Jun 18th, 10:40 AM - 12:00 PM

Water quality risk simulation of Laoguanhe River based on uncertainty

Jun Hu
Beijing Normal University, Institute of Resources and Environment Science, MAPUNI, olive-jun@hotmail.com

Chunhui Li
Beijing Normal University

Xuan Wang
Beijing Normal University

International Environmental Modelling and Software Society (iEMSs)
7th Intl. Congress on Env. Modelling and Software, San Diego, CA, USA
Daniel P. Ames, Nigel W.T. Quinn and Andrea E. Rizzoli (Eds.)
http://www.iemss.org/society/index.php/iemss-2014-proceedings

Water quality risk simulation of Laoguanhe River based on uncertainty

Jun Hu[a,c], Chunhui Li[a,b], Xuan Wang [a,b]
[a] Key Laboratory for Water and Sediment Sciences of Ministry of Education, School of Environment, Beijing Normal University, Beijing 100875, P.R.China;
[b]State Key Laboratory of Water Environment Simulation, School of Environment, Beijing Normal University, Beijing 100875, P.R.China;
[c]Institute of Resources and Environment Science, MAPUNI, Beijing 100101,P.R.China
E-mail: olive-jun@hotmail.com

Abstract: Laoguanhe River as the nearest upstream tributary of Danjiangkou Reservoir to the Taocha diversion main canal in South-to-North Water Diversion Project, its water quality changes will directly affect the water quality level of the project. This study is intended to provide the scientific support for the comprehensive water environment risk assessment and provide the optimization decision-making basis for the water environment management of Laoguanhe River. This research used the QUAL2Kw model to simulate the water quality of Laoguanhe river form sandaohe section to downstream section. And then the calibrated model is used to calculate the water quality risk with Markov process. The Latin Hypercube Sampling is used to improve the flow input of QUAL2Kw and the simulation results are used to analyze the water quality risk for 2012. According to the simulation results, the water quality in the downstream section can satisfy the Ⅱclass which is the basic requirement for the river export to the Danjingkou Reservoir.

Key words: QUAL2Kw, Markov transition matrix, risk assessment, water quality model

1 INTRODUCTION

Drinking water security is one of the important issues in water environment field which deserves limelight from the public. With the rapid development of the science and technology, expanding social economy, urbanization, industrialization and increasing human activities influence, the water environment problem has become one of the key limitations of the sustainable development of social economy. The direct appearance of the water environment problem is that the water quality situation cannot satisfy the needs of industrial production, the lives of residents, environment and ecology. Nowadays due to the large amount of agricultural, municipal and industrial wastewater which is discharged into the water bodies, water quality management has become a serious issue especially in the developing area (Nader & Amir 2012). Rivers are one of the main water resources. Because of the ease of access to the rivers and their potential for self-purification, rivers as one of the main water resources suffer from these anthropogenic effects.

2 STUDY AREA

Laoguanhe River is one of the upstream tributaries of Danjiangkou Reservoir, which is the nearest upstream tributary to the Taocha diversion main canal. Laoguanhe River is located in the southwest of Henan province, between the longitude 111°01′~111°46′, and latitude 33°05′~33°48′. Laoguanhe River is length 254 km, at an altitude of 1340 m. The basin area is 4219 km^2; 3266 km^2 is belonging to Nanyang city. Laoguanhe River is a typical mountain river, about the 116 km head of Laoguanhe River is in the mountains, with the steep banks, and the forest coverage rate is about 90%.

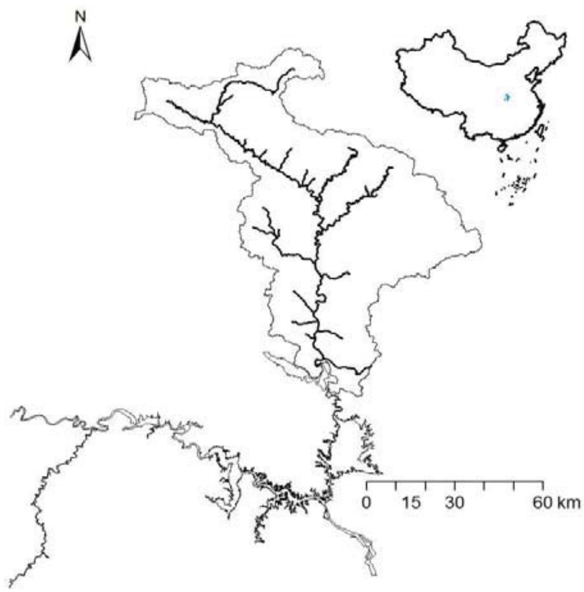

Figure 1 study area

3 METHOD

3.1 QUAL2Kw model

Qual2kw is the newest version of Qual series which can simulate streams and river quality in a one-dimensional steady state condition. In the Qual2k model the river is divided into several reaches and each reach is divided into equal segments. These segments are the model's shortest elements. This model can simulate fate and transport of many parameters and contaminants such as temperature, BOD, DO, phytoplankton, various kinds of nutrients, pH and etc(Chapra et al.2006).

Natural Rivers are influenced greatly by the external environment. The construction of the water quality model requires users to generalize the river channel based on the hydrodynamic and water quality characteristics and divide the reaches firstly, which will help the water quality model to calculate the results easily (see Fig.2).

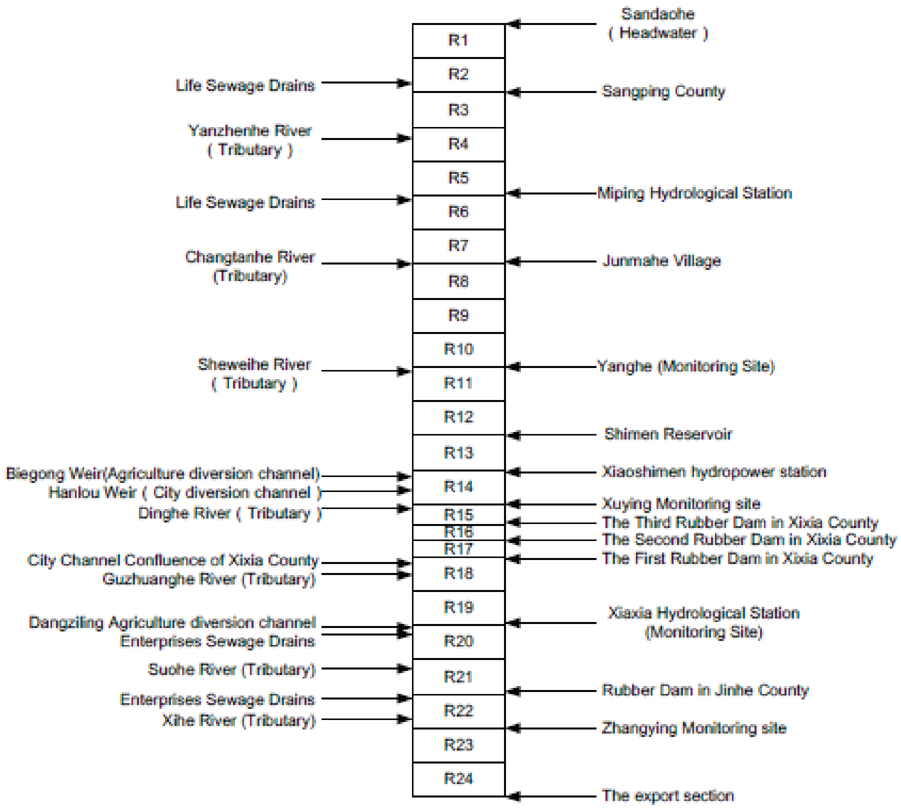

Figure 2 Reach generalization of Laoguanhe River

3.2 Risk simulation and prediction using Markov Process and Latin hypercube method

QUAL2K model is a one-dimensional steady-state model. Flow as one of the most important boundary conditions and initial condition is set as a fixed parameter when the model runs. In previous studies, researchers often used the design flow or fixed flow rate guarantee for QUAL2K model (Nader & Amir 2012), however, these methods brought much error between the monitoring values and prediction values resulting from water quality models for the natural rivers. Therefore, this research will use the Latin Hypercube Sampling (Helton & Davis 2003) to improve the flow input and analyze the water quality uncertainty for 2012. And then, this research will use Markov transfer analysis to calculate the flow probability distribution in different hydrological years and further more to the Latin Hypercube Sampling method to analyze the uncertainty of water quality in different hydrological year.

Markov process put forward by the Russian mathematician A.A.Markovin in 1907. It is a stochastic process which assumes that in a series of random events the probability of an occurrence of each event depends only on the immediately preceding outcome (Maity 2012). It means that if the information of "now", "past" and "future" are independent of each other, that the information of now and the past are equivalent to predict the future.

Markov process can be described as a sequence of uncertainty decision-making process, at every moment of decision the system state to provide the necessary information to select actions for decision-making that is the transition probabilities. Random variables Q, denoted $\{Q_n=Q(n),n=0,1,\ldots\}$, is homogeneous with respect to time t, with the state space I=（a_1， a_2， …， a_i）of one order Marko Cardiff process. The transfer matrix $P = (p_{ij})$ (1) equation, where $p_{ij} = P_{ij}(1) = P\{X_m +1= a_j | X_m = a_i\}$

$$P=\begin{bmatrix} p_{11} & p_{12} & \cdots & p_{1j} \\ p_{21} & p_{22} & \cdots & p_{2j} \\ \vdots & \vdots & \ddots & \vdots \\ p_{1i} & p_{21} & \cdots & p_{ij} \end{bmatrix} \quad (1)$$

Where $p_{ij}=n_{ij}/n_i$, represents the probability that the state from ai transfer to aj from time n to n+1; n_{ij} is the number of samples that the state a_i transfer to a_j from time n to n+1; n_i is the number of samples at time n with the state a_i.

Before construction of Laoguanhe River flow Markov chain, firstly transfer the flow data of miping hydrological station to flow data of Sandaohe monitor point which is the source of this model with the water balance equation. And then construct the first order Markov process, where the results change is only affected by the last change results.

The specific steps are as follows:

1. Use the years of flow data to establish the years flow cumulative frequency distribution. According to the distribution to divide it into 10 state spaces with 10% guarantee rate interval, Q = {Q90, Q80, Q70, Q60, Q50, Q40, Q30, Q20, Q10, Q0}. Where 0% -10% guaranteed rate of flow state as Q0, 10% -20% guaranteed rate of flow state as Q10, 20% -30% rate of flow assurance as Q20, the rest are deduced by analogy, 90% -100% guaranteed rate of flow state as Q90.
2. Due to the limited flow data, in order to ensure the normal operation of the model calculation, we divided the every month flow data into 3 equal portions with an equal difference, and then calculate the arithmetic mean as the initial data for each month to calculate the one order Markov transition matrix.
3. Use flow data generated the flow cumulative distribution of different hydrological year. Then use the Latin Hypercube sampling to extracted the flow data from the cumulative distribution into the one order Markov transition matrix, and use the years flow cumulative frequency distribution to interpolated and generate the flow data of next month.
4. The newly generated flow data is as the source of water flow input into the QUAL2Kw model to calculate the water quality of each month. Finally, the water quality simulation results are used to calculate the risk probability.

4 RESULTS AND DISCUSSION

4.1 Calibration and validation

The research calibrated the model as wet season, dry season and level season using genetic algorithm method. The population that model runs was 100, and the generations in the evolution was 200. After 100 generations the basic convergence was achieved with a floating in small range. The level season had the highest fitness, followed by dry season and wet season. The model preserved the last running parameters as the final parameter calibration results. The wet season, level season and dry season respectively used August, April and February data to calibrate. Figure3 showed the calibration results of NH_4^+N, COD and DO. And DO have a bigger deviation. The figure 4-6 showed the validation results in different seasons.

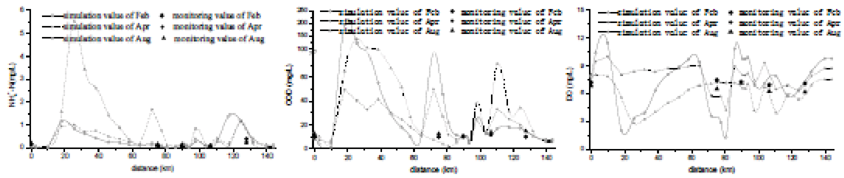

Figure 3 Calibration results of water quality model

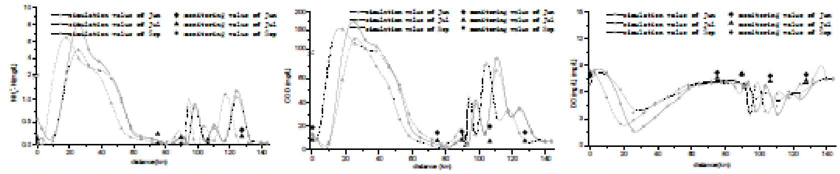

Figure 4 Validation results in wet season

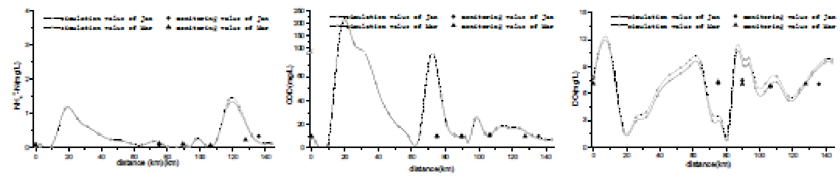

Figure 5 Validation results in dry season

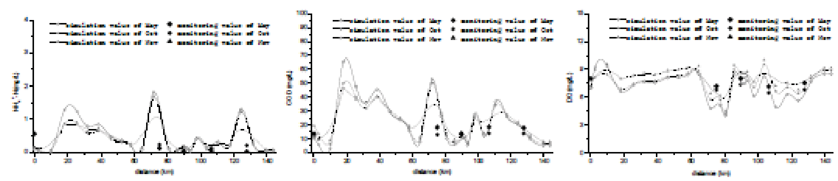

Figure 6 Validation results in level season

4.2 Risk simulation and analysis

In this study, the annual runoff that is more than $5*10^8 m^3$ is wet year, less than $2*10^8 m^3$ is dry year and between these two levels was level year. According to this standard, calculate the annual runoff from 2007 to 2012, the 2010 and 2011 were wet years, the 2007 and 2009 were level years, and the 2008 and 2012 were dry years. This research used the January average daily flow data of 2010 and 2011 to build the cumulative probability distribution as the sampling distribution for the wet year, the cumulative probability distribution with the January average daily flow data of 2007 and 2009 as the sampling distribution for level year, as the same that the cumulative probability distribution with the January average daily flow data of 2008 and 2012 as the sampling distribution for dry year. And then respectively calculate the water quality risk probability of wet year, level year and dry year. The average monitoring data of every season in 2012 was as the initial water quality boundary condition. The results were as figure 7 to 9.

(1) The simulation results in the wet years showed that: the NH_4^+N can meet Ⅱ class standard, and the concentration in Zhangying monitoring site was higher than Xixia hydrological station and Xuying monitoring site. The DO in Xuying and Zhangying monitoring sites can meet the Ⅱ class standard, that the concentration greater than 6mg/L, however, the risk probability of DO non-compliance in Xixia hydrological station in dry season and low season respectively were 4.1% and 8.2%. The COD in Xuying monitoring site and Xixia hydrological station can meet the standard that the concentration less than 15mg/L, and the Zhangying monitoring site which is the nearest monitoring site form the Danjingkou Reservoir had the risk probability of COD non-compliance about 26.5% in wet season.

(2) In the dry year, the water quality was poor in Zhangying monitoring site and Xixia hydrological station. The risk probability of COD non-compliance was 25.1% at Zhangying monitoring site in the wet season. And at the Xixia hydrological station the DO has 0.6% risk probability excessive the standards in the dry season. In the level season, the Xixia hydrological station has 10.6% risk probability with the DO non-compliance the standard, and the Zhangying monitoring site has 0.1% risk probability with the NH_4^+N excessive 500 ug/L.

(3) In the level year, except the wet season ,the DO concentration were greater than 6mg/L, and the Xixia hydrological station had the risk probability of DO non-compliance in dry season and level season respectively 1.8% and 9.2%. The NH_4^+N can meet the standard that the concentration less than 500ug/L all over the level year. The COD was high in wet season, and the concentration at Zhangying monitoring site had the risk probability of excessive the 15mg/L about 27.1%.

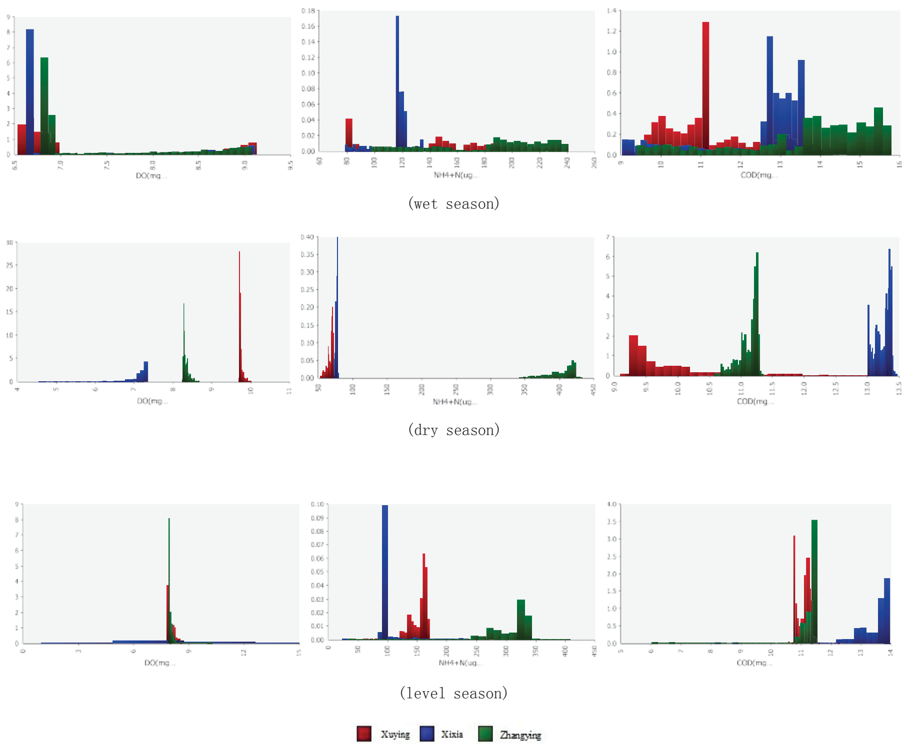

Figure 7 The simulation results of wet year

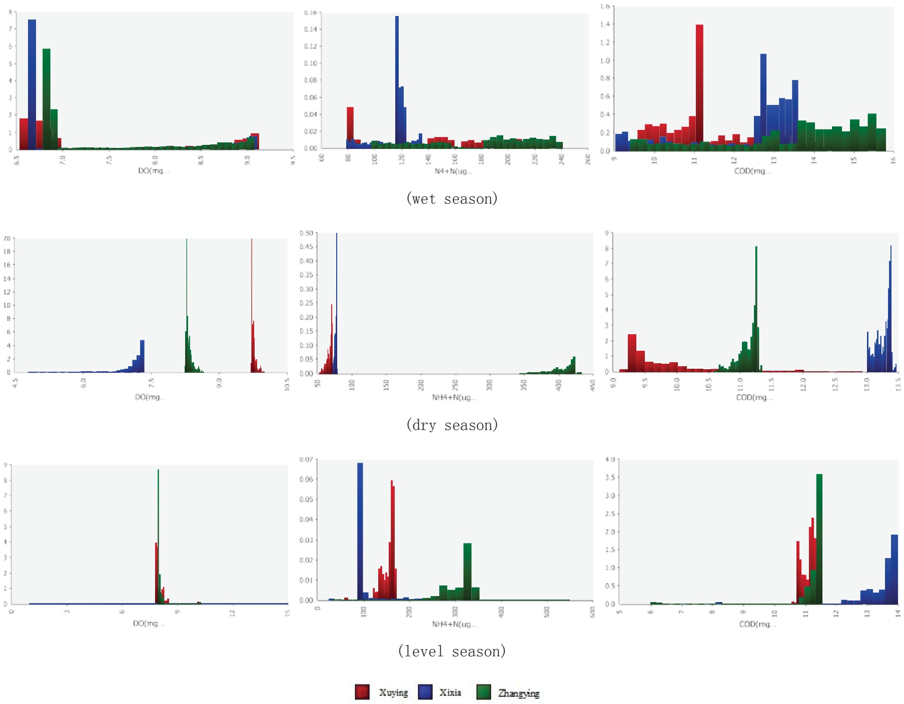

Figure 8 The simulation results of dry year

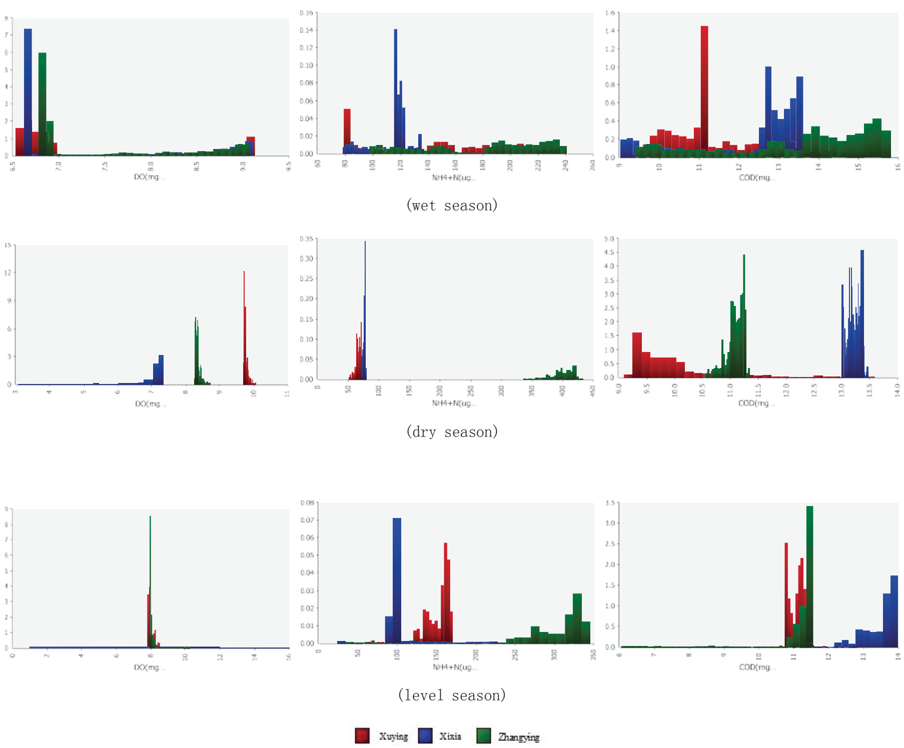

Figure 9 The simulation results of level year

5 SUMMARY AND CONCLUSIONS

The Laoguanhe River is the main tributary exported into Danjiangkou Reservoir which is the water resource of south-to-north water diversion project. The water quality in Laoguanhe River was overall optimistic. The water quality at Zhangying monitoring site was threatened by the excessive concentration of COD, therefore, the industrial pollution and urban sewage discharge need to be controlled in the downstream. In order to make sure that the middle section of South-to-North Water Diversion Project provides potable water, Laoguanhe River need to take a variety of water environment management measures, to ensure the water quality export to Danjiangkou Reservoir fulfill the Ⅱclass standards.

ACKNOWLEDGEMENT

This research was supported by national key technology R&D program of China (2011BAC12AB02).

REFERENCE

Nader N., Amir E.S., 2012. Applying Monte Carlo and classification tree sensitivity analysis to the Zayandehrood River. Journal of Hydroinformatics 14(1),236-250.

Chapra, S.C., Pelletier, G.J., Tao, H., 2006. QUAL2K: A Modeling Framework for Simulating River and Stream Water Quality,Version 2.04: Documentation and Users Manual. Civil and Environmental Engineering Dept., Tufts University, Medford, MA.

Helton, J.C., Davis, F.J., 2003. Latin hypercube sampling and the propagation of uncertainty in analyses of complex systems. Reliability Engineering and System Safety 81 (1), 23-69.

Maity R., 2012. Probabilistic assessment of one-step-ahead rainfall variation by Split Markov Process. Hydrological Process 26,3182–3194.