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ASSESSING IMPACT OF URBANIZATION ON RIVER WATER QUALITY IN THE PEARL RIVER DELTA ECONOMIC ZONE, CHINA

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Abstract. The Pearl River Delta Economic Zone is one of the most developed regions in China. It has been undergoing a rapid urbanization since the reformation and opening of China in 1978. This process plays a significant impact on the urban environment, particularly river water quality. The main goal of this present study is to assess the impact of urban activities especially urbanization on river water quality for the study area. Some Landsat TM images from 2000 were used to map the areas for different pollution levels of urban river sections for the study area. In addition, an improved equalized synthetic pollution index method was utilized to assess the field analytical results. The results indicate that there is a positive correlation between the rapidity of urbanization and the pollution levels of urban river water. Compared to the rural river water, urban river water was polluted more seriously. During the urban development process, urbanization and urban activities had a significant negative impact on the river water quality.

Keywords: river water quality, urbanization, impact assessment, the pearl river delta economic zone, China

1. Introduction

The study area, the Pearl River Delta Economic Zone (PRDEZ), a typical urban group, located in Southern China, is one of the most developed regions in China. According to the regionalism of Guangdong province, it includes nine administrative cities. All the cities develop close to the Pearl River system (Figure 1). As a foreland of the reformation and opening in China, the PRDEZ has been experiencing a rapid urbanization and industrialization at an unprecedented rate since 1978. The urbanization level of the PRDEZ increased from 29.6% in 1982 to 71.4% in 2000 (Population census office of Guangdong Province, 1984, 2002). As a result, urban population increased and urban land cover expanded quickly. For example, according to the fifth population census in China, there were nearly 40 million people living within the PRDEZ as of November 1st, 2000 (Population census office of Guangdong Province, 2002). Concurrently, investment into environmental management was relatively slower. Therefore, it is inevitable that urbanization has significant impact on environment, and the urban environment appeared as a poor situation. For the city or urban group close to water, the quality of the water

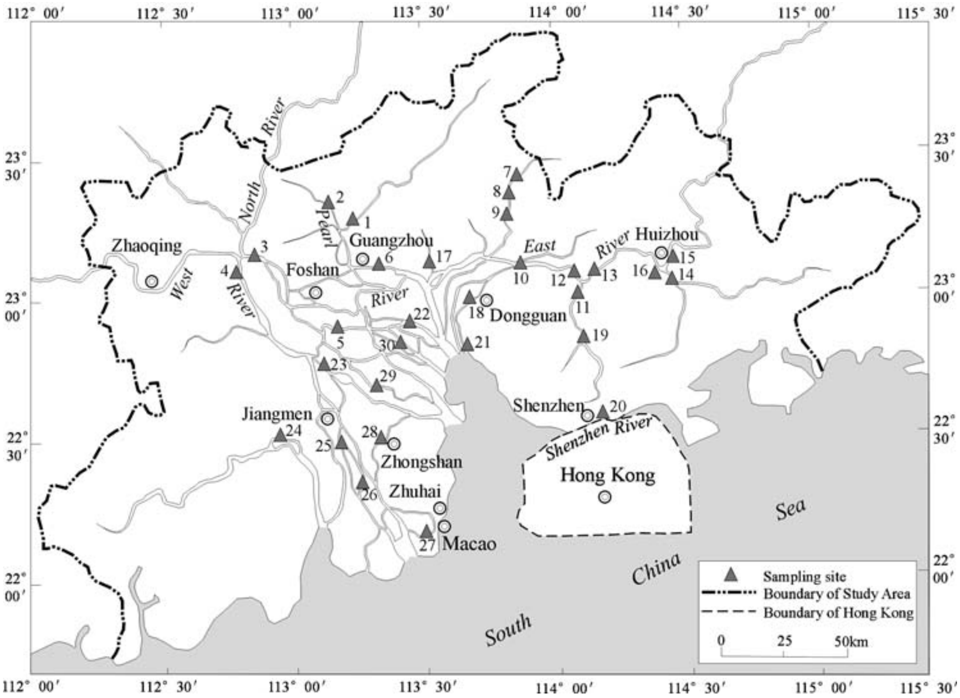

Figure 1. Study area and sampling sites.

bodies is one of the most important parts of environment, and it influences the urban environment directly.

Many geographers have been interested in the urbanization of China in recent years (Simon, 1995; Chen, 2000; Wang, 2000; Chen *et al.*, 2002). Within most of these studies, the contents primarily focused on the dynamics of urbanization, the change of life style brought by urbanization and also the way adapt to this change. Urban development in terms of population and spatial growth were also important research fields (Ning, 1998; Wang *et al.*, 2002; Xu, 2002). With the continuation of the urbanization process, environmental problems became more and more evident day after day. Indeed, the urban environment has been a focus of the environmental scientists for a relatively long time (Martin, 2000; Cao *et al.*, 2001; Zhao, 2002). As part of the implementation of the global strategy for sustainable development, environmental impact of urbanization has become another research emphasis. In addition, some environmental impact of urbanization has been described qualitatively (Euisoon, 1997; Ma *et al.*, 1999). Numerous research regarding to river water quality were performed. These research were relative to contamination level, pollution sources, kinds of pollutants, and the interaction among different pollutants (Olajire, 2001; Laureano, 2002; Zhu *et al.*, 2002). Unfortunately, few researchers paid enough attention specifically to the impact of urbanization on river water quality, particularly in the study area (Zhang, 1998; Silvia *et al.*, 2000; Ha, 2001; Wang, 2001). The main goal of our present research is to assess the impact of urban activities on river water quality for the PRDEZ.

In this present study, some Landsat TM images from 2000 were used to map the areas for different pollution levels of urban river sections in the study area. The pollution index method is the most common for assessing water quality on the basis of field monitoring analytical results (Kong, 1995; Jiang *et al.*, 1999; Fan, 1999). Meanwhile, the result is significantly influenced by the value of weight coefficients contributed subjectively by the researchers. In order to eliminate this subjectivity, and thereby to improve the dependence of the pollution index, an improved equalized synthetic pollution index method was utilized in this study.

2. Materials and Methods

Besides field monitoring, the technology of remote sensing has been applied in monitoring water quality successfully in recent years (Paul, 1993; Sampsa, 2002). The areas of different pollution river water were mapped using Landsat TM images from 2000 for river sections within urban zones in this study. During the mapping process, the river water quality reported by the Bureau of Environmental Protection, Guangdong Province (2001) was used as a reference. In addition, the river water, relating to the mapping results, was classified into four groups named: relatively clean, lightly polluted, moderately polluted and seriously polluted. Comparing to the surface water quality standards, the relatively clean water corresponds to class I and class II, the lightly polluted and moderate polluted water are similar to class III and class IV, respectively. The seriously polluted group corresponds to and worse than class V.

In order to prove the mapping results and compare the river water quality between rural area and urban built-up zone, thirty field water samples were collected from different river sections within the PRDEZ during the low water level period of the hydrological year 2002. The situation of urban river water quality from satellite data was considered when the sampling sites were selected. For the purpose of comparison between rural and urban areas and as representative sampling for urban river sections of the nine cities, two or three samples located within urban or rural zone were enough for the same river. Therefore, thirty samples are enough for the purpose in this study, and the sampling sites were illustrated in Figure 1. On the basis of the environmental report provided by the Bureau of Environmental Protection, Guangdong Province (2002), ten main physicochemical parameters, pH, nitrate ($N\text{-}NO_3^-$), nitrite ($N\text{-}NO_2^-$), ammonium ($N\text{-}NH_4^+$), dissolved oxygen (DO), permanganate value (COD_{Mn}), total organic carbon (TOC), total phosphorus (TP), turbidity, and chroma were analyzed for each water sample. All analytical methods were from Analytical Techniques for the Examination of Water and Wastewaters (Bureau of National Environmental Protection, 1989).

The method of pollution index adopts mathematical models to integrate the impact of various pollutants on the environment. In recent years, water quality assessment has been processing on the basis of the water quality standard for surface water. Many assessing methods have been developed, however, the synthetic pollution index method is one of the most widely used methods. The basic calculation is described by the following equation.

$$I = \sum_{i=1}^{n} \frac{C_i}{S_i} \cdot W_i$$

Where, l stands for synthetic pollution index; C_i is the analytical concentration of the ith parameter; S_i is the standard concentration for the ith parameter; W_i is the weight coefficient.

Contributing a reasonable weight coefficient for every pollutant is the key process when using the above formula. The results would be very different depending on the method used to provide the weight coefficients (Li, 1997). In contrast, the equalized synthetic pollution index method considers different traditional methods. Xiao (1996) used it to assess the groundwater quality and acquired encouraging results. Furthermore, the procedure of this method is relatively simple. The equalized synthetic pollution index method was used in this research to assess the river water quality for the PRDEZ. According to the equalized synthetic pollution index, the assessing standard for water pollution used by Xiao (1996) is listed in Table I.

3. Results and Discussion

Based on the population data from the population census (Population census office, Guangdong Province, 1984, 1992, 2002), the change of urbanization level (urban population percentage) for each city and the whole PRDEZ is illustrated in Figure 2. According to the administrative boundaries of the PRDEZ, the river sections across two or more administrative zone are regarded as boundary-rivers. The urban river water body areas of different pollution levels, as well as the total urban river

TABLE I
Water pollution criterion for equalized synthetic pollution index (Xiao, 1996)

Equalized synthetic pollution index	Water pollution degree	Type of water quality
<0.2	Relatively clean	I
0.2–0.5	Lightly polluted	II
0.5–1.0	Moderately polluted	III
1.0–3.0	Seriously polluted	IV
>3.0	Extremely polluted	V

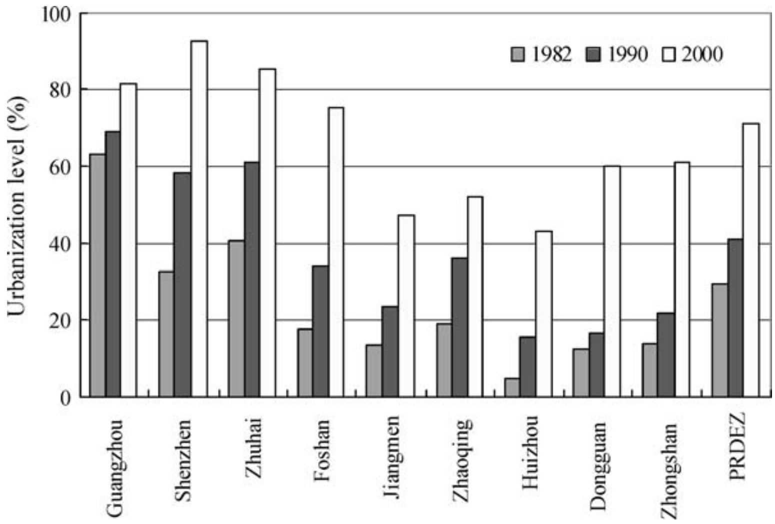

Figure 2. Urbanization level of every city and the whole PRDEZ.

water areas, were summed for each city, the boundary-rivers, as well as the whole study area based on the mapping results of Landsat TM images. Meanwhile, the percentages of different polluted water bodies, the ratio of different polluted water area to total water body area were also calculated and shown in Figure 3 for every city and the whole PRDEZ as well as boundary-rivers.

During the last two decades, especially the 1990s, large numbers of people swarmed into the cities of the PRDEZ for some economic reasons. As a result,

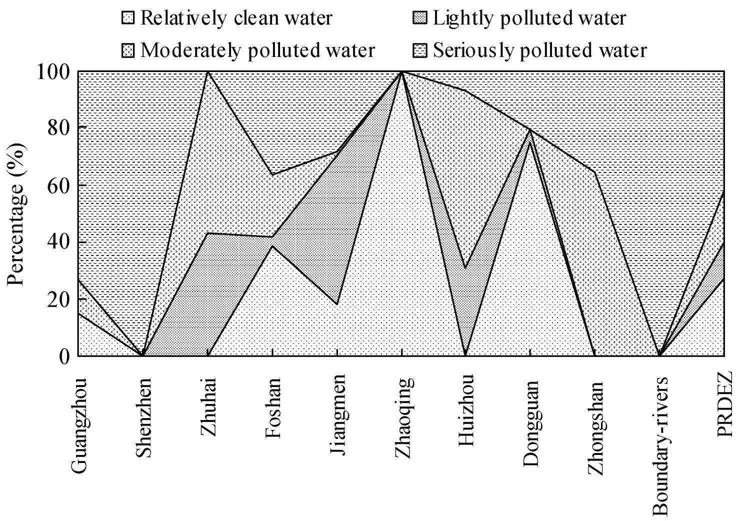

Figure 3. Percentage of river water area for different classes of urban river section.

urbanization of PRDEZ reached its advanced process according to this population urbanization level. The urban population percentage has been increasing to more than 70% by 2000 (Figure 1). As to the result of different polluted water body illustrated in Figure 3, nearly half of the urban river water bodies were seriously polluted in the whole study area. According to the definition of the water quality standard for surface water (better than class III), less than 40 percent of the river water within the urban zones can be used as drinking water sources. This led to some water crises in the PRDEZ even though it has a relatively abundant water resource. This river water quality situation may be due to the rapid population urbanization. Hundred percent of the mapped river water areas was classified as seriously polluted water for Shenzhen city (Figure 3). Shenzhen is a newly founded city since the economic reformation and opening policy in 1978, and has developed at an unprecedented rate in the industry and tertiary sector. As a result of this rapid development, Shenzhen urbanized fastest from 1982 to 2000 and held the highest urbanization level in 2000 of the whole PRDEZ (Figure 2). Concurrently, urban municipal waste discharge increased, land use land cover changed. All these changes contribute to the serious urban river water pollution. In Guangzhou, although the process of urbanization was not so impetuous as in Shenzhen, the total population was greater than the rest of PRDEZ because of its long history and its political position of being the capital of Guangdong province. Both urbanization level and urban population density are very high in Guangzhou city. Furthermore, many polluting industries such as power plants, electronic factories, clothing manufacturing etc. are located within or around the urban zone. The large waste discharge surpassed the self-purification of the river. For example, more than 246 million tons of wastewater was discharged from industry in Guangzhou in 2000 (Bureau of environmental protection, Guangdong Province, 2001). Therefore, even though there was a plentiful total runoff (including local and transit water), serious river water pollution was inevitable in Guangzhou. In the other cities, especially Zhuhai, the urbanization levels were very high, as well. Though the river water quality management was not better than Guangzhou and Shenzhen, the urban population densities of these cities are relatively low. Furthermore, each of the urban river sections within these cities has very abundant runoff. Therefore, the situation of river water quality was much better than that of Shenzhen and Guangzhou.

As for the boundary-rivers, which are located between two or more political zones, hundred percent of these river water bodies suffered serious pollution. For administrative reasons, many industries were located at the interface of different administrative regions. As a result, lots of labors assembled into these regions, and therefore the population density was very high. In addition, most of these factories belong to relatively high pollution industries. No matter how large the runoff and the wastewater discharge, almost no local government has paid enough attention to the water quality of these boundary-rivers for a relatively long time. Therefore, the large waste discharge along with deficient management and wastewater treatment has been deteriorating water quality of these river sections. As a conclusion, it can be said that the more rapidly the urbanization process, the more serious pollution the urban river water suffered.

For technological reasons, only qualitative results can be acquired from satellite imagery. The data cannot be analyzed quantitatively in detail for river water quality. For the purpose of assessing the impact of urbanization quantitatively, thirty field water samples were collected and analyzed for ten physicochemical parameters from the study area in this research. In order to assess the impact of urbanization on river water quality through comparing the analytical results between rural areas and urban zones, these thirty samples were divided into two sub-sets depending on the location of the sampling sites shown in Figure 1. One set can be named as urban samples because the sampling sites were located very close or even within urban or industrial zones. The other set, labeled as rural samples, including those sampling sites located far away from urban and industrial zones. It is worth mentioning that one water sample within the rural set was collected from the estuary of the Pearl River. As a result, it could have been influenced by seawater for some parameters. Using SPSS software, the descriptive analysis was performed for the analytical results of rural samples and urban samples, and the statistical results are summarized in Table II.

Generally, the Std. Deviation of the analytical results for rural samples was smaller than that of urban samples except for pH and nitrite (Table II). For turbidity and chroma, these two parameters are mainly influenced by the sampling location, pollution level, and type of pollutants. Therefore, the analytical results of these two parameters variate diversely, and the Std. Deviation was very high for both rural samples and urban samples. In addition, the maximum values of these two parameters within rural samples were much larger than those within urban samples

TABLE II
Statistical summary of analytical results

	Rural samples				Urban samples			
	Minimum	Maximum	Mean	Std. Deviation	Minimum	Maximum	Mean	Std. deviation
pH	6.580	7.520	7.182	0.335	6.280	7.310	6.924	0.308
N-NO_2^- (N mg/L)	0.001	0.156	0.034	0.050	0.001	0.114	0.018	0.035
N-NH_4^+ (N mg/L)	0.200	2.100	0.454	0.635	0.200	40.000	8.540	12.758
N-NO_3^- (N mg/L)	0.200	1.500	0.722	0.403	0.200	2.000	0.452	0.596
DO (O_2 mg/L)	1.200	9.600	7.318	2.373	0.390	10.000	4.806	3.623
Turbidity (NTU)	13.000	92.000	36.760	20.350	10.000	78.000	45.620	23.550
Chroma (CU)	5.000	45.000	12.760	10.690	5.000	40.000	20.770	12.890
COD_{Mn} (mg/L)	1.200	7.500	2.635	1.778	1.300	29.000	7.800	8.976
TOC (C mg/L)	0.620	4.200	1.402	1.074	0.660	44.500	7.351	12.444
Total P (P mg/L)	0.020	0.130	0.064	0.034	0.010	5.600	0.888	1.548

(Table II). The maximum turbidity and chroma appear at the water sample collected from the Pearl River estuary. These abnormal results must be due to the influence of seawater. Within the urban samples, the seriously polluted water bodies have very high turbidity and chroma, while turbidity and chroma of the relative clean and lightly polluted water bodies are relatively low. As to the other parameters, the Std. Deviation was relatively low for the rural samples. This indicates that the analytical results did not differ from each other very much, and the impact of rural life to river water quality was not so obvious. On the other hand, the Std. Deviation of the analytical results for urban samples was relatively high except for pH, nitrite and nitrate. This result implies that different urbanization level at different sampling sites had different effect extent on river water quality. Furthermore, the most seriously polluted results appeared in the urban samples for almost all of the monitoring parameters except that the highest concentration of nitrite appeared in rural samples. The comparison of analytical results between rural samples and urban samples for each parameter is illustrated in Figure 4.

From Figure 4, it can be generalized that the analytical results in urban samples are much worse than those in rural samples except for nitrite and nitrate that primarily come from the rural life such as agriculture. Although the average values of pH are around neutral in both urban samples and rural samples (Table II), the pH values in urban samples are lower than those in rural samples (Figure 4). In addition, pH value of one urban sample exceeds the boundary values of surface water quality standard. Attention should be paid to acid pollution within urban areas. For the nutrient parameters, ammonium and total phosphorus, the mean results of urban samples are tens of times higher than those of rural samples (Table II). As to every sample, the concentrations of most urban samples are much higher than those of rural samples. And so do the organic pollution parameters, COD_{Mn} and TOC. Though the maximum value of turbidity and chroma appeared in rural samples (Table II), the average results of these two parameters for urban samples are higher than those of rural samples (Table II). As shown in Figure 4, the turbidity and chroma values of urban samples are generally higher than those of rural samples. In rural samples, the concentrations of DO are generally higher than those in urban samples in spite of the highest concentration of DO appear in urban samples (Table II and Figure 4). The extremely high concentrations of nutrient and organic pollutants in urban samples may be due to the large municipal wastewater discharge. The rapid urbanization process could be the reason for the large discharge of municipal and industrial wastewater. Urban development had a significant negative influence on urban river water quality.

Based on the water quality standard for surface water (GB3838-88) and the analytical results, an improved equalized synthetic pollution index method was used to calculate the integrative pollution index for every sample. Here, the water quality standards for class II were used for the calculation. The analytical results of turbidity and chroma were not used for the calculation because there are no definite standards for these two parameters for surface water at

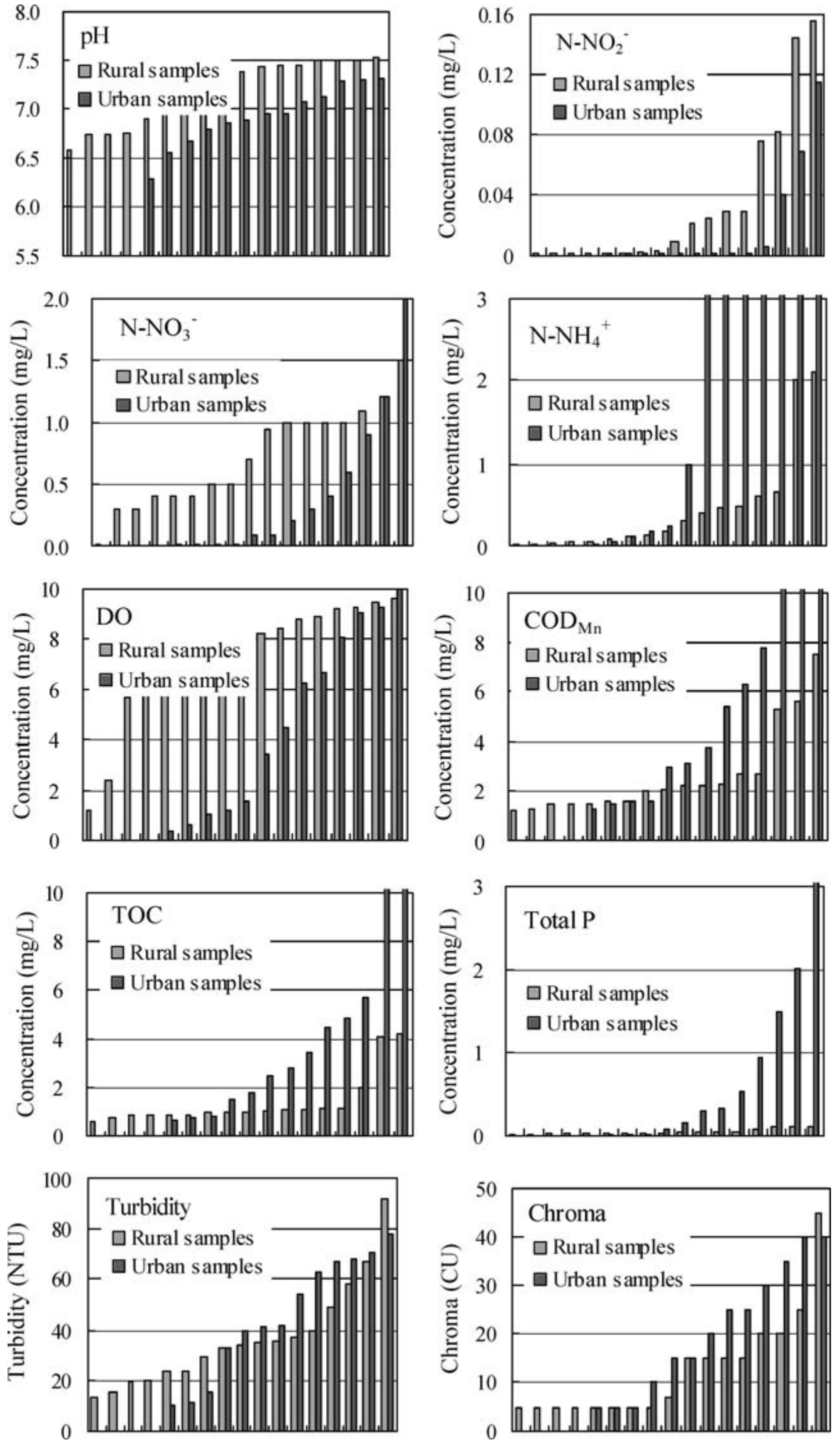

Figure 4. Comparison of analytical results between urban and rural samples.

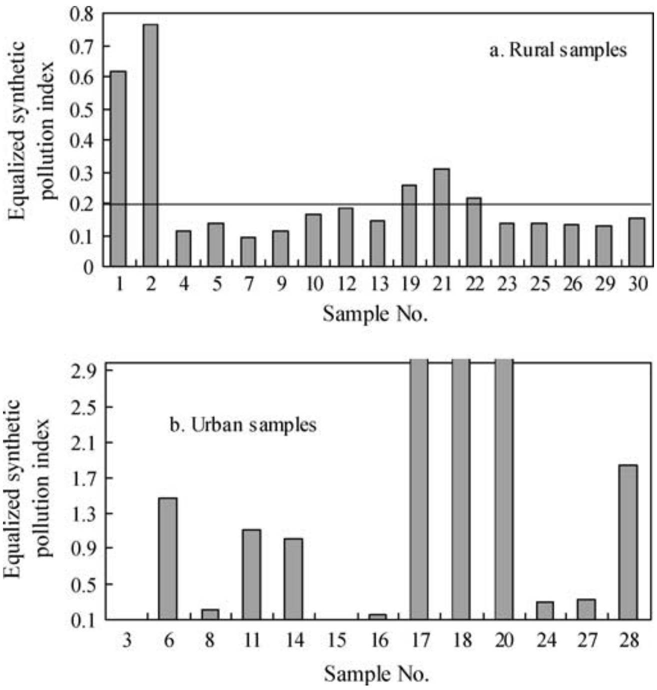

Figure 5. Equalized synthetic pollution index for every sample.

present. The equalized synthetic pollution index of every sample is illustrated in Figure 5.

The equalized synthetic pollution index could be compared to the water pollution criterion for equalized synthetic pollution index listed in Table 1 to assess the river water quality. Generally, urban river sections were polluted more seriously than rural rivers. Most of the rural samples had an equalized synthetic pollution index less than 0.2 (Figure 5). The river water was relatively clean and could be used as a drinking water source. The water bodies at sampling sites 19, 21 and 22 were lightly polluted and the other two, samples 1 and 2 were moderately polluted. The river water quality of these samples was lightly influenced by human activities. Correspondingly, the urban samples were right on the contrary of the rural samples. Only at sampling sites 3, 15 and 16, urban river water was relatively clean. According to the equalized synthetic pollution index shown in Figure 5, more than half of urban samples were seriously contaminated. The samples 17, 18 and 20 are located within the urban zones of Guangzhou, Dongguan and Shenzhen city, respectively. Their equalized synthetic pollution indices were larger than 3.0. The river water bodies at these sampling sites were extremely polluted. Along with the urbanization process, urban activities had an increasingly negative impact on river water quality. For example, samples 7, 8 and 9 were collected from the same river. The only difference is that sample 8 is located within a built-up area while samples 7 and 9 are located at rural areas. The results of equalized synthetic pollution index indicated that water bodies at samples 7 and 9 were relatively clean, but river water at sample 8 was lightly polluted. The difference between samples 10, 12 and 18 is more obvious. All these results indicate that urban development exerted a significant passive and negative influence on river water quality.

4. Conclusions

The satellite imagery can be used to monitor the river water quality qualitatively for a relatively large area. From the results of the interpretation of Landsat TM images, nearly half of the urban river sections were seriously polluted in the PRDEZ in 2000. All the boundary-rivers suffered serious contamination. The river water quality situation appeared different for every city. In general, the more rapid the urbanization process, the more serious pollution the urban river water suffered.

Based on the analytical results for the field water samples, an improved equalized synthetic pollution index method was applied to assess the river water quality for every field sample. Most of the rural river water bodies were relatively clean. Only three and two rural river water bodies were lightly and moderately polluted, respectively. Meanwhile, most of urban river water bodies were seriously polluted. The water bodies within the urban zones of Guangzou, Dongguan and Shenzhen city were extremely polluted. Within the same river, the water quality of sample from rural area was much better than that from urban zone. Urbanization and urban activities had significant passive and negative impact on river water quality.

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