Water Quality Index as a Simple Indicator of Drinking Water Source in the Dongjiang River, China

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***Abstract*-Dongjiang River is the major source of drinking water supply for the Pearl River Delta in South China. In order to assess the spatio-temporal changes of water quality in the watershed, the water quality index (WQI) was applied to calculate scores based on water characteristics data from 2008 to 2010, and then water qualities were classified as excellent, good, medium, bad and very bad. The results indicated good water quality in the upper parts of the watershed. Medium water quality was shown in the middle and lower parts, mainly due to increasing population, frequent anthropogenic activities, sewage discharges and non-point pollution from agriculture in the Dongjiang basin. The applicability of WQI was satisfactory for evaluating the global variations of water quality on spatial and temporal scale in the river.**

Keywords*-*Water Quality Index; Drinking Water Source; Spatio-temporal Change; Dissolved Oxygen

I. INTRODUCTION

Water quality and water pollution have become critical issues in many developing countries, coupled with the worldwide concern that fresh water will be a scarce resource in the future [1]. And these countries have developed a water quality monitoring program for the protection of fresh water resources [1-2]. Traditional approaches to evaluate river water are usually based on the comparison of the parameter values monitored with the local normative. The analysis including one or some parameters grouped according to a common feature may give partial information on the overall quality of water. It is difficult in integrating many parameters via the traditional approaches to providing a global water quality of a watershed [3]. Although mathematical-computational modeling of river water quality is useful for the assessment of the overall quality, the applications of the models were often restricted by the prerequisite knowledge of hydrodynamics and extensive validation [4-6].

The water quality index (WQI) has been recommended as a simple method to overcome many limitations mentioned for the global water quality. This index is a mathematical number, which is calculated from the transformation of a large quantity of water characterization data into water quality levels [7]. A WQI value not only gives a simple and reasonable profile of water quality for the public and decision makers to understand easily, but also provides a spatial and temporal trend of water quality [8]. Therefore, the method has been applied to describe the water quality of surface water in many countries, including the United States of America [9], Argentina [1], Taiwan [10], Chile [3], Spain [7], Nepal [8], and India [11-12].

The Dongjiang River is the major source of drinking water supply for Hong Kong (account for 80% water supply) and several main cities (e.g. Huizhou, Dongguan, Shenzhen, and Guangzhou) in the Pearl River Delta of South China. In recent decades, rapid industrialization, intensive urbanization, and agricultural fertilizer abuse coupled with increasing industrial and domestic sewage discharges [13] in the Pearl River Delta, inevitably result in the deterioration of water quality in the main stream and the tributaries by introducing inorganic and organic pollutants [14]. It is noted that the highlighted sustainability of the water supply from the Dongjiang River with acceptable quality and sufficient quantity is of significance to human welfare and the developments of Hong Kong and the Pearl River Delta. Hence, the use of WQI for assessing the water quality may be a cost-effective way to keep the safety of drinking water in the Dongjiang River.

In this study, the water quality index (WQI) was applied to evaluate the spatial and temporal changes of surface water quality in the Dongjiang River, the scores caculated were used for classifying the water quality and assessing the impacts of industrial and rapid urbanization on the overall water quality along the river basin.

II. MATERIALS AND METHODS

A. Description of Study Area and Sampling

The Dongjiang River is one of the three main tributaries of the Pearl River system located in South China, originates in Xunwu county of Jiangxi Province. Its journey is running through the cities of Longchuan, Heyuan, Huizhou, and Dongguan in Guangdong Province, then converges into the eastern delta of the Pearl River, and ultimately enters into the South China Sea. The watershed covers a total area of about 35,340 km^2 with the annual runoff of 32.4 billion m^3; and the resource is the principal water supply for 40,000,000 residents.

Nine sampling sites were selected to describe the water quality status and the spatial changes along the river. From these, six sites were defined on the main stream, while the other sites were located on tributaries (Fig. 1). The first sampling site was located on upstream at Longchuan county where the region underdeveloped in economics. The second site was located near the center of Heyuan city, while the third site Guzhu is a small town downstream from Heyuan about 30.2 km. The fourth site was located at the city center of Huizhou in which the river receives the water and urban discharges from the Xizhi River. The fifth and sixth sites were near the well-developed towns of Dongguan city, Qiaotou town, and Shilong town respectively. The seventh site was located on the Tributary Xinfengjiang River near the intake of the drinking water supply for the city of Heyuan. The eighth site was located on the Tributary Xizhi River near Huizhou city, while the last site was located on the Tributary Danshui River receives industrial and domestic sewage discharges from Shenzhen and Huiyang city.

B. Water Chemical Analysis

Water samples were analyzed for temperature, pH, dissolved oxygen (DO), ammonia, nitrite, nitrate, and chemical oxygen demand (COD). Temperature, pH and DO were measured by the Universal Pocket Meter Multiline P4 (Universal-Taschenmebgerat, Germany). Ammonia, nitrite, nitrate and COD were detected using Nessler's reagent colorimetric method (according to the Chinese standard method GB7479-87), spectrophotometric method (according to the Chinese standard method GB7493-87), and spectrophotometric method with phenol disulfonic acid (according to the Chinese standard method GB7493-87) and potassium permanganate oxidation method (ISO8467), respectively.

C. Calculation of Water Quality Index

For the calculation of the WQI, the weights and normalization factors of the parameter were adopted from various literatures ([1], [3], [7-8]) and listed in Table Ⅰ, the following equation was used:

$$\mathrm{WQI} = k\frac{\sum_i C_i P_i}{\sum_i P_i}$$

where k is a subjective constant within the range of 0.25~1, the value of 1, 0.75, 0.50 and 0.25 for the visual impression of river contamination: 1.00 = water without apparent contamination (clear or with natural suspended solids); 0.75 = light contaminated water (apparently), indicated by light non-natural color, foam, light turbidity due to no natural reasons; 0.50 = contaminated water (apparently), indicated by non-natural color, light to moderate odor, high turbidity (no natural), suspended organic solids, etc.; 0.25 = highly contaminated water (apparently), indicated by blackish color, hard odor, visible fermentation, etc. Ci is the normalized value of the parameters and Pi is the relative weight of each parameter in terms of its importance for aquatic life conservation (Table Ⅰ). The WQI in the range of 0-25, 26-50, 51-70, 71-90, 91-100 represent the level very bad, bad, medium, good, and excellent of the water quality, respectively.

D. Statistical Analyses

Pearson's correlation matrix for chemical and physical properties of water samples was calculated using SPSS 16 software, and the resulting matrix was used to determine linear relationships and their strength among the water quality variables at $p \leq 0.01$ and 0.05. (Table Ⅱ)

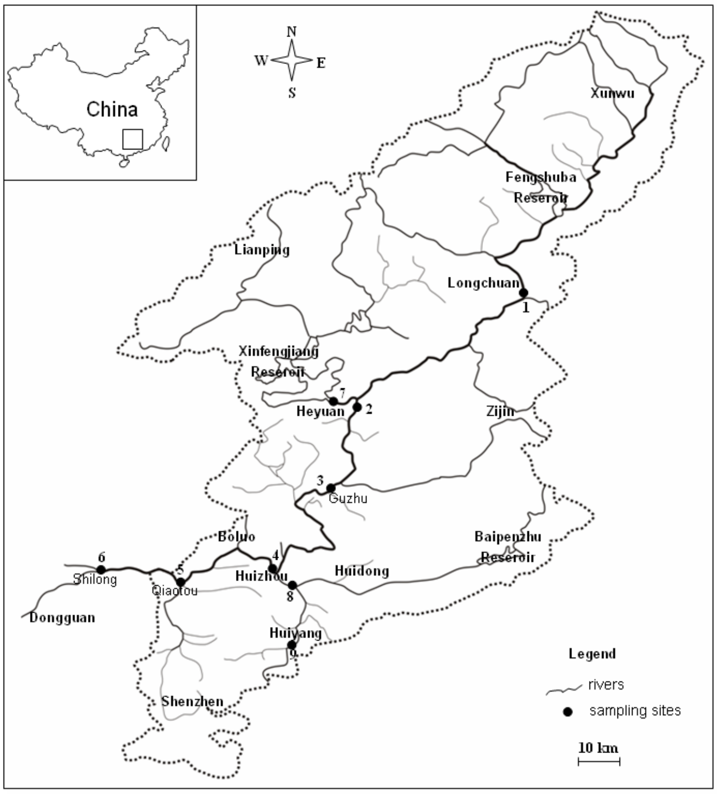

Fig. 1 Locations of sampling stations at the mainstream and the tributaries of the Dongjiang River with Number 1-9 for sampling sites: Longchuan, Heyuan, Guzhu, Huizhou, Qiantou, Shilong, Xinfengjiang River, Xizhi River and Danshui River, respectively

TABLE Ⅰ RELATIVE WEIGHTS (*PI*) AND NORMALIZED VALUES (*CI*) TO DIFFERENT WATER QUALITY VARIABLES

Variable	*Pi*	Normalization Factor (*Ci*)										
		100	90	80	70	60	50	40	30	20	10	0
Temp	1	21/16	22/15	24/14	26/12	26/10	30/5	32/0	36/−2	40/−4	45/−6	>45/<−6
pH	1	7	7-8	7-8.5	7-9	6.5-7	6-9.5	5-10	4-10	3-12	2-13	1-14
DO	4	≥7.5	>7	>6.5	>6	>5	>4	>3.5	>3	>2	≥1	<1
NH_4^+-N	3	<0.01	<0.05	<0.1	<0.2	<0.3	<0.4	<0.5	<0.75	<1	≤1.25	>1.25
NO_2^--N	2	<0.005	<0.01	<0.03	<0.05	<0.1	<0.15	<0.2	<0.25	<0.5	≤1	>1
NO_3^--N	2	<0.5	<2	<4	<6	<8	<10	<15	<20	<50	≤100	>100
COD	3	<5	<10	<20	<30	<40	<50	<60	<80	<100	≤150	>150

All values are in mg L^{-1}, except for pH, water temperature (Temp, °C)

TABLE Ⅱ PEARSON'S CORRELATION MATRIX FOR CHEMICAL AND PHYSICAL PROPERTIES OF WATER QUALITY IN THE DONGJIANG RIVER FROM 2008 TO 2010

	Temp	**pH**	**DO**	**NH_4^+-N**	**NO_2^--N**	**NO_3^--N**	**COD**
Temp	1.000	-0.142	-0.617	0.617	0.533	0.217	0.533
pH	-0.142	1.000	0.192	-0.318	-0.259	-0.008	-0.351
DO	-0.617	0.192	1.000	-0.967**	-0.933**	-0.600	-0.950**
NH_4^+-N	0.617	-0.318	-0.967**	1.000	0.933**	0.517	0.983**
NO_2^--N	0.533	-0.259	-0.933**	0.933**	1.000	0.750*	0.900**
NO_3^--N	0.217	-0.008	-0.600	0.517	0.750*	1.000	0.467
COD	0.533	-0.351	-0.950**	0.983**	0.900**	0.467	1.000

**CORRELATION IS SIGNIFICANT AT THE 0.01 LEVEL (2-TAILED)

*CORRELATION IS SIGNIFICANT AT THE 0.05 LEVEL (2-TAILED)

TABLE III DESCRIPTIVE STATISTICS OF WATER QUALITY PARAMETERS ALONG THE DONGJIANG RIVER FROM 2008 TO 2010

	LC		**HY**		**GZ**		**HZ**		**QT**		**SL**		**XF**		**XZ**		**DS**	
	Mean	std	Mean	std	Mean	std	Mean	std	Mean	std	Mean	std	Mean	std	Mean	std	Mean	std
Temp	23.84	6.30	25.12	6.05	23.56	5.60	24.74	6.13	25.16	6.65	25.02	6.41	18.52	3.09	25.08	5.52	24.84	5.87
pH	7.02	0.22	7.10	0.22	6.96	0.38	6.79	0.29	7.01	0.12	7.03	0.20	7.46	0.27	6.77	0.29	7.03	0.43
DO	6.87	0.96	6.66	1.18	7.83	0.82	6.58	2.22	5.42	0.24	4.54	1.72	9.04	0.84	5.08	1.59	3.06	1.72
NH_4^+-N	0.86	0.55	1.19	1.21	1.03	0.68	3.00	1.28	3.14	2.17	3.53	2.42	0.30	0.19	9.11	6.55	14.14	5.90
NO_2^--N	0.021	0.012	0.048	0.055	0.049	0.035	0.089	0.063	0.166	0.119	0.244	0.138	0.020	0.016	0.142	0.040	0.427	0.286
NO_3^--N	0.92	0.44	0.76	0.39	1.03	0.28	0.81	0.43	1.06	0.34	1.42	0.52	0.37	0.05	0.63	0.30	2.11	1.24
COD	2.23	0.45	3.40	1.21	3.27	1.07	5.93	3.21	3.70	1.70	7.99	6.87	1.63	0.25	12.50	8.85	16.20	9.91

SITE LC, HY, GZ, HZ, QT, SL, XF, XZ, AND DS STAND FOR LONGCHUAN, HEYUAN, GUZHU, HUIZHOU, QIANTOU, SHILONG, XINFENGJIANG RIVER, XIZHI RIVER AND DANSHUI RIVER RESPECTIVELY

III. RESULTS AND DISCUSSION

Water properties, including water temperature, pH, DO, ammonia, nitrite, nitrate and COD, were determined in the Dongjiang River during the wet seasons and the dry seasons from 2008 to 2010 (Table Ⅲ). The averages of water temperature were 24.4±0.8℃ with the exaction of Xinfengjiang River, in which the average of water temperature was lower than 20℃. The average temperature in the mainstream was higher than the mean over years (20.4℃), and a slight increase in temperature contributes to an increase in the biological activity on the degradation of pollutes in the water [7]. The pH of surface water was predominantly neutral with the averaged pH 7.02, but acidic pH was also presented in some locations (e.g., Huizhou, Xizhi River, and Guzhu). Most of the water samples in this study recorded a pH range of about 6.36-7.82, for each site the pH value was fluctuate around 7, which seemed to be a relatively stable parameter similar to the Chini Lake [15]. The averaged pH values of natural waters usually ranged from 6.0 to 8.5, which had no immediate direct effect on human health [12]. However, considering that the pH variation regulates most of the biochemical and chemical reactions affecting water composition [16] and the safe for drinking water, pH 6.5-8.5 for drinking water is recommended by the Chinese standard. The average concentration of DO at each site ranged from 3.06 to 9.04 mg L^{-1}. The lower DO values were observed in Danshui River (3.06 mg L^{-1}), Shilong (4.54 mg L^{-1}). In the other sites, DO values were all higher than 5 mg L^{-1} and the highest DO value was detected in Xinfengjiang River (9.04 mg L^{-1}).

The samples showed high variations in averaged ammonia (NH_4^+-N) contents, from the lowest concentration in Xinfengjiang River (0.30 mg L^{-1}) to the highest one in Danshui River (14.14 mg L^{-1}). Among the nine sampling sites, Xinfengjiang River was the only site satisfied with the drinking water quality standard of ammonia (Chinese National Water Quality Grade II), while the other sites, especially in the lower reach, were far above the standard. The concentrations of nitrate were lower than the drinking water quality standard (10 mg L^{-1} for nitrate), so were those concentrations of nitrite in all samples. Although nitrogen contamination in waters was an important contributor to the deterioration of the water quality and the aquatic ecological systems, compared to the other rivers and lakes in China, including the Yangtze River [17], the Yellow River [18], Haihe River [19], Huaihe River [20], Taihu Lake [19] and Chaohu Lake [21], the overall water quality in the Dongjiang River is still better, and the water in the mainstream is generally good enough to meet the drinking water quality standard [22].

The hydro-chemical relationships were clearly expressed by the results of correlation matrix for the complete three year data set (Table Ⅲ). In the case of dissolved oxygen, negative correlations were observed between DO and ammonia, nitrite, or COD ($p \leq 0.01$). The ammonia and nitrite were oxidized by oxygen to yield nitrite and nitrate, respectively; COD (organic matter) partially oxidized by oxygen. Therefore, such kinds of correlations were expected [11]. Positive correlations between ammonia and nitrite ($p \leq 0.01$), or nitrate ($p \leq 0.05$) were observed, which indicated the contamination of insoluble inorganic matter and the biotransformation of nitrogen among inorganic compounds. COD showed positive correlations with ammonia ($p \leq 0.05$) and nitrite ($p \leq 0.05$), suggesting that organic matter contamination often occurred with nitrogen loading in the river. The increase of nutrients in surface water is responsible for eutrophication, which further results in the increasing concentration of organic matter, and eventually deteriorates the water quality [23].

The WQI was used to classify overall water quality as excellent, good, medium, bad, and very bad based on the critical scores of 90, 70, 50 and 25. The water quality of sites Longchuan, Heyuan and Guzhu in the mainstream and the tributary Xinfengjiang River in upper reaches were good, and the highest score was obtained from the Xinfengjiang River (87.5). While the water quality was medium in middle and lower reaches such as sites Huizhou, Qiaotou and Shilong, and very bad water quality in site Danshui (Fig. 2).

Geographically, water quality showed a decreased trend in the mainstream in the Dongjiang River. For example, there were twenty units of water quality deterioration at the site of Shilong compared with the site Longchuan.

As the river enters the big city area from Longchuang to Heyuan, there was a slight water quality drop of 3.7 units; from Guzhu to Huizhou, there was a significant water quality drop of 11.1 units ($p < 0.05$). These were associated with the city sewage discharges and wastewater treatment plant effluents. In addition, the Dongjiang River mainstream in Huizhou city receives the medium polluted tributary Xizhi River, which merged the highly polluted tributary Danshui River. This situation was partially contributed to the water quality significant drop in the mainstream in Huizhou city. Such deterioration of the river water quality proceeds as the river journey moves downstream. At Qiaotou and Shilong in Dongguan where populations increase significantly, the water quality indices dropped 3.8 and 5.6 units, respectively. It was noted that the overall water quality deteriorated along the mainstream, yet there was 3.7 units increased from Heyuan to Guzhu. The reason for the quality increase might be due to the smaller populations in Guzhu compared with Heyuan city.

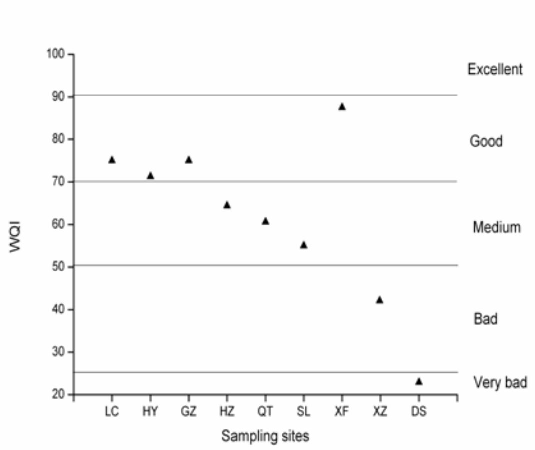

Fig. 2 Water quality indices (WQI) in the Dongjiang River: LC, HY, GZ, HZ, QT, SL, XF, XZ, and DS represent for the sampling sites, Longchuan, Heyuan, Guzhu, Huizhou, Qiantou, Shilong, Xinfengjiang River, Xizhi River and Danshui River respectively

To elucidate the relationship between WQI and the environmental parameters, the variation of selected parameters and WQI at sampling sites were showed in Fig. 3. With the increase of TIN (sum of NH_4^+, NO_2^- and NO_3^{-}) from

Longchuan to Shilong in the mainstream, the water quality got worse, suggesting that nitrogen compounds may cause the deterioration of water quality. The distribution pattern, lower concentration of TIN at upstream sites such as Longchua, Heyuan and Guzhu while higher concentration in downstream indicated that the increased TIN may be due to the larger population, higher anthropogenic activities, more sewage discharges and the non-point pollution from agriculture [13]. Among these three kinds of nitrogen compounds, the major contribution to TIN was from NH_4^+-N (Fig. 3).

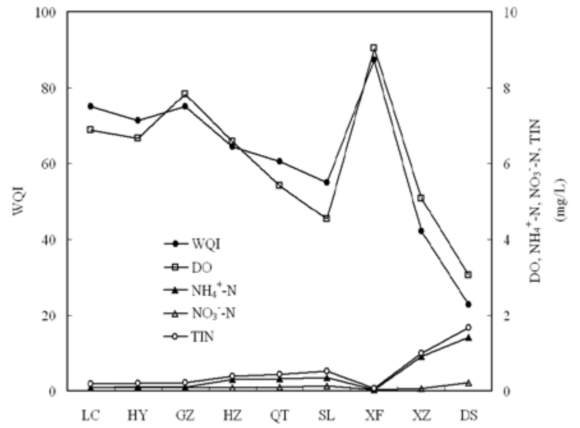

Fig. 3 Variation of selected parameters and WQI at sampling sites along the Dongjiang River from 2008 to 2010: LC, HY, GZ, HZ, QT, SL, XF, XZ, and DS represent for the sampling site Longchuan, Heyuan, Guzhu, Huizhou, Qiantou, Shilong, Xinfengjiang River, Xizhi River, and Danshui River respectively

And the concentration of NH_4^+-N below 0.5 mg L^{-1} is satisfied according to the drinking water standard in China. The DO values were relatively high in sites such as Longchuan, Heyuan, Guzhu, Huizhou and the tributary Xinfengjiang River; this may be due to the great run-off, lower nutrients concentration in the waters. The change trend of DO was similar to that of WQI but dissimilar to TIN, and these results were in a good agreement with the situation of Bagmati River [8].

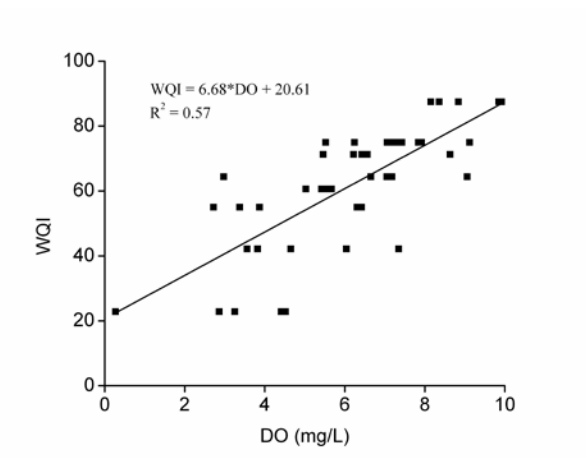

Fig. 4 Regression diagram between WQI and DO in the Dongjiang River

Based on the regression analysis, a high correlation existed between DO and WQI in the Dongjiang River (Fig. 4). Similar results were found by Kannel et al. and Sanchez et al. [7-8]. The relationship between WQI and DO in this study was summarized as: WQI ＝ 6.68*DO + 20.61 (R2 =0.57). As DO is a key environmental factor for aquatic lives, and is easily determined in the situ, it can be used to predict the WQI roughly. Kannel et al. applied their practical equation to predict the water quality indices for sixty eight samples from the Bagmati River, and 93% of total samples showed a good coincidence with the calculation of WQI [8]. Although there may be a high correlation between the overall water quality changes and a separate factor, it is still not easy to evaluate the overall change trend over spatio-temporal scale [1]. Hence, water quality index (WQI) is a useful way to display the variation of the overall assessment by integrating the effects of many environmental parameters.

IV. CONCLUSION

The water quality in the Dongjiang River evaluated by means of WQI showed a good general water quality in most of the surface water sampling sites along the watershed. The WQI scores in sites from Longchuan to Guzhu in the mainstream and the tributary Xinfengjiang were higher than 70 (classified to good); scores in sites from Huizhou to Shilong in the mainstream were range from 55 to 64.4 (classified to medium); the scores of the tributaries Xizhi River and Danshui River were classified as bad and very bad, respectively. These results indicated that serious pollution was embodied in these two tributaries. Water quality in the mainstream of the Dongjiang River showed a decreased trend, for example, there were 20% decrease of water quality at Shilong compared with the upstream sites Longchuan. The water quality deterioration may be attributed to increasing population, frequent anthropogenic activities, sewage discharges, and non-point pollution from agriculture along the Dongjiang River basin.

In conclusion, as a useful method for the classification of water quality based on scientific criteria, the water quality index (WQI) is effectively applicable for the assessment of spatial and temporal variations of global water quality in the Dongjiang River. And the results were easy to understand for the non-scientific public and decision-makers. Moreover, the evaluation of WQI is suitable for the water quality assessments for developing pollution control strategies in many developing countries with scarce budgets.

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REFERENCES

[1] S. F. Pesce and D. A. Wunderlin, Use of water quality indices to verify the impact of Cordoba City (Argentina) on Suquia River, *Water Res.*, vol. 34, pp. 2915-2926, 2000.

[2] E. Ongley, Modernization of water quality programs in developing countries: issues of relevancy and cost efficiency, *Water Quality International*, pp. 37-42, 1998.

[3] P. Debels, R. Figueroa, R. Urrutia, R. Barra and X. Niell, Evaluation of water quality in the Chillan River (Central Chile) using physicochemical parameters and a modified Water Quality Index, *Environ. Monit. Assess.*, vol. 110, pp. 301-322, 2005.

[4] W. Rauch, M. Henze, L. Koncsos, P. Reichert, P. Shanahan, L.

Somlyody and P. Vanrolleghem, River water quality modelling: I. State of the art, *Water Sci. Technol.*, vol. 38, pp. 237-244, 1998.

[5] P. Shanahan, M. Henze, L. Koncsos, W. Rauch, P. Reichert, L. Somlyody and P. Vanrolleghem, River water quality modelling: II. Problems of the art, *Water Sci. Technol.*, vol. 38, pp. 245-252, 1998.

[6] L. Somlyody, M. Henze, L. Koncsos, W. Rauch, P. Reichert, P. Shanahan and P. Vanrolleghem, River water quality modelling: III. Future of the art, *Water Sci. Technol.*, vol. 38, pp. 253-260, 1998.

[7] E. Sanchez, M. F. Colmenarejo, J. Vicente, A. Rubio, M. G. Garcia, L. Travieso and R. Borja, Use of the water quality index and dissolved oxygen deficit as simple indicators of watersheds pollution, *Ecol. Indic.*, vol. 7, pp. 315-328, 2007.

[8] P. R. Kannel, S. Lee, Y. S. Lee, S. R. Kanel and S. P. Khan, Application of water quality indices and dissolved oxygen as indicators for river water classification and urban impact assessment, *Environ. Monit. Assess.*, vol. 132, pp. 93-110, 2007.

[9] C. G. Cude, Oregon water quality index: A tool for evaluating water quality management effectiveness, *Journal of the American Water Resources Association*, vol. 37, pp. 125-137, 2001.

[10] S-M. Liou, S-L. Lo and S-H. Wang, A generalized water quality index for Taiwan, *Environ. Monit. Assess.*, vol. 96, pp. 35-52, 2004.

[11] T. Banerjee and R. K. Srivastava, Application of water quality index for assessment of surface water quality surrounding integrated industrial estate-Pantnagar, *Water Sci. Technol.*, vol. 60, pp. 2041-2053, 2009.

[12] M. K. Chaturvedi and J. K. Bassin, Assessing the water quality index of water treatment plant and bore wells, in Delhi, India, *Environ. Monit. Assess.*, vol. 163, pp. 449-453, 2010.

[13] P. Hills, L. Zhang and J. Liu, Transboundary pollution between Guangdong Province and Hong Kong: threats to water quality in the Pearl River Estuary and their implications for environmental policy and planning, *J Environ. Plann. Manage.*, vol. 41, pp. 375-396, 1998.

[14] K. C. Ho and K. C. Hui, Chemical contamination of the East River (Dongjiang) and its implication on sustainable development in the Pearl River Delta, *Environment International*, vol. 26, pp. 303-308, 2001.

[15] M. Shuhaimi-Othman, E. C. Lim and I. Mushrifah, Water quality changes in Chini Lake, Pahang, West Malaysia, *Environ. Monit. Assess.*, vol. 131, pp. 279-292, 2007.

[16] D. Bellos and T. Sawidis, Chemical pollution monitoring of the River Pinios (Thessalia-Greece), *J Environ Manage*, vol. 76, pp. 282-292, 2005.

[17] J. Chen, X. Gao, X. Xia and D. He, Nitrogen contamination in the Yangtze River system, China, *Environ. Chem.*, pp. 289-293, 1999.

[18] X. Xia, J. Zhou, Z. Yang and J. Chen, An analysis of nitrogen pollution in river water of the Yellow River basin, *Acta Sci. Circumst.*, vol. 21, pp. 563-568, 2001.

[19] G. Liu, B. Fu and P. Yang, Quality of aquatic environment at Haihe River and the pollutant fluxes flowing into sea, *Chin. J. Environ. Sci.*, pp. 46-50, 2001.

[20] J. Mao, J. Zhu and J. Xiao, The relationship between nitrogen contamination and dissolved oxygen in mainstream of the Huaihe River, *Enviromental Monitoring in China*, vol. 19, pp. 41-43, 2003.

[21] Y. Zhu and F. Wang, Water quality in Chaohu Lake watershed and the its envirnmental objects, *Admin. Tech. Environ. Monit.*, vol. 16, pp. 22-23, 26, 2004.

[22] J. H. W. Lee, Z. Y. Wang, W. Thoe and D. S. Cheng, Integrated physical and ecological management of the East River, *Sust. Safe Water Suppl.*, vol. 7, pp. 81-91, 2007.

[23] [24]. M. Vega, R. Pardo, E. Barrado and L. Deban, Assessment of seasonal and polluting effects on the quality of river water by exploratory data analysis, Water Res., vol. 32, pp. 3581-3592, 1