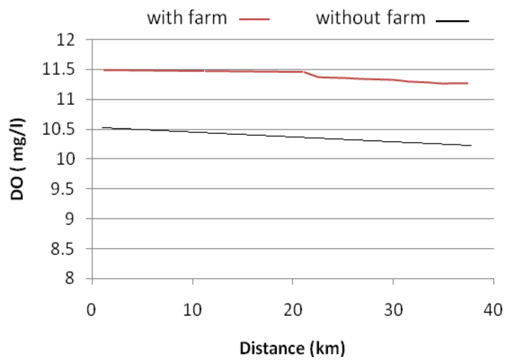

Figure 4: Simulation results for DO (mg/l)

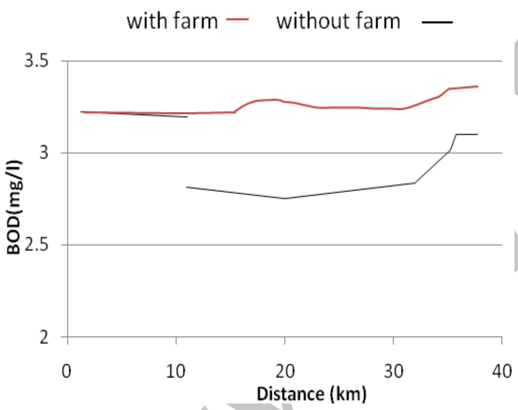

Figure 5: Simulation results for BOD (mg/l)

Discussion

Two farms with a production capacity of 50 tons trout located at 1 km distance from each other were selected to analyze the effects of DO, BOD_5, and nutrient in Haraz basin. During the spring season, where the flow rate is high, the effects of agricultural loads were found to be more important than the loads resulting from existing establishments. However, it was found that Haraz basin could tolerate the effects of establishment loads due to high flow rates in the spring system. Although the Haraz basin ecosystem can tolerate inputs during the spring and summer model (as shown in Figure 12 a and b), by decreasing the flow rate and increasing the temperature, the DO levels are decreased. The simulation results indicate that although potential establishments will not have observable and direct significant effects, their effects on the ecosystem are still expected to be noticeable.

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