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Original Research

Water Quality Status along the Liangtan River and Control Planning Alternatives for Pollution Reduction

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Abstract

The aim of this research is to assess the water quality of the Liangtang River. Water samples were collected from seven sampling stations and four heavy metals (copper, lead, zinc, and chromium) were determined by spectroscopic technique. Physical and chemical parameters, including pH, DO, NH_4^+, TN, TP, and COD also were determined from seven water sampling stations sited along the river. It has been found that chemical oxygen demand (CODcr), ammonia nitrogen (NH_4^+-N), total nitrogen (TN), and total phosphorus (TP) in upstream sites were lower than those of the downstream sites, indicating pollutants being discharged along its course. Analyses also have shown that CODcr, NH_4^+-N, TN, and TP have a very significant positive correlation between each other, while NH_4^+-N, TN, and TP have a negative correlation with DO. The major sources of pollution in Liangtan River are urban wastewaters, wastewaters from industries, and other anthropogenic activities along the river. We proposed the strategies that can be applied for pollution reduction.

Keywords: water quality, Liangtan River, nutrients, pollution, heavy metals

Introduction

Industrial processing is considered to be the main anthropogenic source of heavy metals and organic pollutants. Agriculture may be the main cause of pollution by the generation of chemical wastes from fertilized land. Effluents from domestic activities are a major cause of pollution of river waters due to large volumes of untreated sewage in some cities [1]. It also has been found that anthropogenic activies are the main source of pollution in rivers [2, 3]. Usually in unaffected environments, the concentration of most of the metals in rivers is low and mostly derived from weathering of rock and soil [4]. Recent years have marked a period of incredible development of urbanization and industrialization. However, these advancements have brought enormous negative impacts on the environment. One such region that has been impacted is the Liangtan River. Being used by humans for so long has changed this noble river in many ways. Due to the effects of poultry raising, agricultural activities, industrial pollution, and urban waste, the water quality of Liangtan River is poor. Today, some segments of the Liangtan River are heavily polluted by human activities and are listed as requiring a comprehensive improvement of the aquatic environment in Chongqing [5]. It is seriously affecting the quality of drinking water and irrigation in the coastal regions. Moreover, the Liangtan is an important tributary of the Jialing River, which is the main source of drinking water of Chongqing city. The main anthropogenic sources of contaminants are from the disposal of untreated and partially

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treated effluents containing toxic pollutants from different industries and indiscriminate use of fertilizer and pesticides in agricultural fields [4, 6-8]. The deterioration of water quality in Liangtan River has a drastic effect on water quality of the Jialing River, and threatens the safety of drinking water in Chongqing City. The Jialing River is the second largest tributary of the Yangtze River and is located in the heart of the Three Gorges Reservoir area. Water quality of the Liangtan also has a great influence on the Three Gorges Reservoir. The large quantities of domestic and industrial wastewater discharged into the river lead to the deterioration of river ecosystems. Similar to other rivers around the world, the Liangtan is extensively used as a disposal of waste discharge by industrial, agricultural, and domestic activities.

The objective of this study is to assess the current pollution status of the Liangtan in order to set up some control planning alternatives to improve the water quality of the river.

Materials and Methods

Description of the Study Area

The Liangtan (length 89 km, catchment area 498 km^2, annual average flow 6.6 m^3/s, maximum flow rate 168.01 m^3/s, minimum flow rate 0.81 m^3/s, annual average water level 194.99, total water head 224 m, and average longitudinal slope 2.60‰) is located in the western part of Chongqing Municipality bordering Sichuan Province. The river flows from Jiulongpo district in the south to Beibei town in the north, where it joins the Jialing River, which is a major tributary of the Yangtze. It contains two main tributaries (Fig. 1): The east tributary originates from Liaojiagou Reservoir and flows through industrial and populated areas, while the west tributary is relatively far from populated areas. It is the only passageway to receive industrial sewage. The preliminary investigation showed that the water is discolored and smelly, which may be caused by fertilizers or industrial waste. We have chosen the east branch as our sampling site to assess the influence of industries on the Liangtan. Eventually, it begins to affect people living in that area. The population density in the catchment was approximately 400 inhabitants per square kilometer in 2010 [9].

Collection and Treatment of the Samples

Water samples were collected monthly from seven different locations in the Liangtan River from March to December 2010. The sampling locations are Liaojiagou (LJG), Baishiyi (BSY), Tianciwenquan (TCWQ), Hangu (HG), Tongshangqiao (TSQ), Tuzhu1 (TZ1), and Tuzhu2 (TZ2). The distance (km) between sampling locations can be clearly seen in Figs. 2-4. The samples were taken at 0.5 m below the surface water level midstream and collected in acid-washed 1 L polyethylene bottles. The field measurements also were taken at the locations, including water temperature, pH, and DO. Measurements of temperature and DO were conducted using a portable dissolved oxygen meter "LDOTMHQ10" (Hach Company Ltd., USA). The measurement of pH was conducted using "SENSION 1" pH/mV Meter (Hach Company Ltd., USA). CODcr was tested by DRB2800 COD Analyzer (Hach Company Ltd., USA). TN, NH_4^+-N, and TP were analyzed by QuikChem8500 Automated Flow Injection Analyzer (Lachat Instuments, Ltd., USA) after the water samples were filtered. Heavy metals were tested using inductive co plasma atomic absorption mass spectrometry (ICP-AAS) (Hitachi Ltd., Japan). The experiment data were presented with mean of three tests.

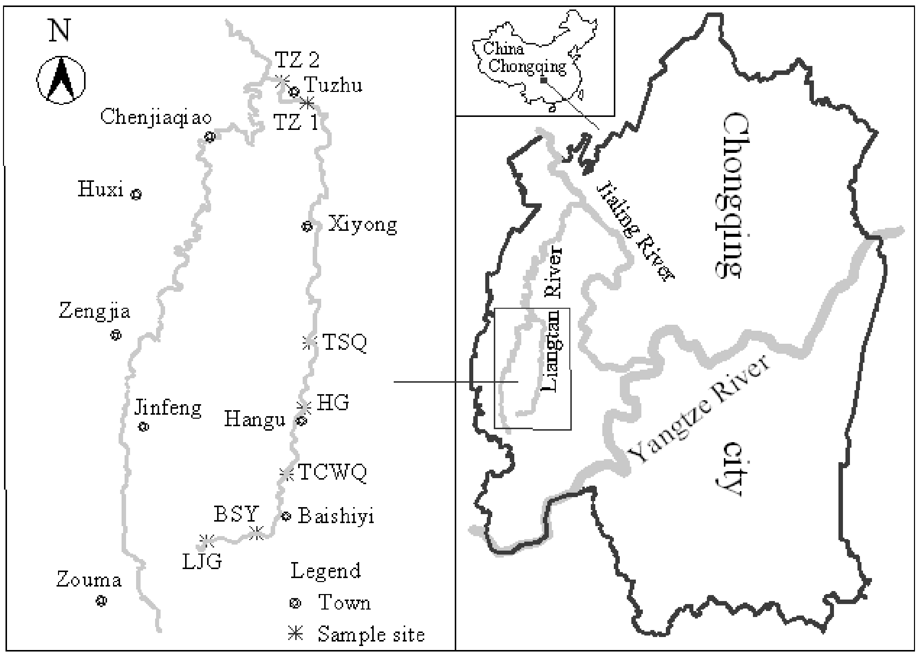

Fig. 1. Map showing the sampling stations.

Results and Discussion

Comprehensive Water Quality Characteristics

pH

The pH of surface waters is vital to aquatic life. It affects the ability of aquatic organisms to regulate basic life-sustaining processes, primarily the exchanges of respiratory gasses and salts with the water in which they live. Failure to adequately regulate these processes can result in numerous sub-lethal effects (e.g., diminished growth rates) and even mortality in cases when ambient pH exceeds the range physiologically tolerated by aquatic organisms.

It has been found that the upstream Liangtan was characterized by acidic pH in spring (March to May), and weak alkaline during another study period. pH of natural waters is governed by the carbonate-bicarbonate-carbon dioxide equilibrium. Slightly alkaline pH is preferable in waters as heavy metals are removed by carbonate or bicarbonate precipitates [10]. Compared with other sampling points, pH at Liaojiagou is slightly high with an average value of 8.5, and this might be due to clean water from upriver sites with low organic matter. While in the downstream the water is heavily polluted, the decomposition of organic matters can lead to acidification and low pH values [11, 12].

Dissolved Oxygen

The content of dissolved oxygen in Liangtan River during the study period shows distinct spatial and seasonal variations. Its value was higher in summer than in winter. Fig. 2 shows that the highest DO was found in Liaojiagou reservoir and at Baishiyi, while the lowest DO value was found at Tianciwenquan sampling station and the lowest value was less than 0.5 mg/l in summer. The low DO in summer was possibly due to high water temperature and considerable activities of microorganisms, which consumed a considerable amount of oxygen as a result of metabolizing activities and decay of organic matters. The DO content depends on physical, chemical, biological, and microbiological characteristics [13-16].

Chemical Oxygen Demand (CODcr)

CODcr is another important water quality index used to assess the amount of organic pollutants in water. It is a measure of the oxygen requirement of the organic matter susceptible to oxidation by a strong chemical oxidant. COD is used to define the organic strength of industrial wastes and polluted waters [17].

Throughout the study period, CODcr attained its highest in Hangu sampling station with the concentrations of 538±38.6 mg/L. The lowest concentration of CODcr was

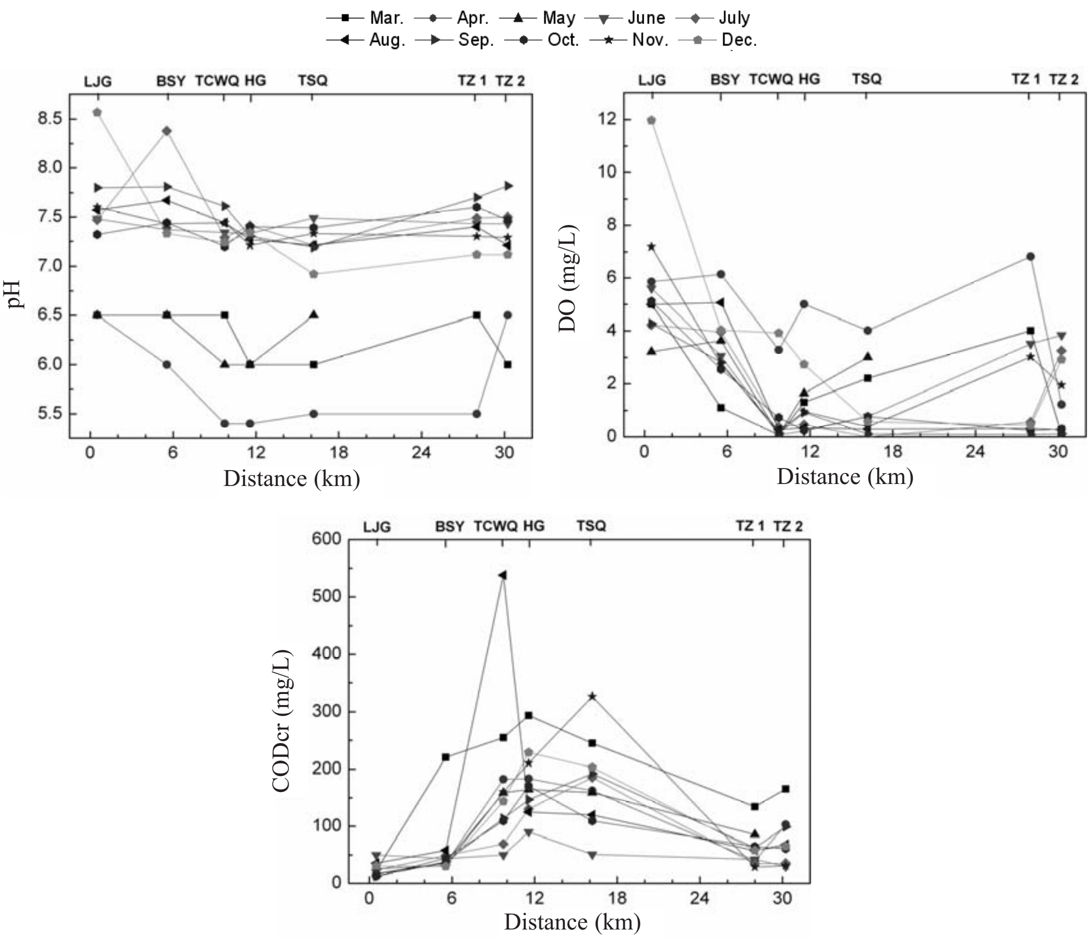

Fig. 2. Variation of comprehensive water quality characteristics (pH, DO, CODcr) in Liangtan River (2010).

found in Liaojiagou station with its value of 37±4.43 mg/L. The extremely high CODcr in August might have been caused by a large amount of wastewater drained in the river during this period. The highest CODcr in downstream shows that there are organic pollution sources being discharged along the river. It has also been found that every year a large amount of wastewater from local restaurants is discharged in Tianciwenquan.

Nutrients

Eutrophication is one of the greatest ecological problems of surface waters. TN, NH_4^+-N, NO_3-N, and TP are the main nutrients in water bodies. The high nutrients in water promote excessive growth of algae and produce much microcystin in water bodies. The study results in the Liangtan River showed enrichment of river water with nutrients (Fig. 3).

The mean concentrations of TP ranged from 0.01±0.002 to 7.98±0.75 mg/L, TN ranged from 0.33±0.047 to 112.38±14.56 mg/L, and NH_4^+-N from 0.08±0.013 to 69.75±9.04 mg/L. On the basis of chemical analyses of the parameters of the oxygen regime and nutrients, Liangtan river could be classified as a grade V water quality class according to Chinese environmental Water Quality standards [18] (Table 3). Characteristics of this class are strongly eutrophic, with polluted waters that receive discharges of organic matter, nutrients, as well as harmful substances [19]. The lowest TN and TP values were observed in Liaojiagou site in June, with average concentrations of 0.33 mg/L and 0.01 mg/L, respectively. As shown in Fig. 3, TN and TP values increased rapidly along the river from upstream to downstream. Their highest concentrations were found in March at the Baishiyi site. The variation trend of NH_4^+-N is similar to that of TN, which indicates that they might have the same pollution source. The sources of these are mainly from agriculture and industrial sewage. There is a large tract of farmland in this area upstream near BaiShiyi town with many flower plantations that use a large amount of fertilizer, which is believed to be the source of pollution in an aquatic environment. Another source of nutrients in Liangtan River is surface runoff. In spring, which is farming season, a lot of nitrogenous and phosphate fertilizers are used for agricultural purposes. This might be the main reason for the detection of high nutrient concentrations in March. It has been found that the increase of agricultural activity and urban development are linked to the increase in levels of total phosphorus as well as the total nitrogen in rivers [4, 6-8].

Assessment of Heavy Metals

The variations of heavy metal concentrations with sampling point are shown in Fig. 4. The concentrations of heavy metals: copper (Cu), zinc (Zn), lead (Pb), and chromium (Cr) were detected and analyzed in the first three months of the study period. Some elements are important

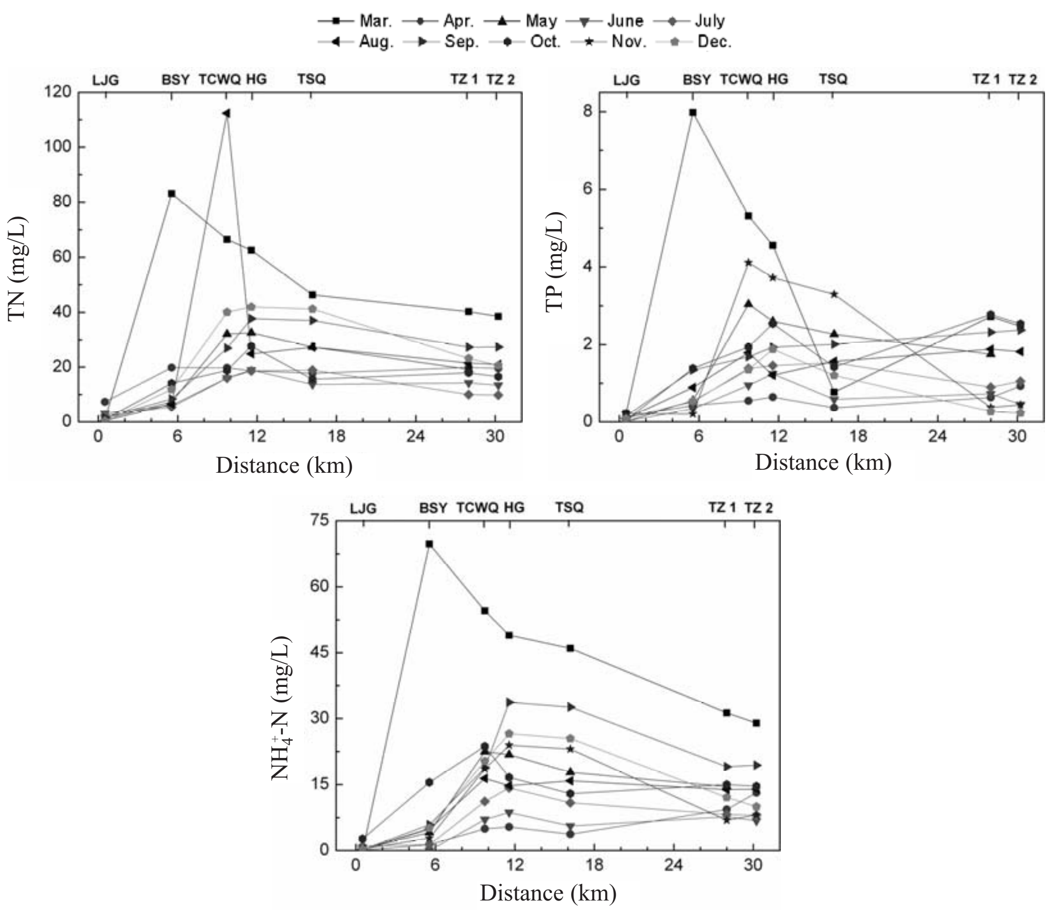

Fig. 3. Variation of nutrients (TN, TP, NH_4^+-N) in Liangtan River (2010).

and necessary for living organisms (e.g. Pb and Cu), but in high concentrations they are toxic to aquatic organisms and human health [20, 21]. Their origin can be found in industrial sewage discharged into the river without any treatment and the domestic activities of the houses located in the same vicinity with the river, which are believed to be the main source of heavy metals. The highest Cu, Pb, and Zn were found at HG in March with the average concentrations of 0.06, 0.13, and 1.07 mg/L, respectively, reflecting the degree of anthropogenic pollution at this site. Cr was the highest in April at TCWQ with 0.08 mg/L. The same results of pollution sources in the Liangtan were found by Liu in his study of PAHs [22].

Statistical Analysis and Pollution Assessment

Table 1 shows the Correlation between water characteristics where pH has a significant negative correlation with COD, TN, and NH_4^+-N, which is consistent with the conclusions from the previous work of [10]. Analyses also have shown that CODcr, NH_4^+-N, TN, and TP have a very significant positive correlation between each other. When the content of organic matter and nutrient is high, microorganisms consume a considerable amount of oxygen, resulting in low value of dissolved oxygen. Consequently, NH_4^+-N, TN, and TP had a very significant negative correlation with DO.

Cu, Pb, and Zn have very significant positive correlations between each other, but they have no significant correlation with Cr, therefore, it can be concluded that Cu, Pb, and Zn have the same pollution sources in Liangtan river, but different from that of Cr. Zn and CODcr also have a very significant positive correlation while there is no obvious correlation between CODcr and Cu or Pb. This shows that Zn is more likely to come from organic matter.

Table 2 shows the statistical values of the monitored parameters as well as the Chinese environmental quality standards for surface water. The results revealed that DO value corresponds to Class V, CODcr, TN, TP, and NH_4^+-N are worse than Class V, indicating that Liangtan river was heavily polluted by organic matters and nutrients. The mean value of Cu and Cr were found to be in Grade I, and Zn and Pb in grade II – indicating that the Liangtan was not heavily polluted by heavy metals.

Control Planning Alternatives for the Liangtan River

The largest improvement in the Liangtan in water quality can be achieved by the proposed strategies shown in Table 3. Nutrient concentrations (NH_4^+-N) are most sensitive to reduction of rural and urban domestic wastewater

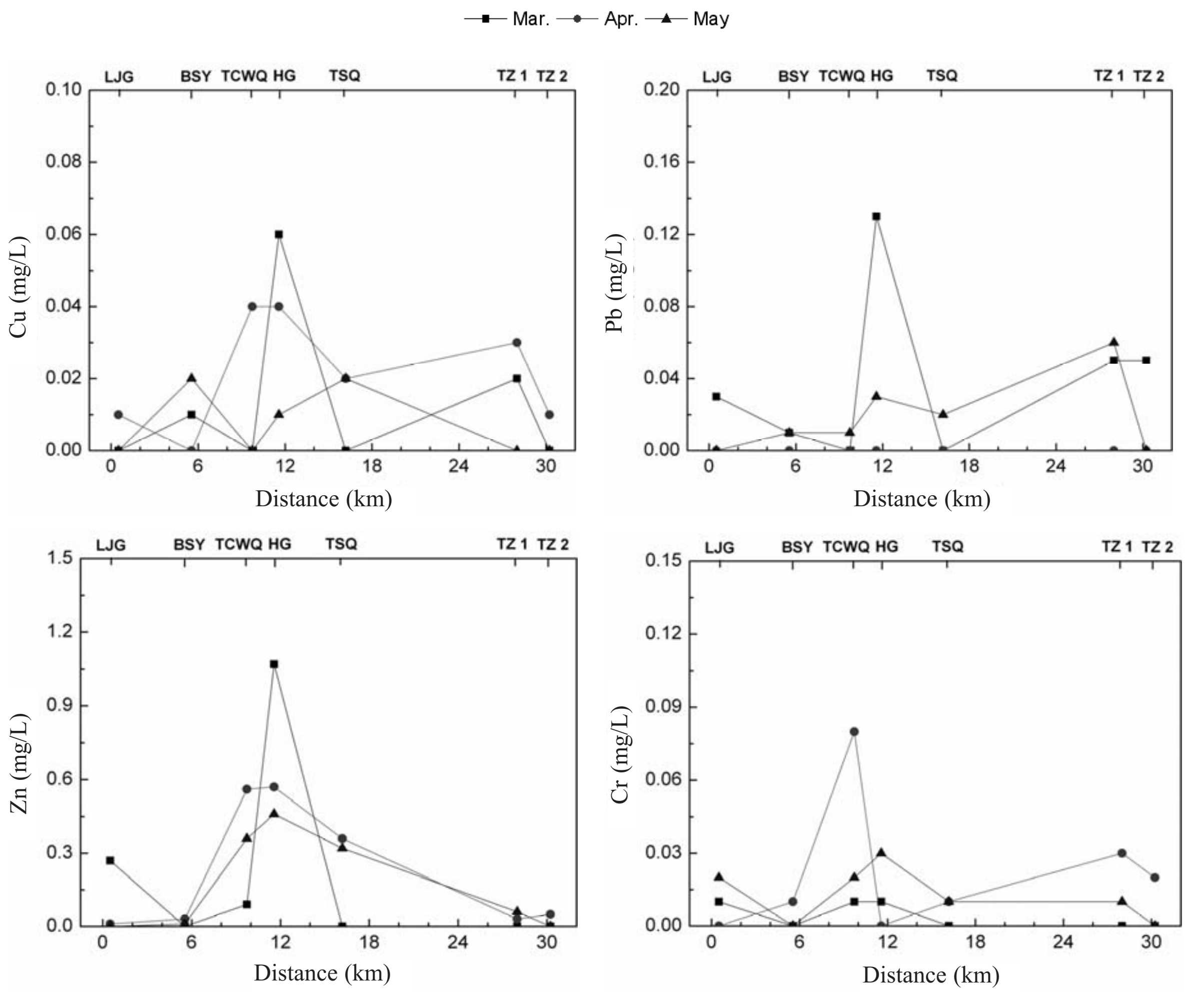

Fig. 4. Variation of heavy metals (Cu, Pb, Zn, Cr) in Liangtan River (2010).

Table 1. Correlation coefficients between water characteristics in Liangtan River (n=68, heavy metal, n=21).

	pH	DO	CODcr	NH_4^+-N	TN	TP	Cu	Pb	Zn	Cr
pH	1	0.128	-0.291*	-0.270*	-0.259*	-0.141	-0.559	-0.430	-0.414	-0.556
DO		1	-0.345**	-0.420**	-0.387**	-0.433**	0.054	-0.126	-0.330	0.053
CODcr			1	0.622**	0.896**	0.564**	0.526	0.510	0.741**	0.077
NH_4^+-N				1	0.775**	0.841**	0.069	0.255	0.399	-0.299
TN					1	0.703**	0.144	0.280	0.457	-0.153
TP						1	-0.008	0.106	0.386	-0.253
Cu							1	0.931**	0.789**	0.164
Pb								1	0.771*	-0.379
Zn									1	0.200
Cr										1

*means significant at p=0.01; **means significant at p=0.05.

Table 2. Statistical values of the monitored parameters and Chinese environmental quality classification.

Unit (mg/L)	Statistical values				Values of Chinese environmental quality standards for surface water				
	Mean	SD	Max	Min	Class I	Class II	Class III	Class IV	Class V
pH	7.07	0.68	8.57	5.40	6~9	6~9	6~9	6~9	6~9
DO	2.40	2.34	11.97	0.07	7.5	6	5	3	2
CODcr	106.9	92.2	538	12	15	15	20	30	40
TN	22.86	19.99	112.38	0.33	0.2	0.5	1.0	1.5	2.0
TP	1.46	1.41	7.98	0.01	0.02	0.1	0.2	0.3	0.4
NH_4^+-N	14.9	13.58	69.75	0.08	0.15	0.5	1.0	1.5	2.0
Cu	0.014	0.017	0.06	0	0.01	1.0	1.0	1.0	1.0
Pb	0.019	0.032	0.13	0	0.01	0.01	0.05	0.05	0.1
Zn	0.202	0.282	1.07	0	0.05	1.0	1.0	2.0	2.0
Cr	0.013	0.018	0.08	0	0.01	0.05	0.05	0.05	0.1

loads while CODcr and heavy metals are most sensitive to reduction of industrial pollution loads. The principle to reduce pollution and make beneficial use of solid waste include composting of organic fractions for reuse as fertilizers, incineration plants for municipal solid waste, incineration plants for co-incineration of municipal solid waste and agricultural residues such as animal waste, and crop residues.

Conclusion

The Liangtan is strongly polluted by different pollution sources which include urban and industrial wastewaters as well as anthropogenic activities. Most urban settlements and industries discharge their wastewaters in the river without treatment. The results of the preliminary investigation of the Liangtan River catchment and the largest industrial enterprises combined with the results of experimental analysis revealed that the quality of Liangtan water corresponds to the Class V surface water quality standard. TN and TP values increased rapidly along the river from upstream to downstream, reflecting the pollutants being discharged along its course. The variation trend of NH_4^+-N is similar to that of TN, which indicates that they have the same pollution sources. The study also found that Cu, Pb, and Zn have the same pollution sources in the Liangtan. The largest improvement can be achieved by enhancing municipal wastewater treatment to meet high water discharge standards.

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Table 3. Pollution reduction alternatives.

Source of pollution	Reduction strategies
Urban Domestic Pollution	Reduction in the urban pollution loads by treatment of urban wastewater.
	Expansion of sewer systems to cover all urban areas.
	Upgrading of existing wastewater treatment plants with sludge treatment and converting sludge to fertilizer.
Urban Domestic Pollution Enhanced nutrient removal	Potential reduction in the urban pollution loads and treatment of urban wastewater with nutrient removal to achieve wastewater discharge standards.
	Local officials should provide comprehensive technical assistance on waste reduction opportunities.
Domestic Solid Waste	Potential reduction by 100% collection and controlled disposal of solid waste.
Rural domestic wastewater	Potential reduction of diffuse rural domestic pollution load by decentralizing wastewater treatments.
	Composting of organic waste can be an effective waste reduction measure to prevent organic materials from entering the waste streams.
Industrial Pollution	Potential reduction by all industrial enterprises meeting wastewater discharge criteria.
	Construction of trunk sewers to intercept water from scattered outlets in urban areas for centralized discharge.
Municipal solid waste	Construct incineration plants for waste-to-energy production by the incineration of municipal solid waste.

References

1. HOAGLAND P., ANDERSON D. M., KAORU Y., WHITE A. W. The economic effects of harmful algal blooms in the United States: estimates, assessment issues, and information needs. Estuar. Coast. **25**, (4), 819, **2002**.
2. ADAIKPOH E. O., NWAJEI G. E., OGALA J. E. Heavy metals concentrations in coal and sediments from River Ekulu in Enugu, Coal City of Nigeria. J. Appl. Sci. Environ. Manag. **9**, (3), 5, **2005**.
3. AKOTO O., BRUCE T. N., DARKO G. Heavy metals pollution profiles in streams serving the Owabi reservoir. Afr. J. Environ. Sci. Technol. **2**, (11), 354, **2008**.
4. REZA R., SINGH G. Heavy metal contamination and its indexing approach for river water. Int. J. Environ. Sci. Technol. **7**, (4), 785, **2010**.
5. CHONGQING ENVIRONMENTAL PROTECTION AGENCY (CQ EPA). Water Quality Monitoring (October 2011) of 14 Rivers in the Main city of Chongqing. Chongqing: EPA. **2011** [In Chinese].
6. MACKLIN M. G., BREWER P. A., HUDSON-EDWARDS K. A., BIRD G., COULTHARD T. J., DENNIS I. A., LECHLER P. J., MILLER J. R., TURNER J. N. A geomorphological approach to the management of rivers contaminated by metal mining. Geomorphology. **79**, (3-4), 423, **2006**.
7. MARTIN C. W. Heavy metal trends in floodplain sediments and valley fill, River Lahn, Germany. Catena. **39**, (1), 53, **2000**.
8. NOURI J., MAHVI A. H., JAHED G. R., BABAEI A. A. Regional distribution pattern of groundwater heavy metals resulting from agricultural activities. Environ. Geol. **55**, (6), 1337, **2008**.
9. STATISTICS C. M. B. Chongqing Statistical Year book 2011. China Statistics Press: Beijing, **2011**.
10. AHIPATHY M. V., PUTTAIAH E. T. Ecological characteristics of Vrishabhavathy River in Bangalore (India). Environ. Geol. **49**, (8), 1217, **2006**.
11. CHETANA S. A., SOMASEKHAR R. K. Ecological study onthe riverine ecosystem of Karnataka. I. Physico-chemical characteristics of River Cauvery. J. Environ. Pollut. **4**, (1), 57, **1997**.
12. CHETANA S. A., SOMASEKHAR R. K. Ecological study onthe riverine ecosystem of Karnataka. III. Physico-chemical characterisation of River Vrishabhavathi. J. Environ. Pollut. **4**, (1), 71, **1997**.
13. CONLEY D. J., PAERL H. W., HOWARTH R. W., BOESCH D. F., SEITZINGER S. P., HAVENS K. E., LANCELOT C., LIKENS G. E. Controlling eutrophication: nitrogen and phosphorus. Science. **323**, 1014, **2009**.
14. DUAN S.W., XU F., WANG L. J. Long-term changes in nutrient concentrations of the Changjiang River and principal tributaries. Biogeochemistry. **85**, (2), 215, **2007**.
15. TURNER R. E., RABALAIS N. N., JUSTIC D., DORTCH Q. Global patterns of dissolved N, P and Si in large rivers. Biogeochemistry. **64**, (3), 297, **2003**.
16. VOUTSA D., MANOLI E., SAMARA C., SOFONIOU M., STRATIS I. A study of surface water quality in Macedonia, Greece: speciation of nitrogen and phosphorus. Water, Air, Soil Pollut. **129**, (1-4), 13, **2001**.
17. WANG Z., HUANG K., YU Y. J., GUO H. C., LIU Y. Sediment chemistry and the variation of three altiplano lakes to recent anthropogenic impacts in south-western China. Water SA. **33**, (2), 305, **2007**.
18. GB 3838-2002. Environmental quality standards for surface water. Beijing: The State Environmental Protection Administration of China. **2002** [In Chinese].
19. SUNDARAY S. K., NAYAK B. B., LIN S., BHATAA D. Geochemical speciation and risk assessment of heavy metals in the river estuarine sediments – a case study: Mahanadi basin, India. J. Hazard. Mater. **186**, (2-3), 1837, **2011**.
20. ALEMAYEHU T. The impact of uncontrolled waste disposal on surface water quality in Addis Ababa, Ethiopia. SINET: Ethiop. J Sci. **24**, (1), 93, **2001**.
21. MELAKU S., WONDIMU T., DAMS R., MOENS L. Simultaneous determination of trace elements in Tinishu Akaki River water sample, Ethiopia, by ICP-MS. Can. J. Anal. Sci. Spectros. **49**, (6), 374, **2004**.
22. LIU Y., YU N., LI Z., WEI Y., MA L, ZHAO J. Sedimentary record of PAHs in the Liangtan River and its relation to socioeconomic development of Chongqing, Southwest China. Chemosphere. **89**, (7), 893, **2012**.