A Case Study of Water Quality Modeling of the Gargar River, Iran

Mojtaba Rafiee[1], Ali Mohammad Akhond Ali[1], Hadi Moazed[1], Steve W. Lyon[2], Nemat Jaafarzadeh[3], Banafsheh Zahraie[4]
[1]Faculty of Water Science and Engineering, Shahid Chamran University, Ahvaz, Iran
[2]Faculty of Physical Geography and Quaternary Geology, Stockholm University, Stockholm, Sweden
[3]Faculty of Environmental Health, Ahvaz Jondishapour University of Medical Science, Ahvaz, Iran
[4]School of Civil Engineering, College of Engineering, University of Tehran, Tehran, Iran

Abstract

Human activities in the recent years have considerably increased the rate of water pollution in many regions of the world. In this case study, the main sources of wastewater discharging into the Gargar River were identified. Using river and point source flow rates and water quality parameters measured along the river, the river water quality was simulated using a commonly used, one-dimensional water quality model, the QUAL2K model. Simulated values of DO, CBOD, NH_4-N and NO_3-N demonstrated the accuracy of the model and despite a significant data shortage in the study area, QUAL2K model was found to be an acceptable tool for the assessment of water quality. Still, for this case study, it was found that the model was most sensitive to river and point source flows and moderate to fast CBOD oxidation, and nitrification rates.

Keywords: Water Quality, QUAL2K, Modeling, Wastewater Discharge, Whole-System Water Management

1. Introduction

Continuously increasing human activities have considerably increased global rates of water pollution in recent decades. Agricultural, municipal, and industrial activities typically lead to discharge of significant amounts of nutrients and organic materials into rivers and streams. Discharge of degradable wastewaters into flowing waters can impair water quality. For example they can result in a decrease of dissolved oxygen (DO) concentrations due to assimilation of pollutants by microorganisms, chemical oxidations of reduced pollutants, and respiration of plants, algae and phytoplankton (Drolc and Konkan, 1996). The problems associated with low DO levels are even more critical during low flow periods. Low DO concentrations or, in an extreme situation, anaerobic conditions create unbalanced ecosystems with fish mortality, odors and aesthetic nuisances (Cox, 2003). Since fish typically cannot survive when DO content is less than 3mg/L (Novotny, 2002), DO content is therefore often considered a barometer of the ecological health of a stream and is one of the most important water quality parameters to maintain for protecting fish (Chang, 2005). To ensure good overall river health, however, water quality must also meet threshold levels of several other key parameters including carbonaceous biochemical oxygen demand (CBOD), total nitrogen (TN), total phosphorus (TP), temperature and pH (Kannel et al., 2007). For example, the permissible range of pH is 6.5–8.5 for fisheries (EMECS, 2001) and 6.5–9.2 for drinking water quality according to the Iranian drinking water standard (IPBO, 1992). Considering BOD levels in rivers, even though there are currently no regulations or recommended limits according to Iranian standards, other international guidelines (e.g., the European Union directives) indicate a permissible range for BOD between 3 and 6 mg/L for various types of fisheries (EEC, 1978).

In order to achieve such targets of water quality, planning and management are needed along an entire river to ensure that the assimilative capacity remains sufficient along the entire river (Campolo et al., 2002). To address this, the complex relationships between waste loads from different sources and the resulting water quality of the receiving waters need to be characterized. These relationships are best described with mathematical models (Deksissa et al., 2004). A widely used mathematical model for assessing conventional pollutant impact is QUAL2E (Brown and Barnwell, 1987; Drolc and Konkan, 1996). One of the major inadequacies of this model, however, is its lack of provisions for conversion of algal death to carbonaceous biochemical oxygen demand (Ambrose et al., 1987, 1988; Park and Uchrin, 1996, 1997). As such, Park and Lee (2002) developed QUAL2K, a one-dimensional, steady flow model, which includes the simulation of new water quality interactions such as conversion of algal death to BOD, denitrification process, and DO change caused by plants. To date, applications of the freely available QUAL2K model (see http://www.ecy.wa.gov/) for water quality strategies are numerous and varied. Kannel et. al (2006) confirmed the usefulness of QUAL2K in data-shortage conditions. Fan et al. (2009) applied a HEC-RAS-assisted QUAL2K to simulate water quality and the QUAL2K model proved to be an effective tool in evaluation of potential water quality improvement programs in a tidal river. Cho et al. (2010) calibrated the QUAL2K input parameters in the Gangneung Namdaecheon River on the Korean peninsula using an optimization technique. Their calibration results showed good correspondence for most of the water quality variables considered with the exception of DO and Chl-a that showed relatively large errors in some parts of the river. Zhang et al. (2012) simulated the water quality in Hongqi River, a polluted river in China, and could evaluate the reduction rates of BOD, NH_3-N, TN and TP along the river.

In the real situation of a river, unsteady and two- or three-dimensional models are typically considered more appropriate for representing interactions between waste loads and the receiving waters; however, these types of models typically require large amounts of data that are unavailable in many systems. For example, in the Gargar River, where this current study focuses, there is a data deficiency with regards to water quality monitoring. To work around this shortcoming, QUAL2K, a steady-state model, was chosen and tested as a framework appropriate for a modest water quality modeling. Moreover, when the flow and pollution transport are dominated by longitudinal changes (such as in Gargar River) and the river is long with respect to the mixing length relative to the cross-section, the central QUAL2K assumption of one-dimensional processes is typically valid. In the current study, QUAL2K model was applied in a data-limited setting along the Gargar River, Iran. The discharges of municipal wastewater and fisheries along the river were identified and analyzed. This case study is novel as, in addition to identifying wastewater discharge into the river, it simulates Gargar River water quality for the first time and tests the applicability of the simplifying assumptions (i.e., one-dimensional flows and transports) behind QUAL2K. This gathering of observed water quality data and a case study simulation model provides a solid basis for future work into model development and optimization strategies relevant for river-scale water quality management.

2. Material and methods

2.1. Study area

The Gargar River (Gargar Canal) is a historical, man-made branch of the Karoon River, which is separated from the main channel north of Shoushtar City. The Gargar River's monthly average flow varies between 10 and 31 m^3/s based on data measured in the last ten years. Water is diverted to Gargar River by an ancient dam known as Band-e Mizan. It flows about 82 km before re-joining the Karoon main river in a place called Band-e-ghir. The Gargar River is a part of Shoushtar historical hydraulic system and was registered as an UNESCO world heritage site in 2009 (UNESCO, 2009). There are a number of canals, historical dams and watermills of the Shoushtar historical hydraulic system located adjacent to the Gargar River. The upstream section of the Gargar River has been dug in a solid rock and in the downstream section it enters a soft-soil plane (ICHHTO, 2008).

The Gargar River is highly polluted because many fish farms discharge their wastewater into the river. Further, due to the world heritage status and associated protection issues and some water intakes preparing water for municipal and agricultural purposes along the river, the investigation of water quality management is very important in this region. The high temperatures in the region, with average monthly temperatures that vary between 14.7 and 37.5 ^oC in the coolest and warmest months, respectively, lead to higher chemical/biological reaction rates in the river than would be expected in temperate regions. Altogether, these factors make the Gargar

River a good and interesting candidate for a case study application of QUAL2K to test the model's utility as a water quality model in a data limited situation.

2.2. Monitoring sites and available data

The monitoring stations used in this study (Figure 1) consist of five stations: Band-e mizan (S1), Pol-e Koshtargah (S2), Dar Khazineh (S3), Seyd Hasan (S4) and Band-e ghir (S5). Data were gathered at these stations and from several wastewater dischargers (Table 1) in dry and wet seasons. For the wet season, observations were conducted on 3 May 2011. For the dry season, observations were conducted on 13 October 2010. Since it was only possible to collect two observations at each station, there is a lack of data relative to typical applications of QUAL2K (e.g., Kannel et al., 2006). The parameters measured at each station included discharge, water temperature, pH, 5-day biochemical oxygen demand as O_2 (BOD_5), dissolved oxygen (DO), ammonium (NH_4-N), nitrate (NO_3-N) and nitrite (NO_2-N). It should be noted, however, that the nitrite concentrations were negligible in the river. Water samples from the river and wastewater samples from the dischargers were collected, transported and analyzed following methods described in Standard Methods (APHA, 2005). Samples were collected by the Khouzestan Fishery Organization, the Khouzestan Water and Power Authority (KWPA), and the Khouzestan Environmental Protection Office. Supplemental field observations were also performed to confirm some outlier and unmatched data gathered by these three organizations.

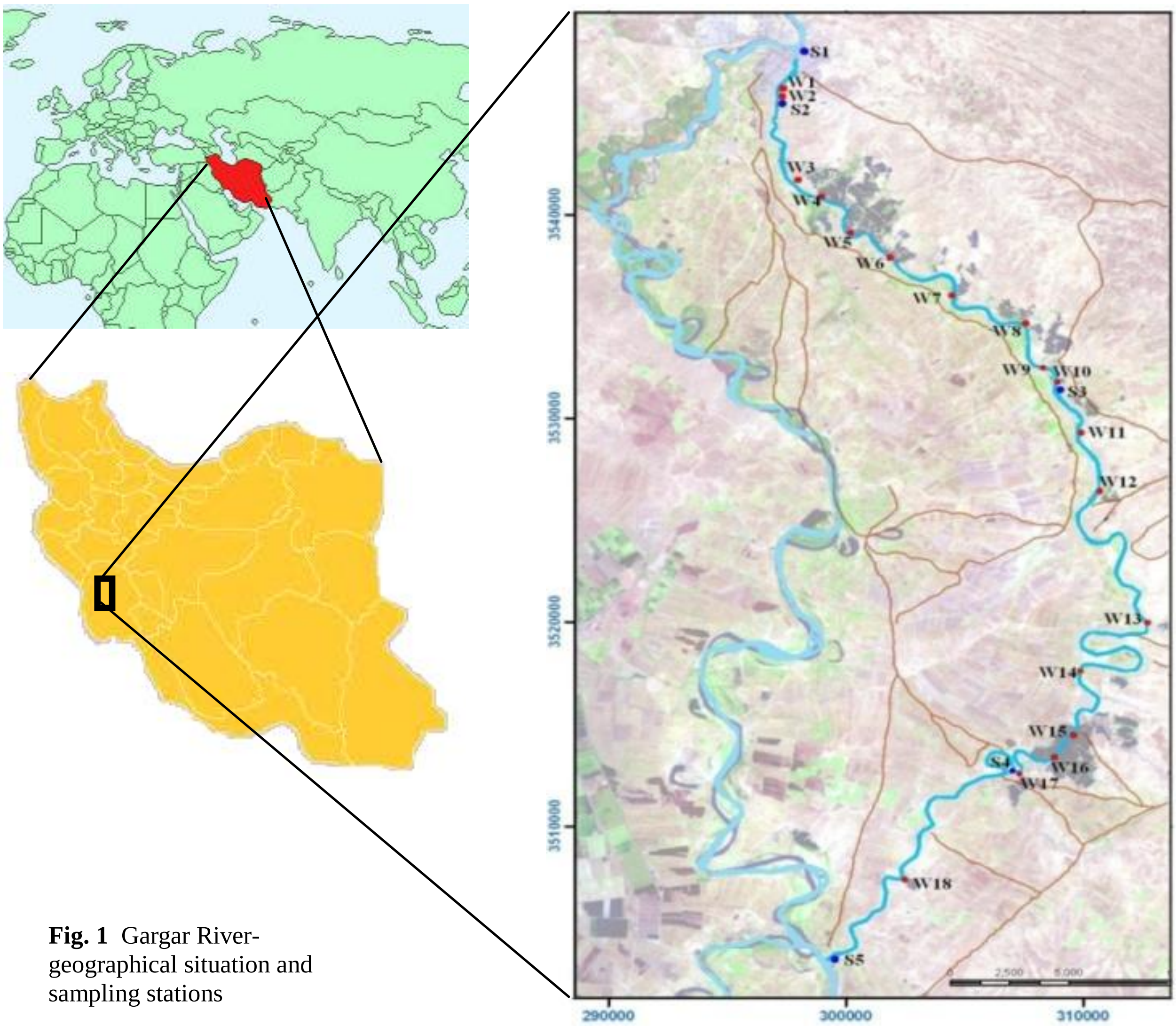

Fig. 1 Gargar River- geographical situation and sampling stations

Table 1 Water quality monitoring stations in the Gargar River

Types	Stations (abbreviations)	Distance from Downstream (Km)	Description
Stations on river	Band-e-mizan (S1)	82	North of Shoushtar
	Pol-e-Koshtargah (S2)	78	Shoushtar
	Dar Khazineh (S3)	55	South of Shoushtar
	Seyd-Hasan (S4)	24	
	Band-e-ghir (S5)	1	
Wastewaters	Shoushtar municipal wastewater (W1)	80	
	Slaughterhouse (W2)	79	
	Fish culture drainage 1 (W3)	74	
	Fish culture drainage 2 (W4)	73	
	Fish culture drainage 3 (W5)	70	
	Fish culture drainage 4 (W6)	66	Upstream of Qal'e soltan
	Fish culture drainage 5 (W7)	62	Downstraem of Qal'e soltan
	Fish culture drainage 6 (W8)	60	
	Fish culture drainage 7 (W9)	58	
	Fish culture drainage 8 (W10)	56	Downstream of Dar-Khazineh
	Fish culture drainage 9 (W11)	55	
	Fish culture drainage 10 (W12)	53	Upstraem of Shagharij-paein
	Fish culture drainage 11 (W13)	48	
	Fish culture drainage 12 (W14)	38	
	Fish culture drainage 13 (W15)	29	Upstream of Basir sofla
	Fish culture drainage 14 (W16)	24	
	Fish culture drainage 15 (W17)	19	
	Fish culture drainage 16 (W18)	7	

2.3. Modeling tool

QUAL2K has at its core a one-dimensional advection-dispersion equation as the governing equation:

$$V\frac{\partial c}{\partial t} = \frac{\partial(A_c E\frac{\partial c}{\partial x})}{\partial x}dx - \frac{\partial(A_c U c)}{\partial x}dx + V\frac{dc}{dt} + s \qquad (1)$$

in which U (LT^{-1}) is averaged velocity, A_c is cross sectional area (L^2), E equals longitudinal dispersion (L^2T^{-1}), c is concentration (ML^{-3}), V is volume (L^3), x is distance (L) and s stands for sources and sinks, which is additional inflow of water or constituent mass. QUAL2K solves this governing equation in a steady-state condition for a constituent concentration c_i in the water column (excluding hyporheic exchange) of a stream reach i (Figure 2). This gives in a general mass balance equation (the transport and loading terms for bottom algae modeling are omitted) that can be expressed as (Pelletier et al., 2006):

$$\frac{dc_i}{dt} = \frac{Q_{i-1}}{V_i}c_{i-1} - \frac{Q_i}{V_i}c_i - \frac{Q_{ab,i}}{V_i}c_i + \frac{E_{i-1}}{V_i}(c_{i-1} - c_i) + \frac{E_i}{V_i}(c_{i+1} - c_i) + \frac{W_i}{V_i} + S_i \qquad (2)$$

where Q_i is the flow at reach i (L/d), $Q_{ab,i}$ is abstraction flow at reach i (L/d), V_i stands for volume of reach i (L), W_i stands for the external loading of the constituent to reach i (mg/d), S_i are sources and sinks of the constituent due to reactions and mass transfer mechanisms (mg/L/d), E_i is bulk dispersion coefficient between reaches (L/d), E_{i-1} and E_{i+1} are bulk dispersion coefficients between reaches $i-1$ and i and i and $i+1$ (L/d), respectively, c_i is concentration of water quality constituent in reach i (mg/L) and t is time (d).

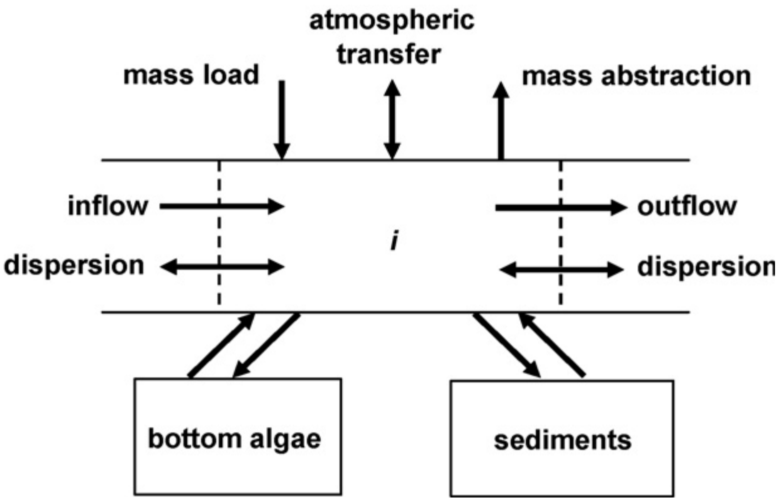

Fig. 2 Mass balance in a reach segment *i* (from Chapra et al., 2006)

Figure 3 shows a schematic diagram of the interacting water quality state variables in the model which are considered as sources and sinks (equation 2). The complete description of processes and mathematical representations of the interacting water quality state variables, which constitute constituent specific governing equations, are available in Chapra et al. (2006).

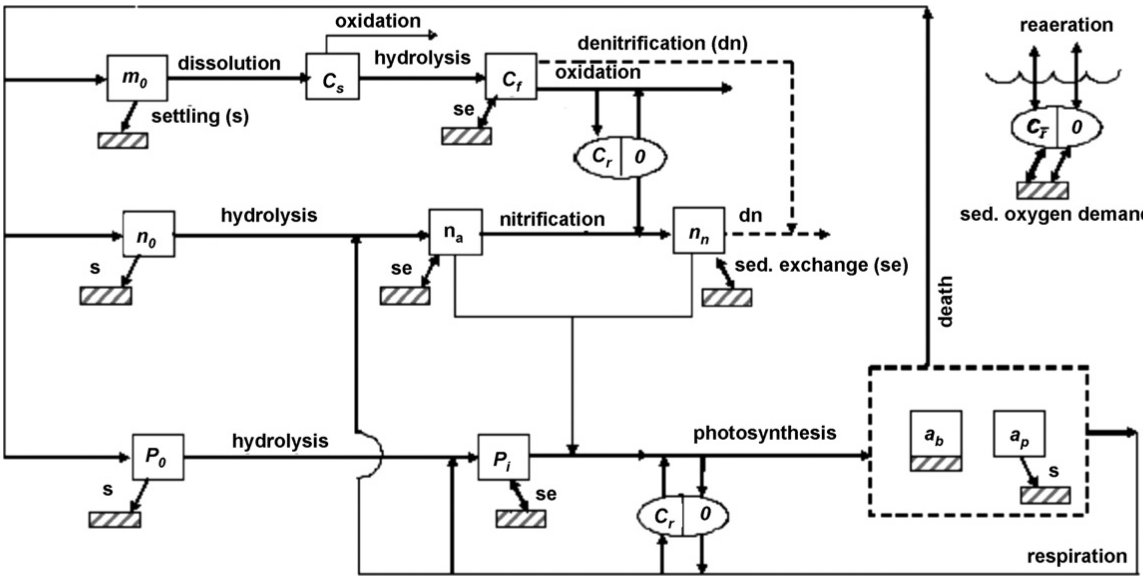

Fig. 3 Schematic diagram of interacting water quality state variables (from Chapra et al., 2006)

To constrain the parameters of this QUAL2K mass balance equation for a given stream reach, Chapra and Canale (2002) proposed that a combination of flow, Manning's coefficient and river cross section be used (e.g., Equations 3 through 6). The method (which was adopted in this case study) can be applied iteratively from an initial depth estimate and terminated when the estimated error (equation 4) fall below a specified value 0.001%. Then, the cross-sectional area can be determined with Equation 5 and the velocity determined from the continuity equation (Equation 6).

$$H_k = \frac{(Qn)^{3/5}\left(B_0 + H_{k-1}\sqrt{s_{s1}^2+1} + H_{k-1}\sqrt{s_{s2}^2+1}\right)^{2/5}}{S^{3/10}\left[B_0 + 0.5(s_{s1}+s_{s2})H_{k-1}\right]} \tag{3}$$

$$\varepsilon_a = \left|\frac{H_{k+1}-H_k}{H_{k+1}}\right| \times 100\% \tag{4}$$

$$A_c = \left[B_0 + 0.5(s_{s1}+s_{s2})H\right]H \tag{5}$$

$$U = \frac{Q}{A_c} \tag{6}$$

2.4. Model implementation

The full 82 km length of the Gargar River was discretized into 23 reaches along with the locations of point source of identified wastewaters (Figure 4). This segmentation forms the basis for the QUAL2k modeling application. Table 2 shows the river hydraulic characteristics used as the input of the QUAL2K model. As the model simulates ultimate CBOD, it assumed 1.5 times the measured $CBOD_5$ (Kannel et al., 2006 and Chapra et al., 2006). Stream flow, temperature, pH, DO, BOD, organic nitrogen, ammonium nitrogen, nitrate nitrogen, and phosphorus data were all included in the model as input parameters. The data on phytoplankton and pathogens were not measured and, thus, these inputs were left blank. This is likely to have minimum impact on the model results as the phytoplankton concentration in the Gargar River is negligible (Rasti et al., 2007). The algae and bottom sediment oxygen demand coverage were assumed to be 50%. The

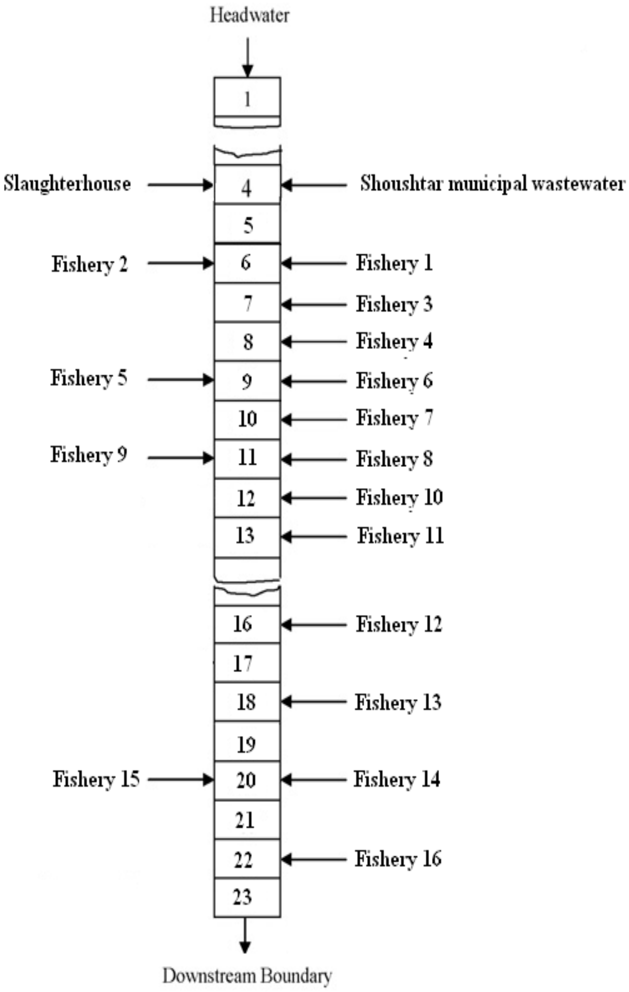

Fig. 4 System segmentation with location of pollution sources along Gargar River

sediment/hyporheic zone thickness, sediment porosity and hyporheic exchange flow were assumed as 10 cm, 0.4 and 10%, respectively, based on field observations and available operational experience. The organic nitrogen was assumed to be 35% of the total nitrogen since it was not specifically analyzed.

Fishery wastewater qualities (W3 to W18) (Figure 5) were assumed to be the same across all fisheries and set equal to the average of the quality of samples collected and analyzed by the Iranian Fishery Organization at the effluent of several fish culture farms. Fisheries water abstraction considered to be twice that of the fishery discharges located in near upstream positions. There are some different fishery wastewater data issued by the Khouzestan Environmental Protection Office, however, the office had measured these wastewater qualities just when the fisheries were appealed because of their high pollution effluents. Therefore the data from Khouzestan Environmental Protection Office could not be considered as normal data and were not used in this study. The water quality at the first monitoring station of the Gargar River, S1 (Band-e Mizan), was considered as the upstream boundary condition for the QUAL2K model.

The ranges of the model rate parameters, which are presented in Table 2, were collected from literature values including the United States Environment Protection Agency (USEPA) guidance document (USEPA, 1985) and Bowie et al. (1985). The Owens–Gibbs formula (Owens et al., 1964), which is given equation 7, was applied for calculating re-aeration rates. This equation was developed for stream depths from 0.4 to 11 ft and velocities from 0.1 to 5 ft/s (Ghosh and Mcbean, 1998).

$$K_a = 5.32\ U^{0.67} / H^{1.85} \quad (7)$$

Here, K_a is the oxygen reaeration rate coefficient (d^{-1}), U is the water velocity ($m.s^{-1}$), and H is the water depth (m).

An exponential model was applied for oxygen inhibition for CBOD oxidation, nitrification, de-nitrification, phytorespiration and bottom algae respiration. Meteorological parameters were considered equal to the data issued by the nearest meteorological station, the Shoushtar synoptic station. A Manning coefficient equal to 0.026 was used along the river consistent with sections surveyed by Khouzestan Water and Power Authority. All the other parameters were adjusted as default values in QUAL2K as there were insufficient data available to modify them.

The measured data in October 2010 were utilized for calibration of the QUAL2K model. For calibration, the model parameters such as, for example, fast CBOD oxidation rate, ammonium nitrification rate, nitrate denitrification rate, and organic N settling velocity, were changed until the differences between observed and simulated water quality parameter values were minimized. The goodness of fit was tested by a root mean squared error (RMSE), mean absolute percentage of error (MAPE), and percent bias (PBIAS) between the difference of the model predictions and the observed data for water quality constituents as presented in Equations 8, 9 and 10, respectively. These statistical error parameters are commonly used for calibration and validation of the models (Najafzadeh et al., 2013; Najafzadeh and Azamathulla, 2013; Najafzadeh and Barani, 2011; Moriasi, 2007)

$$RMSE = (\Sigma(O_{i,j} - P_{i,j})^2 / m)^{0.5} \quad (8)$$

$$MAPE = (\Sigma(|P_{i,j} - O_{i,j}|) / \Sigma(O_{i,j}) * 100/m) \quad (9)$$

$$PBIAS = (\Sigma(O_{i,j} - P_{i,j}) / \Sigma(O_{i,j}) * 100 \quad (10)$$

where $O_{i,j}$ equals to observed values, $P_{i,j}$ equals to predicted values and m is the number of pairs of predicted and observed values of the state variables (i.e. DO, CBOD and etc.). To test the ability of the calibrated model to predict water quality conditions under different conditions, the model was run to estimate water quality values observed on May without changing the calibrated parameters. Again, Equations 8, 9, and 10 were applied to assess the goodness of fit between the model predictions and the observed water quality values (i.e., validation).

3. Results and discussion

3.1. Comparing observations and model predictions

The observed data from the monitoring stations along the river conducted on 3 May 2011 and 13 October 2010 are summarized in Table 2 and Table 3, respectively. The identified wastewater quality values are provided in Table 4. The calibrated model parameters are given in Table 5. The simulation results demonstrated that the profiles of water quality upstream of 20 km have modest fitness and were well-represented in the model. Downstream of 20 km chainage, however, poor calibration was achieved using available data in the region. Unlike the simulation results, the last station (S5) was higher in CBOD and Nitrate and lower DO than the upstream station S4. This could be because of discharging wastewater into the river between S4 and S5; however, there is no detected major discharger between S4 and S5. Therefore, the profiles between S4 and S5 are not likely well-produced in the model and calculation of error statistics (RMSE, MAPE, and PBIAS) for both calibration and validation (and the subsequent sensitivity analysis) was performed without considering the data of the last station, S5.

Table 2 Water quality observed at monitoring stations along Gargar River on 3 May 2011

Station	Chain (km)	Flow (m^3/s)	Water temperature (◦C)	DO (mg/L)	BOD (mg/L)	NO_3-N (mg/L)	NH_4-N (mg/L)
S1	82	5.43	18	9.34	3.41	6.70	0.16
S2	78	-	18	8.72	3.82	7.26	0.021
S3	55	-	18	7.06	5.3	9.91	0.058
S4	24	-	19	7.97	4.8	7.87	0.068
S5	1	-	20	9.56	5.64	7.67	0.069

Table 3 Water quality observed at monitoring stations along Gargar River on 13 October 2010

Station	Chain (km)	Flow (m^3/s)	Water Temperature (◦C)	DO (mg/L)	BOD (mg/L)	NO_3-N (mg/L)	NH_4-N (mg/L)
S1	82	5.23	22	9.15	2.27	6.62	0.141
S2	78	-	23	7.27	4.16	6.92	0.470
S3	55	-	23	6.66	5.77	6.12	0.660
S4	24	-	23	8.08	3.7	5.77	0.830
S5	1	-	25	8.68	5.2	6.66	0.740

Table 4 The average measured wastewater quality discharging into Gargar River

Station	Chain (km)	Flow (L/s)	Water temperature (◦C)	pH	DO (mg/L)	BOD_5 (mg/L)	NO_3-N (mg/L)	NH_4-N (μg/L)
W1	80	81	28	6.8	0	120	2.390	22.5
W2	79	2	25	7.2	2.4	253	5.5	47
W3	74	41	28	8.9	7.1	11.9	5.5	2.4
W4	73	60	28	8.9	7.1	11.9	5.5	2.4
W5	70	195	28	8.9	7.1	11.9	5.5	2.4
W6	66	101	28	8.9	7.1	11.9	5.5	2.4
W7	62	42	28	8.9	7.1	11.9	5.5	2.4
W8	60	144	28	8.9	7.1	11.9	5.5	2.4
W9	58	80	28	8.9	7.1	11.9	5.5	2.4
W10	56	44	28	8.9	7.1	11.9	5.5	2.4
W11	55	7	28	8.9	7.1	11.9	5.5	2.4
W12	53	43	28	8.9	7.1	11.9	5.5	2.4
W13	48	31	28	8.9	7.1	11.9	5.5	2.4
W14	38	190	28	8.9	7.1	11.9	5.5	2.4
W15	29	14	28	8.9	7.1	11.9	5.5	2.4
W16	24	286	28	8.9	7.1	11.9	5.5	2.4
W17	19	32	28	8.9	7.1	11.9	5.5	2.4
W18	7	22	28	8.9	7.1	11.9	5.5	2.4

From the model results, the average velocity and water depth were 1.9 m/s and 1.4 m, respectively, along the river confirming the applicability of Owen-Gibbs equation as a re-aeration model.

The DO concentration gradually decreased along the river and remained in the standard range of values (Figure5).

However, the Gargar River water quality parameters such as BOD_5 did not meet minimum levels permissible in some stations. CBOD from municipal wastewater in the upstream parts of the river and from fisheries between chainage 70 to 20 km led to increasing CBOD along the river.

Generally, the model calibration results were in modest agreement with the measured data. The RMSE for example between the simulated and observed values for river DO, CBOD, NH_4-N and NO_3-N were 20, 18, 17 and 13%, respectively (Table 6). In the validation dataset (Figure 6), the RMSE between observed and modeled values for the river DO, CBOD, NH_4-N, and NO_3-N were 13, 32, 26, and 29%, respectively (Table 6). This indicates that the model can be calibrated in one condition and still be rather valid in another. The maximum registered levels of CBOD, NH_4-N, and NO_3-N in this study were at (or below) 8.8, 0.83 mg/L (both in October) and 9.9 mg/L (in May), respectively. The minimum observed DO was 6.7 mg/L along the river occurring in October. The modeled water quality parameters along the river in Figures 5 and 6 imply that the river, in its current condition, could largely dampen the sudden discharge of CBOD, NH_4-N, and NO_3-N. As such, the Gargar River can receive increased loading from dischargers and lessen them in some parts of the river by its self-purification capacity. However, DO decreases permanently over the entire river length. This means that oxygen used to oxidize the constituents has permanently been shifted to a level more than the re-aeration potency of the river. Apparently, DO deficit can be problematic in this system if more wastewater discharging leads to more oxygen consumption and/or different environmental conditions (e.g., weather or climate shifts) lead to poor re-aeration.

Some errors in the modeling considered in this case study are inevitable as the field work consists of collecting a single sample in each station rather than multiple samples to assess variability. As the model predictions are based on the daily data, the observed DO may be different depending upon the time of samplings during the day. The DO levels decrease during the nighttime hours because of lower rates of photosynthesis by river plants. During the daytime, DO (and thus pH) increases because of the higher rates of photosynthesis of the plants. In spite of some incommensurability errors, the modeling results were quite acceptable to achieve goals for such a severe data shortage condition which is typical in many rivers especially in the developing countries. However, greater accuracy could likely be achieved through monitoring various input variables including algae coverage, sediment oxygen demand, and organic nitrogen over time. Further, using sophisticated 2D or 3D models may allow for a more interpretation of water quality between sites in time. Such work is outside the scope of this initial case study to explore the utility of the QUAL2K model in data-limited conditions.

Table 5 Calibrated parameters for the Gargar River water quality modeling on 3 May 2011

Parameters	Values	Units	Min. value	Max. value
ISS settling velocity	0.9209	m/d		
Fast CBOD oxidation rate	0.3	/d	0	5
Organic N settling velocity	0.84	m/d	0	2
Organic N hydrolysis	0.8	/d	0	5
Ammonium nitrification	2.0	/d	0	10
Nitrate Denitrification	0.2	/d	0	2
Sed. denitrification transfer coef.	0.9627	m/d	0	1

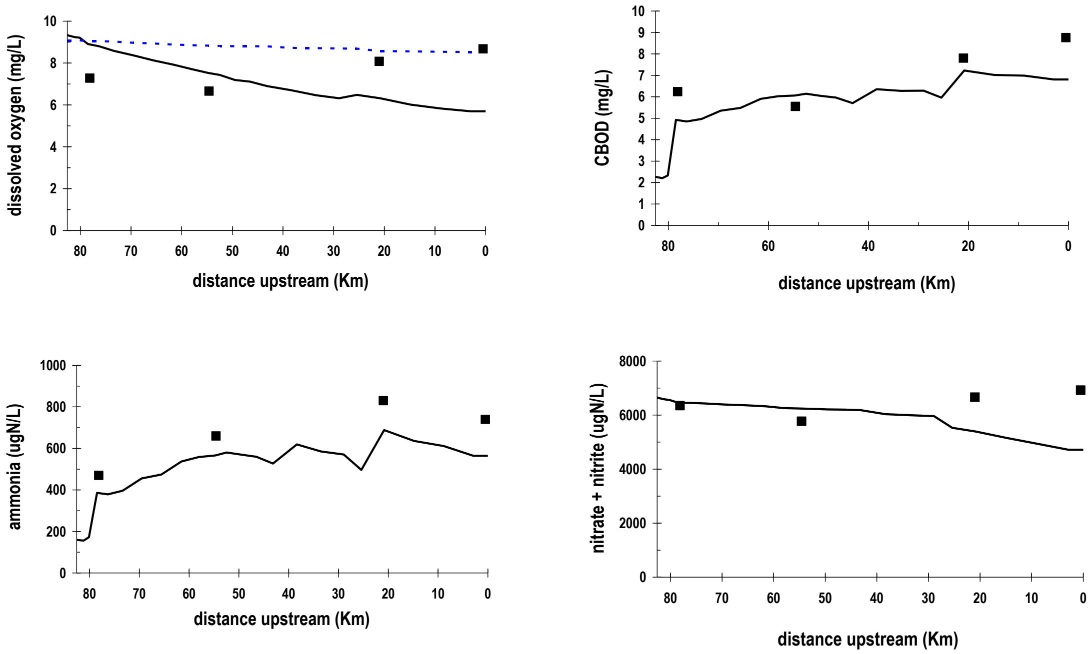

Fig. 5 Model results in Gargar River based on the data gathered on 13 October 2010

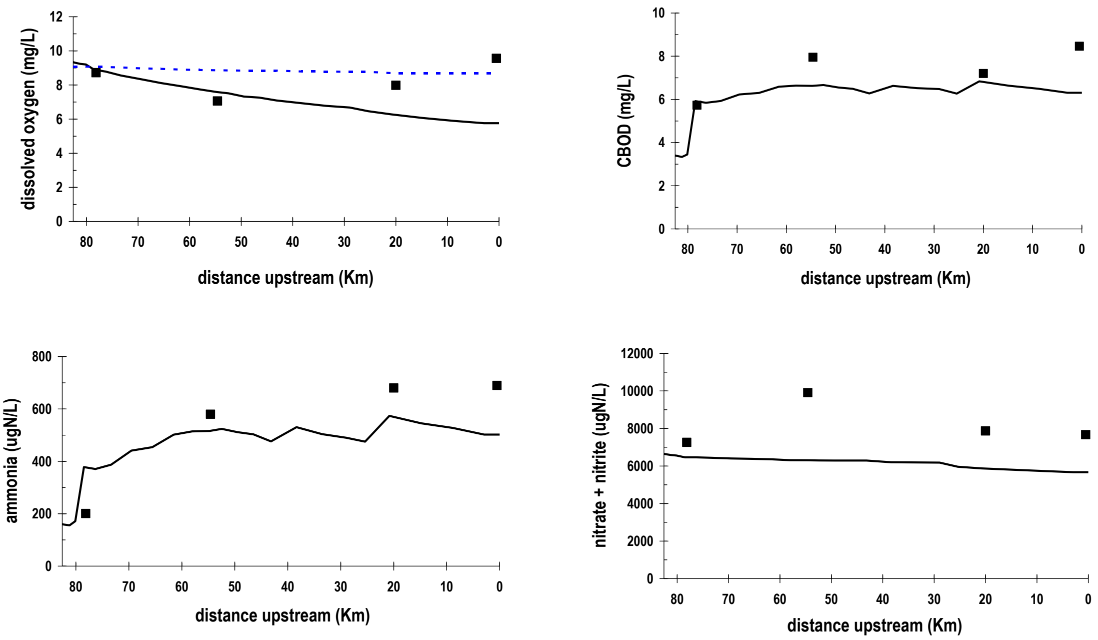

Fig. 6 Model results in Gargar River based on the data gathered on 3 May 2011.

Table 6 Root mean squared errors (RMSE), mean absolute percentage error (MAPE) and percent bias (PBIAS) for modeled versus measured water quality parameters

Parameter	RMSE		PBIAS		MAPE	
	Calibration	Validation	Calibration	Validation	Calibration	Validation
DO	1.5	1.0	-3.2	4.0	6.4	3.5
CBOD	1.2	2.2	3.2	-2.8	5.7	9.2
NH_4-N	0.108	0.124	16.1	-0.7	5.4	7.8
NO_3-N	0.817	2.415	4.0	25.4	3.4	8.5

3.2. Sensitivity analysis

To identify the parameters of the QUAL2K water quality model that have the highest influence on model predictions, a simple sensitivity analysis was performed with respect to DO estimates. The analysis was performed for the main seven model parameters and forcing functions (Table 7) by increasing and decreasing each parameter by 20% of its calibrated value and keeping the remaining parameters constant. The impacts of these changes on DO estimates were then assessed. It was found that the model was rather highly sensitive to river flow and point source discharges and moderately sensitive to fast CBOD and nitrification rate.

Table 7 Sensitivity analysis for the QUAL2K model on Gargar River based on the 3 May 2011 data

Parameters	Description	DO Change (%)	
		+20% parameter	-20% parameter
Q	River flow	3.59	-4.08
q	Point source flow	-2.34	2.54
k_{dc}	Fast CBOD oxidation rate	-0.62	1.49
k_{na}	Nitrification rate	-1.04	1.25
n	Manning coefficient	-0.43	0.83
CBOD	Point sources CBOD	-0.73	0.74
k_{dn}	Denitrification rate	0.72	-0.70

4. Conclusion

The current study characterized the quality of wastewater discharge into the Gargar River. 18 dischargers were identified along the river and their flow and water quality characteristics were analyzed. In the samples analyzed at five stations along the river, water quality parameters such as fast CBOD and DO varied between 3.47 and 5.77 mg/L and between 6.66 and 9.34 mg/L, respectively. In addition, we presented here a case study to simulate Gargar River water quality for the first time using the commonly-used, one-dimensional water quality model QUAL2K. It was possible to calibrate the model by changing various constituent rates. As such, fast CBOD oxidation, Ammonium nitrification and Nitrate denitrification rates were calibrated to be 0.3, 2.0 and 0.2 d^{-1}, respectively. While this initial study found that the model was most sensitive to river flow, point sources flow, fast CBOD oxidation rate and nitrification rate compared with the other model input parameters, QUAL2K clearly has potential for assessing water quality along the river and could be implemented as a valuable tool to inform Gargar River management strategies. For example, based on the observations provided in this study, it appears that DO may be manipulated using well-defined management strategies to keep DO concentrations above minimum allowable levels. The QUAL2K model could be used to simulate the amount of DO required and the potential impacts of such management on other water quality factors along the entire river. As such, the implementation of QUAL2K with regard to optimization techniques and accuracy assessments under various conditions warrants further consideration.

5. Acknowledgements

The present study was supported by the World Bank's RSM (Robert S. McNamara) fellowship in the form of research exchange funding for M. Rafiee. In addition, we give special thanks to Dr. Manuel Pulido-Velázquez for his advice on this work.

References

1 Ambrose, R.B., Connolly, J.P., Southerland, E., Barnwell, T.O., Schnoor, J.L., 1988. Waste allocation simulation models. J. Water Pollut. Control Fed. 6, 1646–1655.

2 APHA (American Public Health Association), 2005, Standard Methods.

3 Bowie G.L., M.B. William, Porcella D.B., Campbell C.L., Pagenkopf J.R., Rupp G.L., Johnson K.M., Chan P.W., Gherini S.A and Chamberlin C.E., 1985, Surface Water Quality Modeling. 1985, California, USA.

4 Brown, L.C., Barnwell, T.O.Jr., 1987. The Enhanced Stream Water Quality Models QUAL2E and QUAL2E-UNCAS: Documentation and User Manual. USEPA, Environmental Research Laboratory, Athens, GA, EPA/600/3-87/007.

5 Campolo M., Andreussi P., Soldati A., 2002. Water quality control in the river Arno, technical note. Water Res. 36, 2673–2680.

6 Chapra, S.C., and Canale, R., 2002. Numerical Methods for Engineers, 4th Ed. New York, McGraw-Hill.

7 Chapra, S.C., Pelletier, G.J., Tao, H., 2006. QUAL2K: A Modeling Framework for Simulating River and Stream Water Quality, Slaughterhouse2.04: Documentation and Users Manual. Civil and Environmental Engineering Dept., Tufts University, Medford, MA.

8 Cho, J. H., Sung Ryong Ha , 2010, Parameter optimization of the QUAL2K model for a multiple-reach river using an influence coefficient algorithm, Science of The Total Environment, Volume 408, Issue 8, Pages 1985-1991.

9 Cox, B.A., 2003. A review of currently available in-stream water-quality models and their applicability for simulating dissolved oxygen in lowland rivers. Sci. Total Environ. 314–316, 335–377.

10 Deksissa, T., Meirlaen, J., Ashton, P.J., Vanrolleghem, P.A., 2004. Simplifying dynamic river water quality modelling: a case study of inorganic dynamics in the Crocodile River, (South Africa). Water Air Soil Pollut. 155, 303–320.

11 Drolc, A., Konkan, J.Z.Z., 1996. Water quality modeling of the river Sava, Slovenia. Water Resources 30 (11), 2587–2592.

12 EEC, 1978. Council Directive (78/659/EEC) on the Quality of Fresh Waters Needing Protection or Improvement in order to support fish life,

retrieved 20 April 2005 from: http://europa.eu.int/comm/environment/

13 EMECS, 2001. Water Quality Conservation for Enclosed Water Bodies in Japan, International Center for the Environmental Management of Enclosed Coastal Seas (EMECS) retrieved 20 April 2005 from: http://www.emecs.or.jp/.

14 Fan, Chihhao, Chun-Han Ko, Wei-Shen Wang, 2009, An innovative modeling approach using Qual2K and HEC-RAS integration to assess the impact of tidal effect on River Water quality simulation

15 Ghosh, N.C., Mcbean, E.A., 1998. Water quality modeling of the Kali river, India. Water Air Soil Pollut. 102, 91–103.

16 ICHHTO (Iranian Cultural Heritage, Handicrafts and Tourism Organization), 2008, SHUSHTAR HISTORICAL HYDRAULIC SYSTEM, Tehran, Iran.

17 IPBO (Iranian Plan and Budget Organization),1992. Drinking Water Quality Standard (3-116), Tehran.

18 Kannel, P.R., Lee, S., Kanel, S.R., Lee, Y., Ahn, K.-H., 2007. Application of QUAL2Kw for water quality modeling and dissolved oxygen control in the river Bagmati. Environtal Monitoring Assessment 125, 201–217.

19 Moriasi, D.N., Arnold J.G., Van Liew M.W., Bingner R.L., Harmel, R. D. and Veith, T.L., 2007, Model Evaluation Guidelines for Systematic Quantification of Accuracy in Watershed Simulations Vol. 50(3): 885−900

20 Najafzadeh, M. and Azamathulla, H.M., 2013. Group method of data handling to predict scour depth around bridge piers, Neural Comput & Applic, 23:2107–2112

21 Najafzadeh, M. and Barani, G.A., 2011, Comparison of group method of data handling based genetic programming and back propagation systems to predict scour depth around bridge piers, Scientia Iranica A, 18 (6), 1207–1213

22 Najafzadeh, M., Barani, G.A., Kermani, M.R., 2013, Abutment scour in clear-water and live-bed conditions by GMDH network, Journal of Water Science Technology, 67(5):1121-8

23 Novotny, V., 2002. Water Quality: Diffusion Pollution and Watershed Management. Wiley, Hoboken, NJ. Chang, H., 2005. Spatial and temporal variations of water quality in the Han River and its tributaries, Seoul, Korea, 1993–2002. International Journal of Air and Water Pollution 161, 267–284.

24 Owens, M., Edwards, R.W., Gibbs, J.W., 1964. Some reaeration studies in streams. International Journal of Air and Water Pollution 8, 469–486.

25 Park, S.S., Na, Y., Uchrin, C.G., 2003. An oxygen equivalent model for water quality dynamics in a macrophyte dominated river. Ecological Modeling 168, 1–12.

26 Park, S.S., Lee, Y.S., 1996. A multiconstituent moving segment model for the water quality predictions in steep and shallow streams. Ecological Modeling 89, 121–131.

27 Pelletier, G.J., Chapra, C.S., Tao, H., 2006. QUAL2Kw, A framework for modeling water quality in streams and rivers using a genetic algorithm for calibration. Environmental Model. Software 21, 419–4125.

28 Rasti, M, Nabavi, S.M, Jaafarzadeh N., 2007, Investigation of Fish Farm Wastewater on Gargar River using algae as biologic indicator, 7th IREC, Ahvaz, Iran. (In Persian)

29 Tao, H, 2008. *“Calibration, Sensitivity and Uncertainty Analysis in Surface Water Quality Modelling: Dissertation for doctoral degree”*, Tufts University, MA, USA.

30 Thompson, D.H., 1925. Some observations on the oxygen requirements of fishes in the Illinois River, 111. Natural History Survey Bulletin 15, 423–437.

31 UNESCO, 2009. Shushtar Historical Hydraulic System, retrieved 24 April 2013 from: http://whc.unesco.org/en/list/1315/documents/

32 USEPA, 1985. Rates, constants and kinetics formulations in surface water quality, second ed. EPA 600/3-85-040, U.S. Environmental Protection Agency, Athens, GA, retrieved 20 October 2006 from: http://www.ecy.wa.gov/.

33 Zhang, R., Xin Qian, Huiming Li, Xingcheng Yuan, Rui Ye, 2012, selection of optimal river water quality improvement programs using QUAL2K: A case study of Taihu Lake Basin, China, Science of The Total Environment, Volume 431, Pages 278-285.