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Developing Indicators and Monitoring Systems for Environmentally Livable Cities in China

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Forword »

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Since its opening-up and reform, China has been in the process of rapid economic development with its people enjoying an increasingly improved standard of life. Meanwhile accompanying this dramatic economic growth is the degradation of environment which has, to some extent, damaged the gains of the opening-up and reform and prevented the economy from a healthy and sustainable development. The Chinese government is increasingly aware of that without addressing the environmental issues it is facing now will jeopardize its long term goal of the great rejuvenation of the Chinese nation. Given the magnitude and complexity of the environmental issues in China, there is no easy way in addressing them and the solution to them entails an equal priority being given to environmental protection, ecological conservation and economic development or even higher than the latter by mainstreaming the former into the overall socio-economic decision-making process. As a matter of fact, China has been in the struggle against environmental pollution since the very beginning of its economic take-off and trying to explore a pathway that could help address China's environmental issues in the way most suitable to China's specific circumstances.

In recent years, especially since the 12th Five-Year Plan period, the enhanced measures including legislation, policy, regulatory and economic means have been taken by the Chinese government in dealing with environmental problems, of which environmental policies have played an important role in this regard. Corresponding to this situation and in meeting the demand of governments at different levels for environmental policy tools, the environmental policy research projects on topics of a wide range have been conducted by some Chinese environmental research institutions including the Chinese Academy for Environmental Planning (CAEP).

CAEP founded in 2001 is a research advisory body supporting governments in the development of key environmental planning, national environmental policies, and major environmental engineering projects. In the past more than 10 years, CAEP accomplished the development of the overall planning of national environmental protection for the 10th, 11th and 12th Five-Year Plan periods; water pollution prevention and control planning for key river basins; air pollution prevention and control planning for key regions; soil pollution prevention and control planning; and some regional environmental protection plans. In the same period of time, CAEP also actively engaged in research on such topics as green GDP, environmental taxation, emission trading, ecological compensation, green financing, etc. By so doing, CAEP has become an indispensable advisory body in the environmental decision-making in mainland China. According to *2013 Global Go To Think Tanks Report and Policy Advice* published by University of Pennsylvania, CAEP was ranked 31 in the field of environment in the world. Many of CAEP's research results and project outcomes regarding environmental policies have drawn great attention of decision makers and international institutions, and have been utilized to contribute to the formulation of national environmental policies concerned.

The Chinese Environmental Policy Research Working Paper (CEPRWP) is a new internal publication produced by CAEP for the purpose of facilitating the academic exchange with foreign colleagues in this field, in which the selected research papers on environmental policies from CAEP are set out on the irregular basis. It is expected that this publication will not only make CAEP's research results on environmental policies be known by foreign colleagues but also serve as a catalyst for creating opportunity of international cooperation in the field of environmental policies, and environmental economics in particular, with a view of both the academic research and practical policy needs.

While the environments of more and more Chinese cities are becoming less polluted following successful introduction of pollution control and environment renovation measures in recent years, more attention is now being given to the livability of cities. However, these successes are often not quantifiable and are not universally recognized. Based on a survey of globally- recognized urban livability indices and their monitoring systems, the paper is to develop and agree with the government counterparts on a verifiable and measurable environmental livability index system targeting the PRC cities, and find a suitable approach for investment assessments in reaching the benchmarks, i.e. the costs of producing changes in environmental livability. With the Chinese Environmental Livability Index System developed in the paper, environmental performance of 33 Chinese cities were ranked and the environmental challenges of these cities are identified with the further Pressure-State-Response analysis and trend analysis. With a comprehensive analysis with the trends of long-term environmental livability and the pollution control investment of Chinese cities, more effective and aim-oriented incentives and investment policies for urban environmental livability improvement are put forward in this paper.

Contents

1. BACKGROUND AND METHODOLOGY

With the development of environmental protection work, the pollution control has been well functioned, in consequence that environmental quality has been improved, and the urban environmentally livability is getting more and more attention. In order to better evaluate of livable environmental level of Chinese cities in recent years, based on "China Livable Environment Evaluation (ADB project) of 2007"[1], this paper aim at updating the livable environmental level by using 2014 data for China municipality directly administrated under the central government, provincial capital cities and other specific cities.

The indicators matrix relating to 'environment' and 'livability' were developed based on the PSR framework in the following areas: Aquatic environment, Water resources, Atmospheric environment, Solid waste, Acoustic environment, Ecological environment, Domestic livability and Environmental management. Environmental Livability system has 41 indicators, of which 8 indicators for aquatic environment, 3 indicators for water resource, 11 indicators for atmospheric environment, 6 indicators for solid waste, 1 indicator for Acoustic environment, 4 indicators for ecological environment, 4 indicators for Domestic livability, 4 indicators for environmental management.

Table 1 Environmental Livability Indicators and Weights

Sub-index	Sub-index weight	Indicator	Unit	Indicator weight
Water environment	0.14	COD discharge intensity	kg per ten thousand CNY	0.11
		Wastewater discharge intensity (industrial and domestic)	ton per ten thousand CNY	0.13
		Heavy metal discharge intensity	kg per 100 million CNY	0.13
		Proportion of national surface water monitoring sections under Class V	%	0.12
		Water quality up-to-standard rate of centralized drinking water source areas	%	0.14
		Sewage network coverage rate	%	0.12
		COD (industrial and domestic) removal rate	%	0.12
		Above Class II treatment rate of urban wastewater	%	0.12
Water resources	0.14	Water resource availability per capita	m^3 per capita	0.37
		Water reuse rate	%	0.32
		Water use intensity	m^3 per ten thousand CNY	0.31
Atmospheric environment	0.17	SO_2 emission intensity	kg per ten thousand CNY	0.09
		NOx emission intensity	kg per ten thousand CNY	0.09

* [1] The project participants are YU Fang, Peng Fei, Cao Dong, Wang Jinan (Chinese Academy for Environmental Planning, Beijing, China) , Jianglin (Beijing Academy for Environmental Science, Beijing, China), Ian V. Green (Culpin Planning Limited, Bristol, United Kingdom).

Sub-index	Sub-index weight	Indicator	Unit	Indicator weight
Atmospheric environment	0.17	Smoke dust emission intensity	kg per ten thousand CNY	0.09
		Energy consumption intensity	ton per ten thousand people	0.09
		Number of days with urban air quality meeting Class II	%	0.10
		Annual PM_{10} average concentration	mg/m^3	0.09
		Annual SO_2 average concentration	mg/m^3	0.09
		Annual NO_2 average concentration	mg/m^3	0.09
		Industrial SO_2 removal rate	%	0.09
		Industrial NO_x removal rate	%	0.09
		Industrial smoke dust removal rate	%	0.09
Solid waste	0.08	Municipal domestic waste generation intensity	ton per capita	0.15
		Hazardous waste generation intensity	kg per ten thousand CNY	0.17
		Industrial solid waste generation intensity	ton per ten thousand CNY	0.15
		Urban domestic waste disposal rate	%	0.18
		Safe disposal rate of hazardous waste	%	0.18
		Utilization rate of industrial solid waste	%	0.17
Acoustic environment	0.07	Reginal noise level	dB(A)	0.07
Ecological environment	0.10	Population density	Number of persons per square kilometers	0.25
		Groundwater exploitation rate	%	0.26
		Farmland change (loss) rate	%	0.23
		Green coverage in built-up areas	%	0.26
Domestic livability	0.16	Water supply coverage rate	%	0.27
		Gas supply network coverage rate	%	0.26
		Per capita green space	m^2	0.25
		Daily water use per capita	m^3/d	0.23
Environmental management	0.13	Normal operation rate of urban wastewater treatment facilities	%	0.28
		Environmental protection treatment personnel per 10,000 people	personnel per ten thousand people	0.21
		Proportion of environmental investment in GDP	%	0.26
		Resolved proportion of environmental pollution letter and visit cases	%	0.26

2. AGGREGATION OF INDICATORS INTO SUB-INDEX AND ELI

There are two levels of aggregation: (i) aggregation of sub-index and (ii) composite environmental livability index. To make indicators comparable, normalization is an important step for integrating the indicators system into the sub-indices and ELI. According to the data index, the standard method is different. The score of the sub-indices and ELI will be ranged from 0 to 1 since all the indicators will be normalized into a range from 0 to one and sum-up of the weights is equal to one. A higher score represents a better quality.

The sub-index can be given by

$$Sub\_ELI_{i,s} = \sum_{j=1}^{J} W_j N_{i,s,j}$$

Where

Sub-ELIi, s = city i for sub-index s, sub-index can be water environment, water resource, air quality, Acoustic environment, solid waste, ecosystem, environmental management

Wj = weight for the j-th indicator

NIi,s,j = normalized j-th indicator value under sub-index s for city i

The composite ELI can be calculated from

$$ELI_i = \sum W_s * Sub\_ELI_{i,s}$$

Where

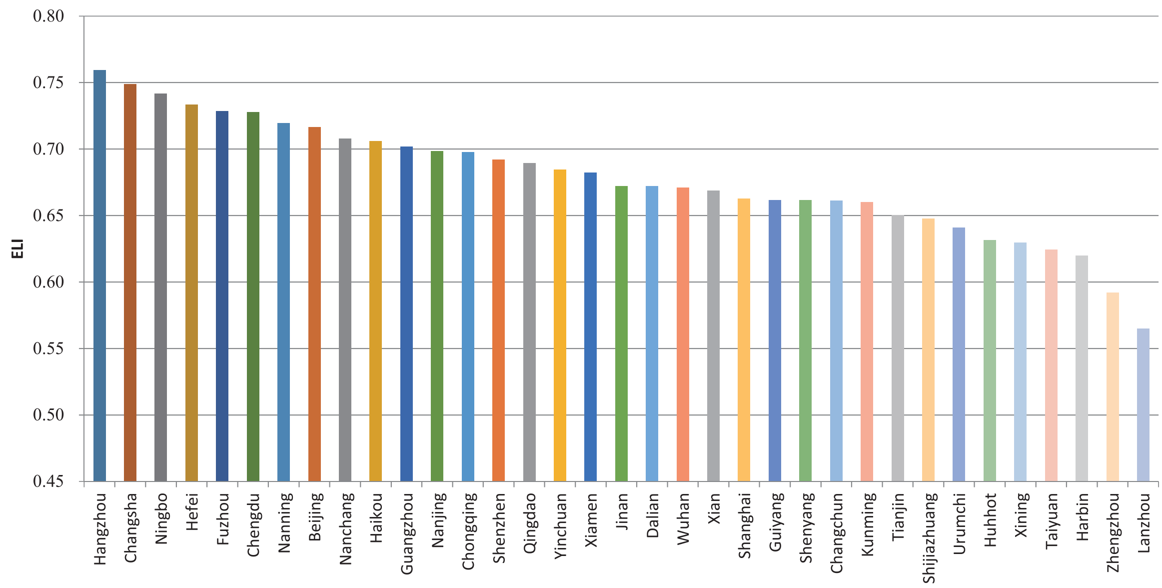
ELIi = environmental livability index for city i;

Ws = weight for the s-th sub-index

3. COMPOSITE OF URBAN ENVIRONMENTAL LIVABILITY INDEX (ELI)

Figure 1, which ranks 35 major Chinese cities in 2014 according to their environmental livability indices, demonstrates that the ELI is generally higher in southern China, eastern coastal cities and economically developed regions and lower in the north, northwest and less-developed regions. For example, Hangzhou, Ningbo, Fuzhou, Beijing, Qingdao, Dalian, and Tianjin score better than Lanzhou, Harbin, Taiyuan, Urumqi, and Shijiazhuang. The index is also higher in cities with good natural conditions or with large environmental capacity such as Nanning, Haikou and Hangzhou. Of China's megacities, Beijing has a higher ELI than Shanghai and Guangzhou. Hangzhou ranks the highest and Lanzhou has the lowest ELI score.

Figure 1 Urban Environmental Livability Indices in China (2014)



4. TREND ANALYSIS IN MAJOR CITIES

From 2000 to 2014, environmental livability in Beijing, Shanghai, Guangzhou, Wuhan, Lanzhou and Shenyang have rose consistently, as shown in Figure 2. Table 2 compares the six cities, showing their index values and rankings for the years 2000, 2003, 2005, 2007, 2011, and 2014. Guangzhou has the highest improvement rate (55.1%) and Shanghai has the lowest (31%). Over the period, environmental livability in Guangzhou, Beijing and Wuhan rose significantly. Growth in Shanghai and Shenyang was slower. Lanzhou's position at the bottom of the group remained unchanged.

Figure 2 Trend Analysis of Environmental Livability Indices of Major Cities

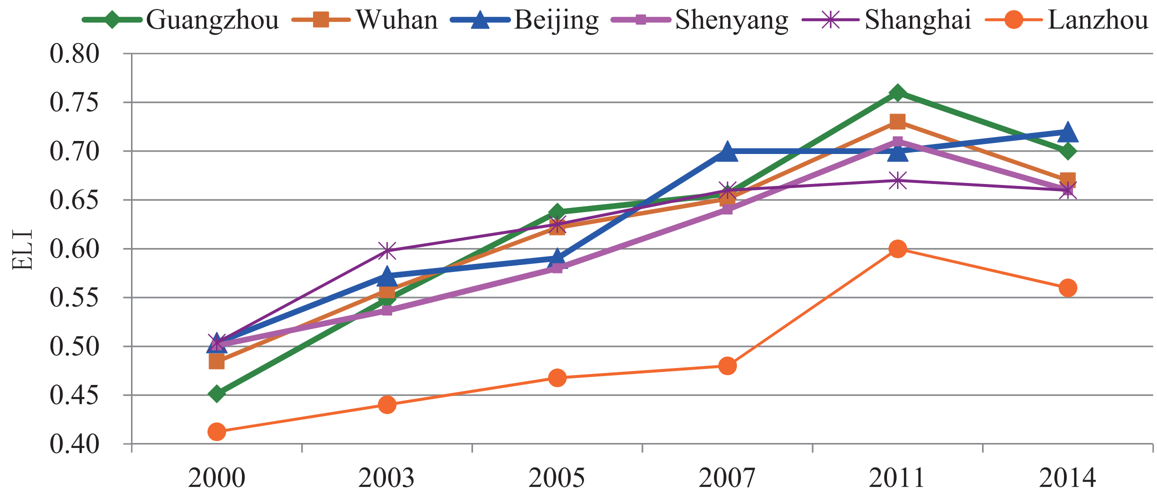


Table 2 Ranking Comparison of Environmental Livability Indices of Major Cities

City	2000		2003		2005		2007		2011		2014		% improvement (2000 to 2014)
	Index	Ranking	Index	Ranking	Index	Ranking	Index	Ranking	Index	Ranking	Index	Ranking	
Guangzhou	0.45	5	0.55	4	0.64	1	0.66	2	0.76	1	0.70	2	55.1
Wuhan	0.48	4	0.56	3	0.62	3	0.65	3	0.73	2	0.67	3	38.3
Beijing	0.50	2	0.57	2	0.59	4	0.70	1	0.70	4	0.72	1	42.9
Shenyang	0.50	3	0.54	5	0.58	5	0.64	4	0.71	3	0.66	4	31.8
Shanghai	0.50	1	0.60	1	0.63	2	0.66	2	0.67	5	0.66	4	31.0
Lanzhou	0.41	6	0.44	6	0.47	6	0.48	6	0.60	6	0.56	6	35.7

4.1 Beijing

Figure 3a shows that in 2000 the main environmental problems in Beijing were in the areas of water environment, water resources, air quality and solid waste. By 2007 (Figure 3b) its water environment index had risen from 0.43 to 0.82, water resources from 0.32 to 0.49, air quality from 0.23 to 0.52 and solid waste from 0.42 to 0.68, rising by 91.2%, 51.8%, 125.3% and 62.4% respectively. Despite these improvements, water resource and air quality indicators remain poor because Beijing has low per capita water resources, high concentrations of nitrogen oxide and limited ability to remove these.

From 2007 to 2011, Beijing water resources index has become deteriorated, but the atmospheric environmental index has relatively improved. From 2011 to 2014, Beijing water resources, atmospheric environment, and the ecological environment has improved. Overall water resources and atmospheric environment index of Beijing city is still low. To tackle such problems, Beijing should strengthen water resource management and air quality control.

Figure 3a Beijing ELI(2000)

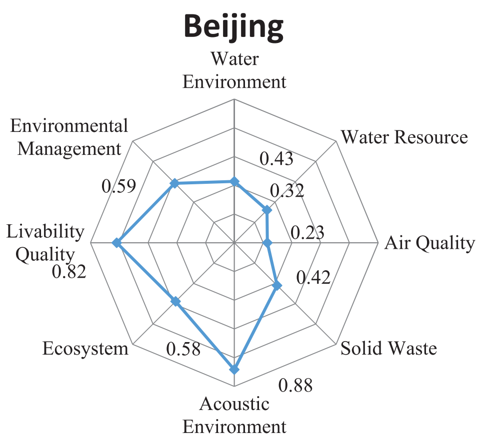


Figure 3b Beijing ELI(2007)

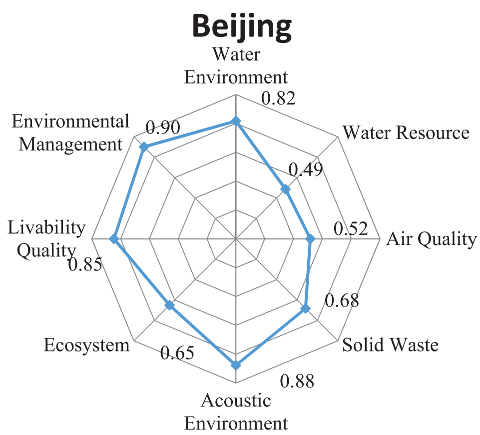


Figure 3c Beijing ELI(2011)

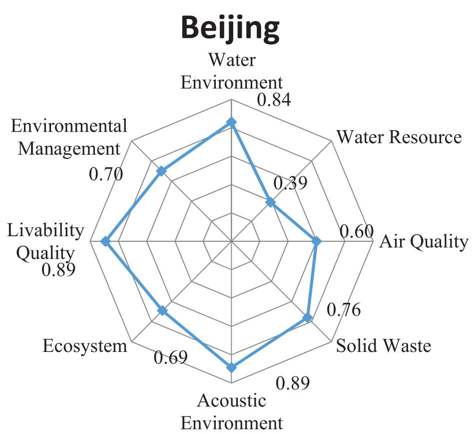
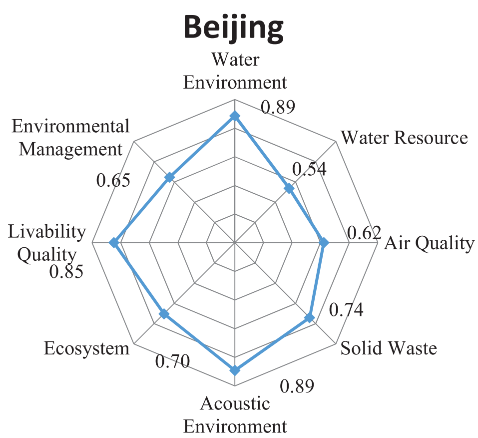


Figure 3d Beijing ELI(2014)



4.2 Shanghai

Figure 4a shows that Shanghai's major environmental problems in 2000 are related to water resources and environment, and air quality. All aspects had improved significantly by 2007, as shown in Figure 4b. However, water resource and air quality remained weak when compared to other indicators because of Shanghai's low per capita water resource base, heavy sulfur dioxide pollution and limited ability to remove pollutants at source. Solid waste and ecological indices during the seven-years period fell by 15.7% and 24.6% respectively as urban domestic waste production increased but treatment capacity lagged behind.

Figure 4c shows that the atmospheric environment, water resources and solid waste management in Shanghai city has been improved, but the environmental management has declined. Figure 4d shows that environmental management and ecological environment in Shanghai has declined, in which the decline of environmental management index is mainly due to the low proportion of environmental protection investment accounted for GDP.

Shanghai must focus attention on water resources, air quality, and the management of solid waste.

Therefore in the process of continuing to strengthen the management of water resources and atmospheric environment, Shanghai needs to pay more attention to environmental management and ecological environmental management, and investment in environmental protection.

Figure 4b Shanghai ELI(2004)

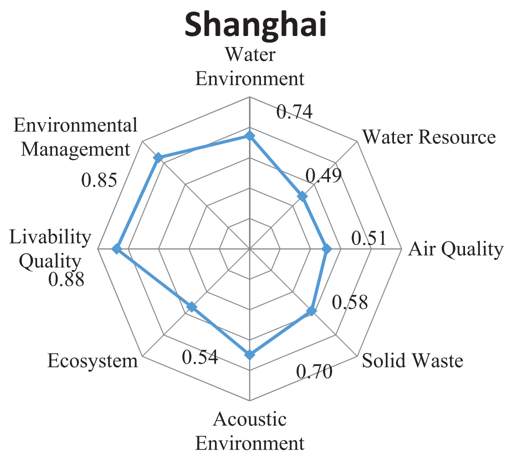


Figure 4a Shanghai ELI(2000)

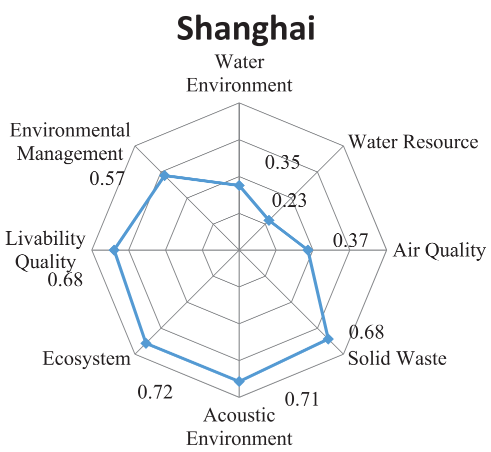
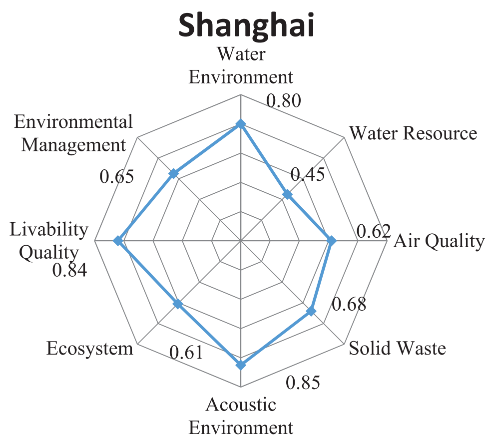
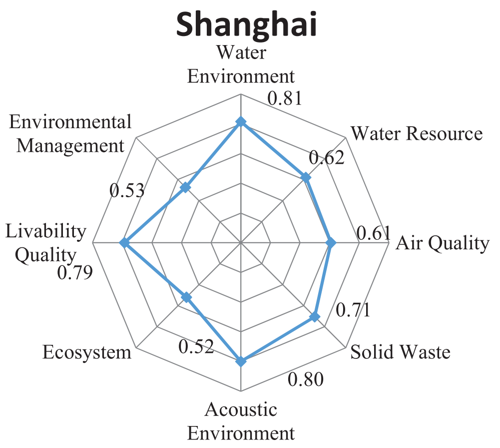


Figure 4c Shanghai ELI(2011)



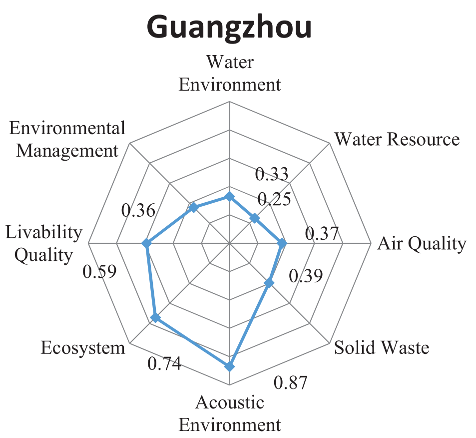
■ Figure 4d Shanghai ELI(2014)



4.3 Guangzhou

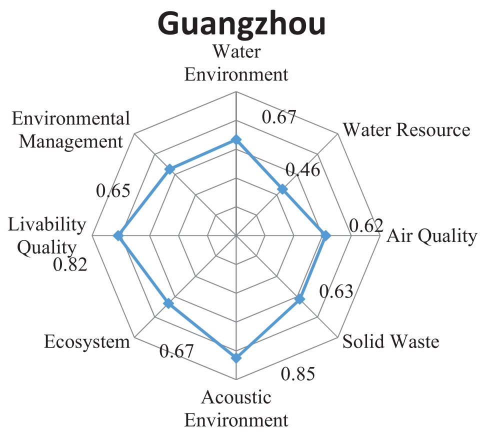
Figure 5a indicates that in 2000, Guangzhou's water environment, water resource, air quality, solid waste and environmental management index were in low level. By 2007, as shown in Figure 5b, many of these indicators had risen substantially: water environment, water resource, air quality, solid waste and environmental management index had risen by 101.9%, 82.1%, 68%, 58.3% and 82.3% respectively. From 2007 to 2011, Guangzhou's ELI continued to improve(Figure 5c). From 2011 to 2014, the ecological environment index has declined, and other index changed slightly (Figure 5d).

■ Figure 5a Guangzhou ELI(2000)



Ecological environment index is mainly due to the high population density in 2014, resulting in a slight decline in the ecological environment index. Overall, Guangzhou city has made great achievements in environmental protection. At present, the ecological environment, water resources and environment livable index in Guangzhou city is still low. The city's water resource indicator remains low because Guangzhou has low per capita water resources and low water recycling rates. Further work is needed in the water resource and ecological environment.

■ Figure 5b Guangzhou ELI(2007)



■ Figure 5c Guangzhou ELI(2011)

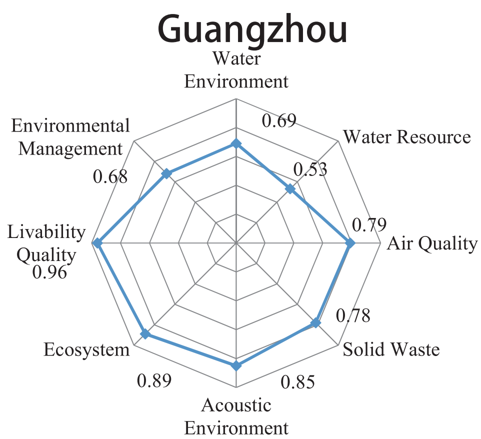
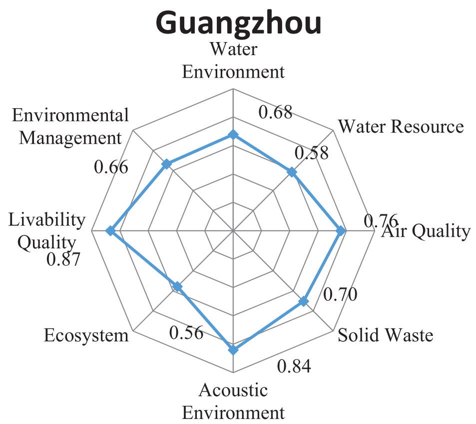


Figure 5d Guangzhou ELI(2014)



4.4 Wuhan

Figure 6a demonstrates that Wuhan's key environmental problems in 2000 were related to its water environment, water resources and air quality. By 2007, as shown in Figure 6b, it had recorded significant improvements in all of these areas, most particularly in relation to water environment (where the index climbed by 218%). Nonetheless, Wuhan's water resource and air quality indicators remain low because of low per capita water resources, sulfur dioxide and particulate pollution, and its limited ability to treat nitrogen oxides. Wuhan City, in addition to the acoustic environment and the ecological environment has declined slightly, the rest of the livable index has increased by 2007-2011, as shown in Figure 6c. From 2011 to 2014, in addition to a slight increase in the acoustic environment index, the rest of the index has declined, as shown in Figure 6d.

Wuhan must continue to focus on the management of water resources (by advocating for more economical use of water and encouraging improved water circulating utilization rates) and strengthen the treatment of atmospheric pollution.

Figure 6a Wuhan ELI(2000)

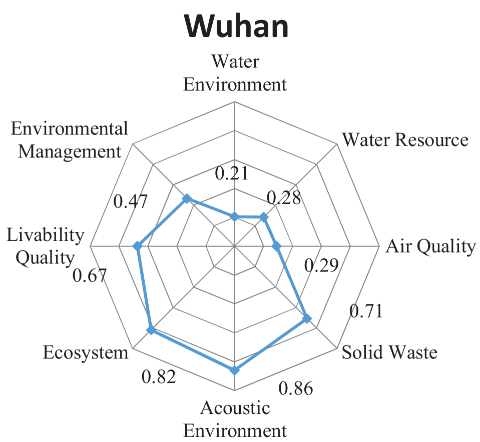


Figure 6b Wuhan ELI(2007)

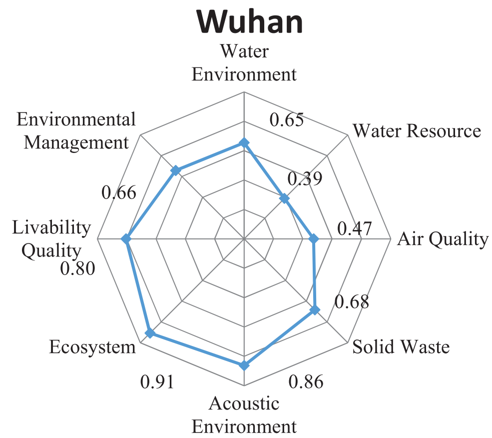
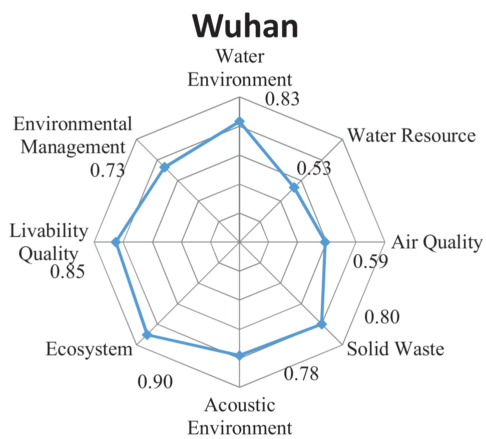
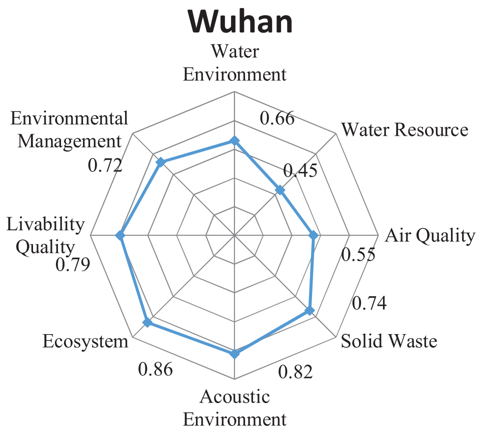


Figure 6c Wuhan ELI(2011)



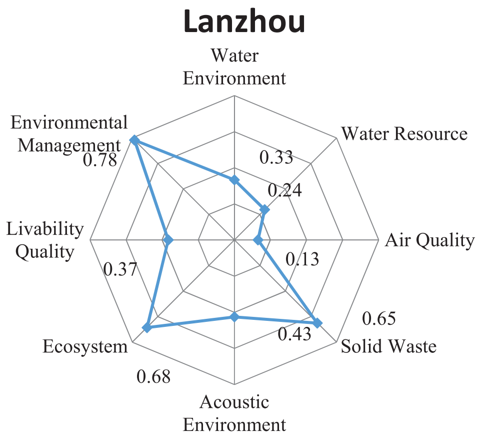
■ **Figure 6d Wuhan ELI(2014)**



4.5 Lanzhou

Figure 7a shows that in 2000 the main environmental problems facing Lanzhou are related to its water environment, water resources, air quality and domestic livability. By 2007, as demonstrated in Figure 7b, all of those indicators had improved, with strong improvements in air quality especially. From 2007 to 2011, water resources, water environment, and livability quality index are improved, the atmospheric environment index decreased slightly (Figure 7c). From 2011 to 2014, water resources, water environment, and livability quality index slightly decreased, and the atmospheric environment index increased(Figure 7d).

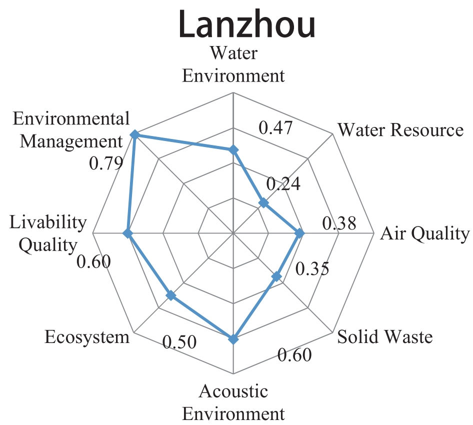
■ **Figure 7a Lanzhou ELI(2000)**



However, Lanzhou's solid waste and ecosystem indicators fell from 2000 to 2007, by 46.5% and 26.9% respectively, mainly because of the city's inability to treat hazardous and harmful domestic waste. But solid waste livable index continues to improve from 2007 to 2014.

Lanzhou's indices in these areas remain relatively weak, despite the improvements, due to COD emissions, high concentrations of sulfur dioxide and particulates, limited wastewater treatment and high levels of urban water consumption.

■ **Figure 7b Lanzhou ELI(2007)**



■ **Figure 7c Lanzhou ELI(2011)**

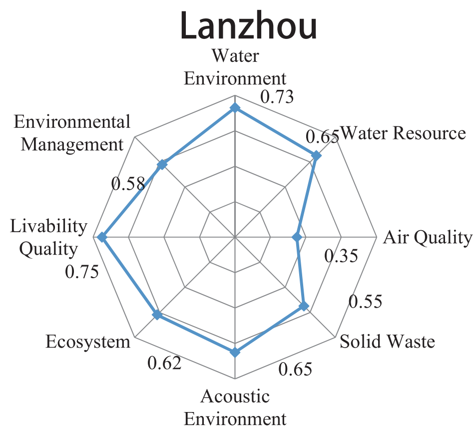
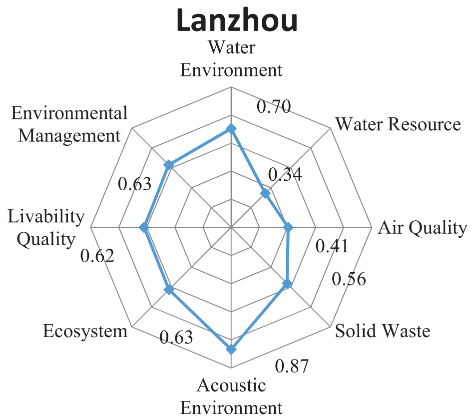


Figure 7d Lanzhou ELI(2014)



4.6 Shenyang

Figure 8a shows that in 2000 the main environmental problems facing Shenyang related to its water environment, water resources and air quality. By 2007, indicators in all of these areas had improved, with particularly strong growth in water environment (150%) (Figure 8b). Its ecological environment and environmental management indices dropped over the study period by 13.3% and 3.81% respectively due to rising groundwater exploitation and insufficient investment in protection of the urban environment. From 2007 to 2011, water resources, water environment and atmospheric environment index are improved (Figure 8c), and from 2011 to 2014, atmospheric environment and environmental management index decreased(Figure 8d).

When compared with other cities, however, indicators of water resources, atmospheric environment, and environmental management are weak due to Shenyang's poor surface water quality, low per capita water resources, high sulfur dioxide and particulate concentration, and limited ability to remove major atmospheric pollutants . In addition, due to the high level of groundwater exploitation in Shenyang, inadequate investment in urban environmental protection. Therefore, Shenyang need to increase investment in environmental protection, and strength environmental management in water resources, atmospheric environment and environmental management to improve the city's environmental livability.

Figure 8a Shenyang ELI(2000)

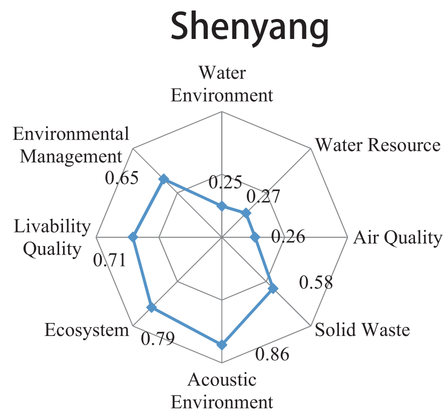


Figure 8b Shenyang ELI(2007)

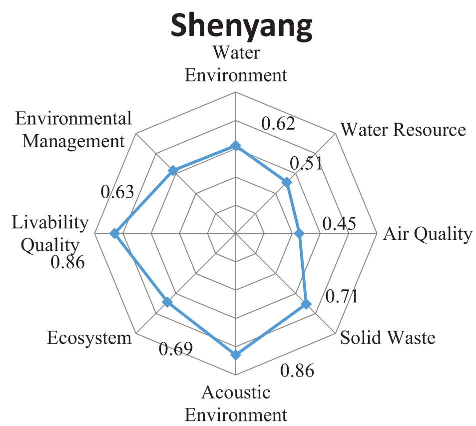


Figure 8c Shenyang ELI(2011)

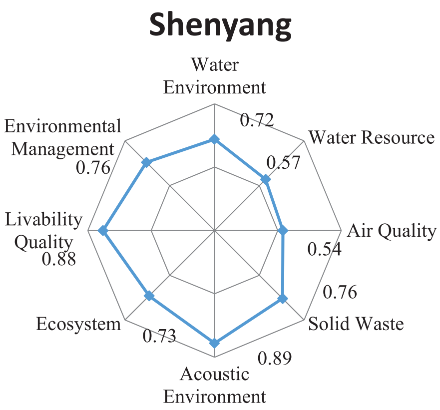
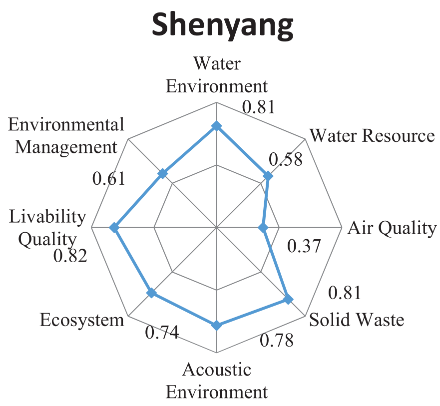


Figure 8d Shenyang ELI(2014)



5. FINDINGS BY SUB-INDEX

In this section, the report offers information about (i) each city's ranking within the sub-index area , (ii) a general overview of the findings as they relate to pressure-state-response(PSR), and (iii) case studies demonstrating problems PRC cities may try to address.

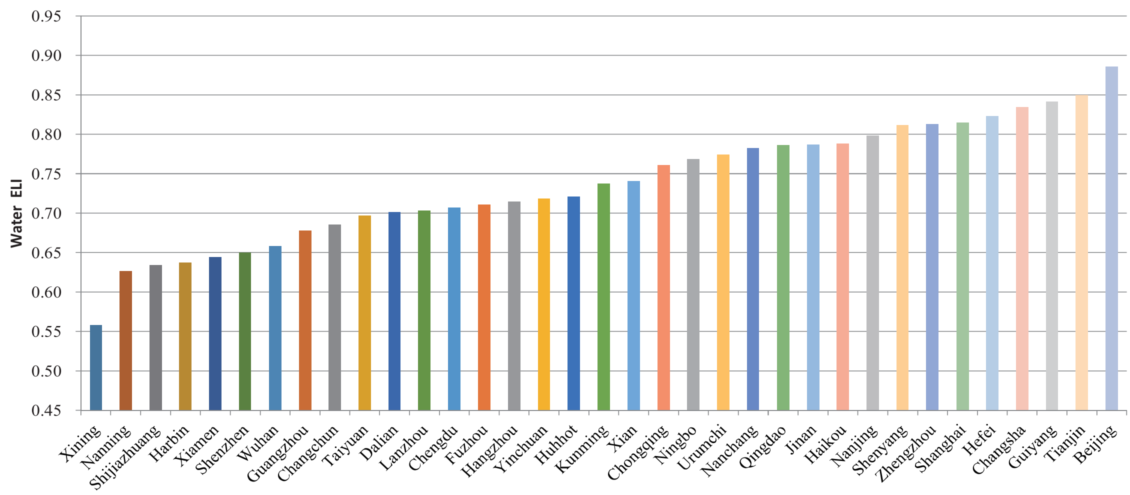
5.1 Urban Aquatic Environments

City ranking

Figure 9 compares the Water Environmental Livability Index of the 35 cities studied. The highest index city of Water environment is Beijing, the lowest index city is Xining. Among megacities, Beijing and Shanghai rank better than Guangzhou. In general, cities with a greater water environmental capacity, such as Haikou and Qingdao, do better than those without. Cities built on or around major river basins or lakes score badly, indicating that these water sources are of poor quality and efforts to improve water quality are urgently needed. Examples include Kunming in the Dianchi Lake, Harbin and Changchun in the Songhua River drainage area, and Wuhan in the Changjiang River drainage area. Water environment index of Water shortage area in West is not high, such as Xining, Taiyuan and Lanzhou.

The water ELI average of 35 cities studied is 0.74, and 17 cities' water ELI, half of selected cities, are lower than the average level. There are maybe three reasons leading to the low scores in these cities: i. The water environmental capacity is low in nature and the pressure of water pollution discharge is high in some cities of Xining and Lanzhou, and the pollution disposal capacity is also not sufficient in these cities; ii. The population density is relatively high (especially in some megacities as Guangzhou, Shijiazhuang, Shenzhen, Chengdu, Wuhan and Dalian) and their pollution discharge exceeds their environment capacity. In addition, the pollution disposal capacity of these cities also need further improvement; iii. In some less-developed cities, such as Changchun, Harbin, and Nanning, the waste water disposal capacity is too low and their waste water disposal rate is lower than the average level.

Figure 9 Ranking of Urban Water Environmental Livability Indices in China



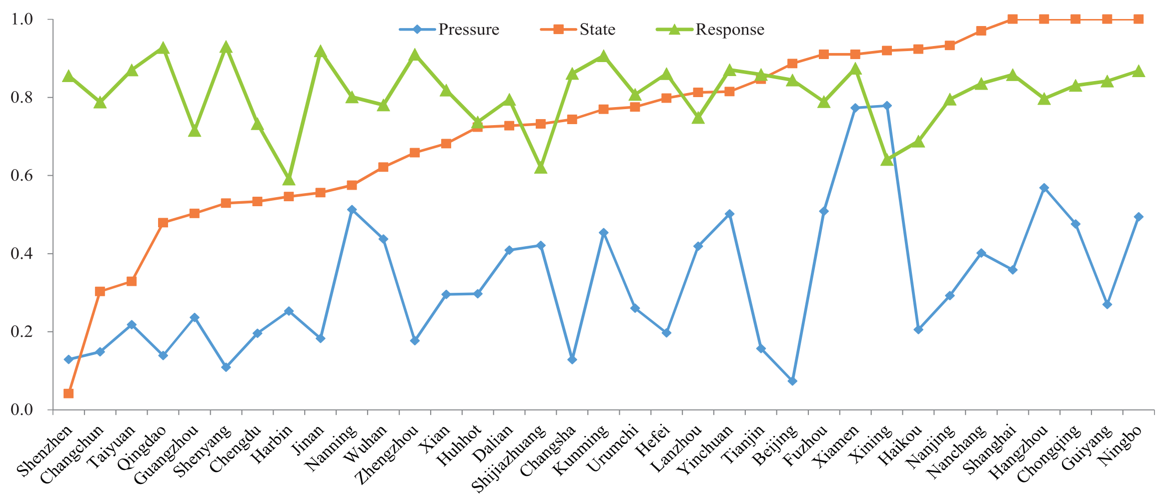
Pressure-state-response

Figure 10 demonstrates the pressure-state-response of different cities. It shows for example that Xining has the highest water environmental pressure and Beijing the lowest; Ningbo has the best water environmental state and Shenzhen the worst; Qingdao has the best water environmental response and Harbin the worst. Of the megacities Guangzhou's and Shanghai's pressure is higher than Beijing's. Guangzhou's response and state are lower than Beijing's and Shanghai, the reason is that Above Class II treatment rate of urban wastewater of Guangzhou is low.

There is a positive correlation between water environmental condition and response, with cities suffering poor water quality showing a stronger response than those with good water quality. Urban water environmental pressure is affected by upstream pressure as well as local discharge, so the pressure index does not correlate well with the state and response indices.

The water environmental state in cities with low pressure is better in those with high pressure, for example Guiyang's, Nanjing's, Haikou's, and Beijing's state are better than Wuhan's, Shijiazhuang's and Nanning's. Cities with poor water environmental state, such as Qingdao, Shenyang, Jinan and Zhengzhou, have a high response rate, indicating that they attach great importance to protection and treatment of water. Some cities that earned average ratings for environmental pressure and response are rated relatively strongly for environmental state thanks to their naturally high water environmental capacity. Examples include Nanjing and Haikou.

Figure 10 Pressure-State-Response Analysis of Urban Water Environmental Livability Index in China



A comparison of the pressure, state and response of all 35 cities leads to a number of suggestions regarding the improvement of water environmental quality and reduction of environmental pressure. These are detailed in Table 3.

Table 3 Pressure-State-Response Analysis for Water Environment

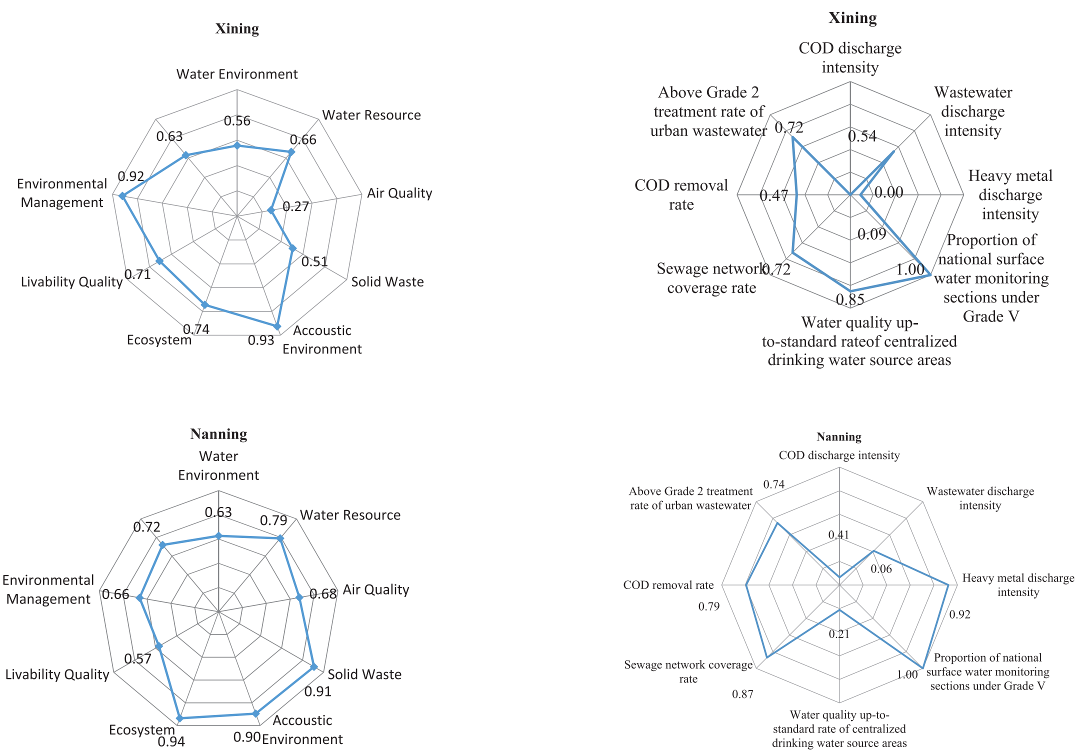
Environmental state	Environmental pressure and response	Major cities	Suggestions
Good quality	Medium environmental pressure and low response	Guiyang	Urban water environmental livability can be improved by strengthening pollution abatement and enhancing environmental management capacity
Relatively Poor quality	High environmental pressure and low response	Nanning, Wuhan	Further strengthen water environmental treatment work, reduce urban water environmental pressure and improve water environmental quality
Poor quality	High response and low environmental pressure	Shenzhen, Qingdao, Shenyang	Carry out comprehensive rectification and improvement with the upstream regions to release urban water environmental pressure and improve water environmental quality

Notes: Poor quality means that the quality state index is below 0.55. Relatively Poor quality means that the quality state index is between 0.55 and 0.8. Good quality means that the quality state index is between 0.8 and 1.

Case study

Figure 11 analyzes Xining and Nanning. In Xining water environmental issues rank second only to atmospheric and solid waste problems: the city suffers from high discharge of major pollutants and low capacity for removing these pollutants or treating water. To improve its urban environmental livability, Xining must raise its ability to treat and dispose of water pollutants. In Nanning water environmental problems are also serious. The city has substantial discharge of water pollutants, and treatment of wastewater and pollutants is average.

Figure 11 Identification of Major Issues in Xining and Nanning

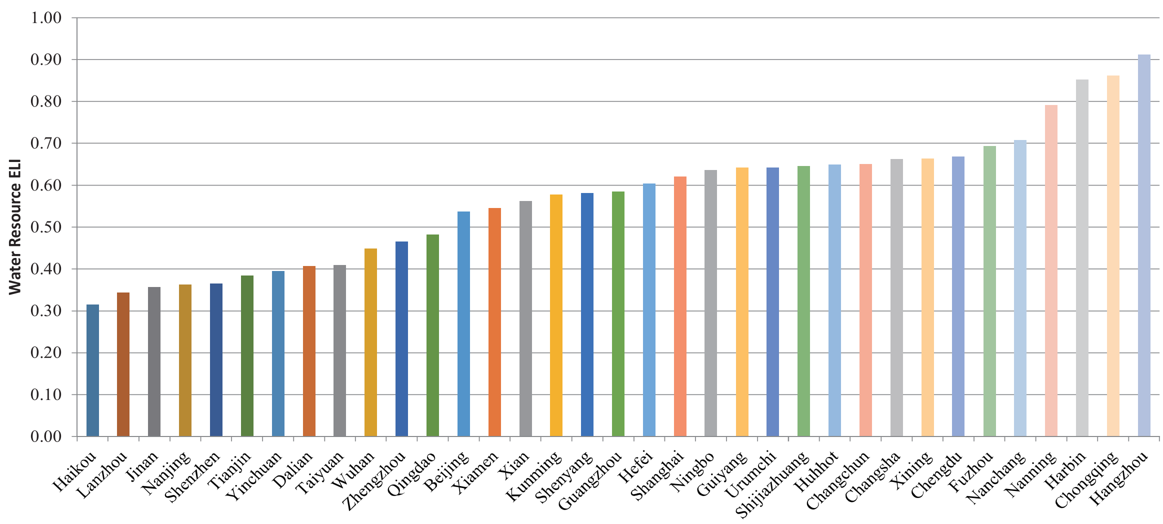


5.2 Water Resources

City ranking

Figure 12 ranks water resource environmental livability index in the 35 cities. Hangzhou ranks the highest and Haikou the lowest. Haikou City, mainly due to lower water reuse rate, and higher water intensity caused by low water resources livable index. Of the megacities, Beijing ranked higher than Guangzhou and Shanghai. In general, large and medium-sized cities like Beijing, Nanjing, Jinan, Zhengzhou, Qingdao, and Tianjin have low index due to their large populations and relatively limited water resources. Some other cities with low indices, such as Shenzhen, Dalian, Wuhan, and Haikou, rank poorly because of intensive water use but limited recycling capacities. Cities like Lanzhou, Yinchuan and Taiyuan with limited water resources have comparatively low index.

Figure 12 Ranking of Urban Water Resource Environmental Livability Indices in China



Pressure-state-response

Figure 13 demonstrates the pressure-state-response data for urban water resources. It shows that Lanzhou has the highest water resource environmental pressure and Chongqing with the lowest; Hangzhou has the best water resource environmental state and Zhengzhou the worst; Wuhan has the best water resource environmental response and Shenzhen the worst. Of China's megacities, Beijing and Guangzhou have higher water resource pressure than Shanghai. Beijing's state is lowest. But Beijing's response is higher than that of Guangzhou and Shanghai , that is because relatively scarce of water resources, the high intensity of water use in Beijing.

By comparing the relationship between water resource pressure, state and response in all 35 cities, suggestions regarding how to reduce pressure and enhance management capacity have been developed. They are outlined in Table 4.

Figure 13 Pressure-State-Response Analysis of Urban Water Environmental Livability

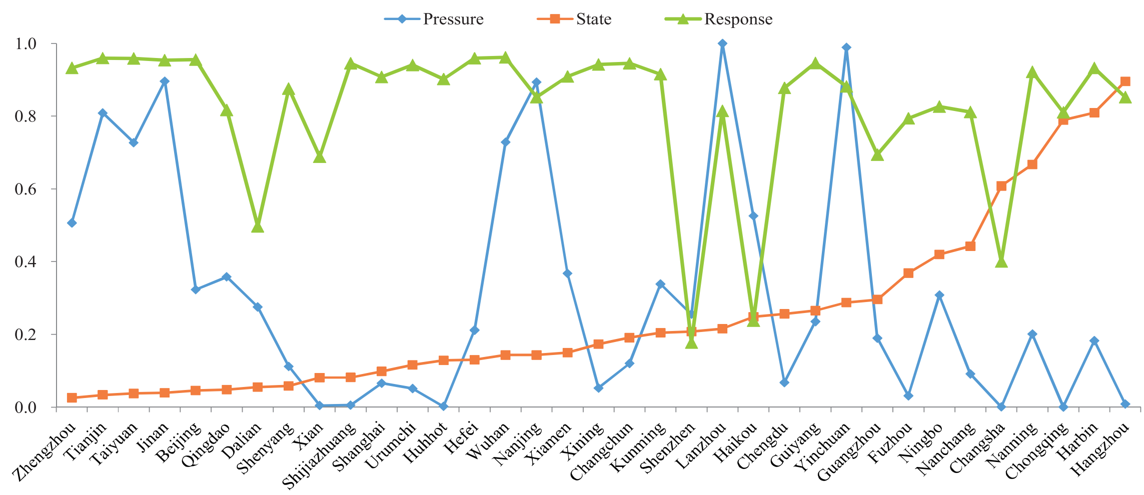


Table 4 Pressure-State-Response Analysis for Water Resource Environment

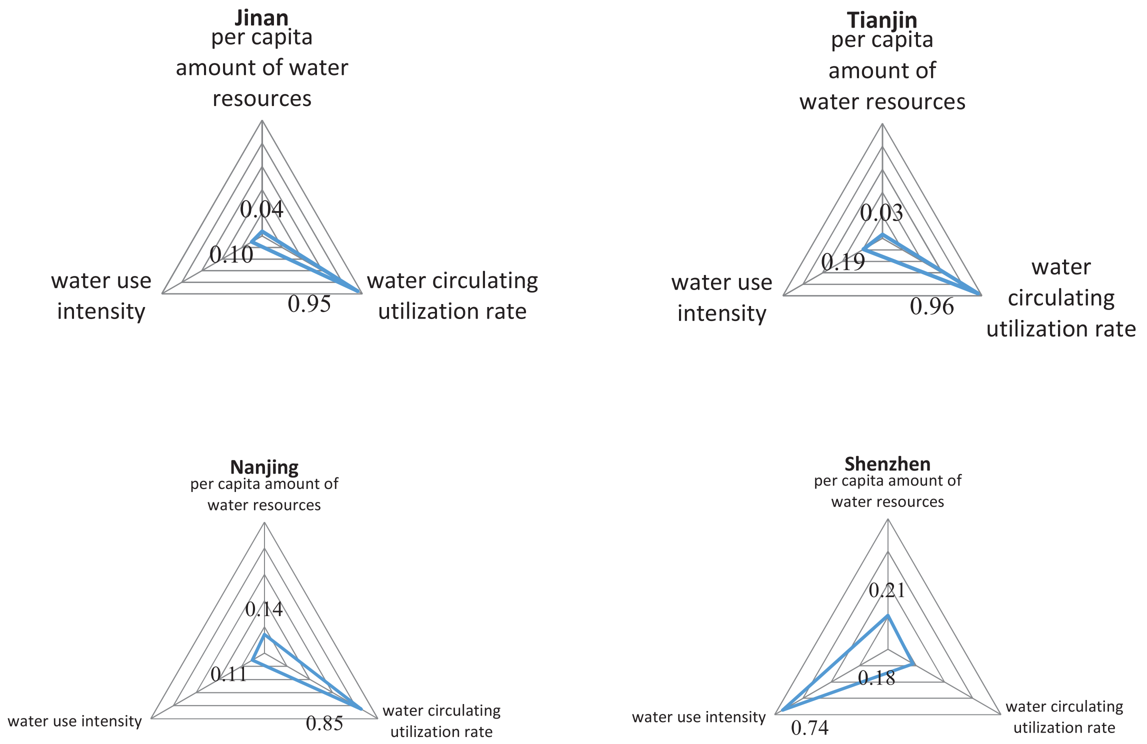
State	Pressure and Response	Major Cities	Suggestions
Good quality	Low pressure and low response	Changsha, Guangzhou	Enhance water resource management capacity and improve urban water resource livability
Relatively Poor quality	Low pressure and medium response	Lanzhou, Nanjing	Increase water reuse rate and wastewater treatment levels
Poor quality	High pressure and low response	Tianjin, Taiyuan, Jinan	Tap new resources and economize on expenses, further enhance comprehensive utilization of water resources, relieve urban water resource pressure and improve the state of water resources

Notes: Poor quality means that the quality state index is below 0.06, Relatively Poor quality means that the quality state index is between 0.06 and 0.3, Good quality means that the quality state index is between 0.3 and 1.

Case study

In Jinan, Tianjin, and Nanjing, where per capita water resources are quite low, but usage is very high, resource problems are remain severity, as shown in Figure 14. In order to improve the environmental livability of water resources in these cities it is necessary to both raise awareness of the need to save water and reduce consumption. Water resource problems in Shenzhen is the cities' main environmental problems as shown in Figure 14. This is mainly because their per capita water resources are low, and the water circulating utilization rate is low.

Figure 14 Identification of Major Issues for Jinan , Tianjin, Nanjing, and Shenzhen



5.3 Atmospheric Environment

City ranking

Figure 15 ranks atmospheric environmental livability indices in the 35 cities studied. It shows that Shenzhen ranks the highest and Xining the lowest. Among megacities, Guangzhou ranks more highly than Beijing or Shanghai. In general, southern cities have a higher atmospheric environmental livability index than northern cities while industrialized and resource-based cities such as Shijazhuang , Taiyuan and Urumuchi rank relatively poorly.

Figure 16 shows that Xining has the highest atmospheric pressure and Haikou the lowest. Haikou, however, has the highest atmospheric environmental state and Jinan the lowest. Shenzhen scores highest in terms of response and Shenyang scores lowest. Of China's megacities, Shanghai and Guangzhou have lower atmospheric response than Beijing. But Shanghai and Guangzhou have higher atmospheric state than Beijing. Cities such as Haikou, Shenzhen, Xiamen, and Guangzhou with low pressure rank well in terms of environmental state. Those under high pressure, such as Shijiazhuang, Taiyuan, Yinchuan, and Huhhot, tend to rank poorly in terms of atmospheric state. Some cities where pressure is relatively low (such as Jinan, Shenyang, Tianjin, and Harbin) nonetheless rank poorly with regard to atmospheric quality because of their weak response.

To reduce atmospheric environmental pressure and enhance treatment of atmospheric pollution, a number of suggestions are made and outlined in Table 5.

Figure 15 Ranking of Urban Atmospheric Environmental Livability Indices in China Pressure-state-response

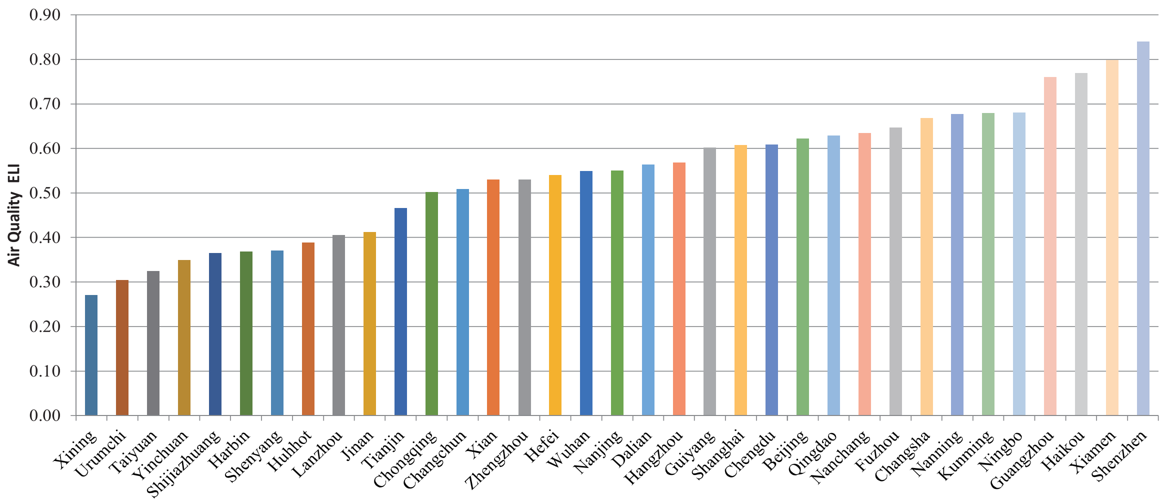


Figure 16 Pressure-State-Response Analysis of Urban Atmospheric Environmental Livability Indices

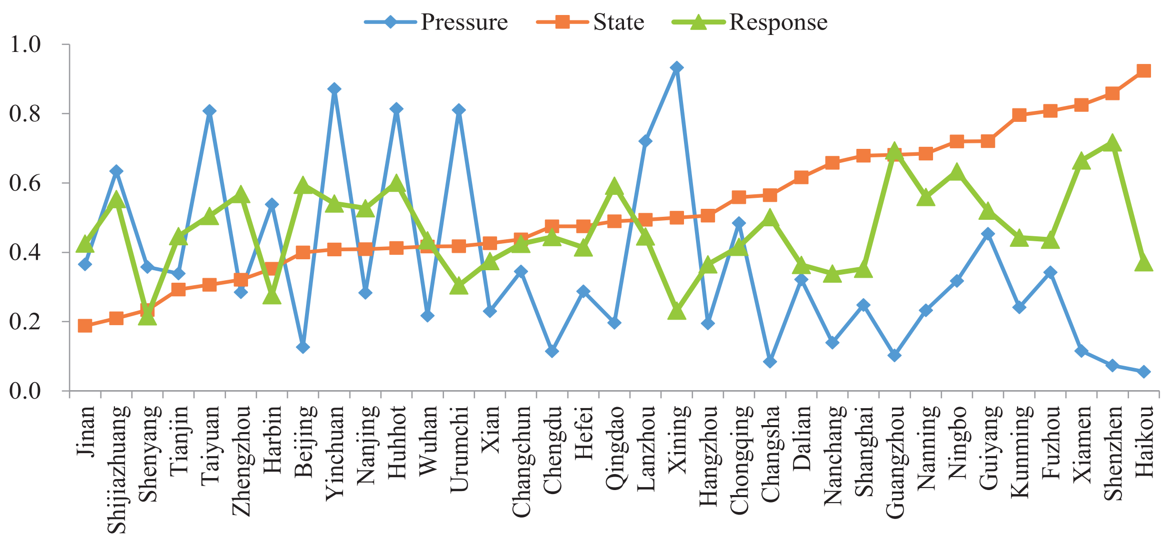


Table 5 Pressure-State-Response Analysis for Atmospheric Resource Environment

Environmental State	Pressure and Response	Major Cities	Suggestions
Good quality	Low pressure and low response	Haikou, Fuzhou, Kunming	Further strengthen treatment of atmospheric pollution and improve environmental management capacities.
Relatively poor quality	Average pressure and low response	Xi'an, Changchun, Chengdu, and Hefei	Strengthen treatment of atmospheric pollution sources, increase investment in atmospheric pollution abatement and improve urban air quality

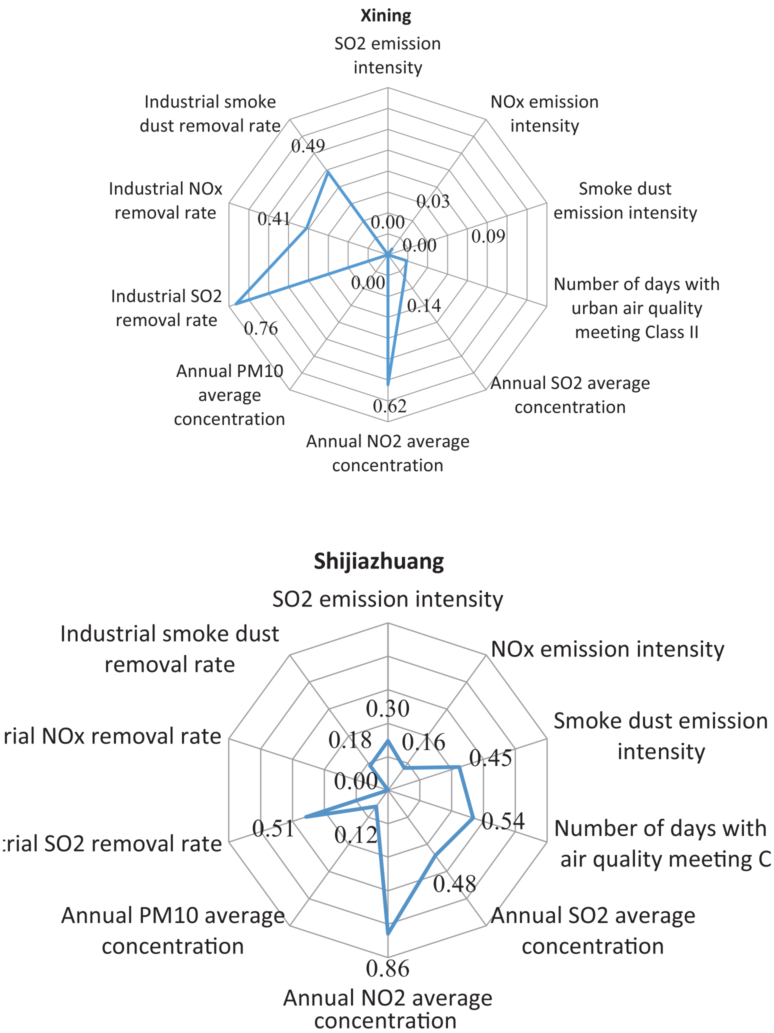
Environmental State	Pressure and Response	Major Cities	Suggestions
Poor quality	High pressure	Shijiazhuang, Taiyuan, and Harbin	Strengthen treatment of urban atmospheric pollution, enhance regional and urban air quality, and increase urban ecological environmental construction

Notes: Poor quality means that the quality state index is below 0.4. Relatively Poor quality means that the quality state index is between 0.4 and 0.8. Good quality means that the quality state index is between 0.8 and 1.

Case study

Atmospheric environmental problems are extensive in Xining and Shijiazhuang (Figure 17). Xining due to high NOx and smoke dust emissions but low cleaning and pollutant removal abilities. Shijiazhuang due to high sulfur dioxide and NOx emissions but low cleaning and pollutant removal abilities.

Figure 17 Identification of Major Issues for Xining and Shijiazhuang

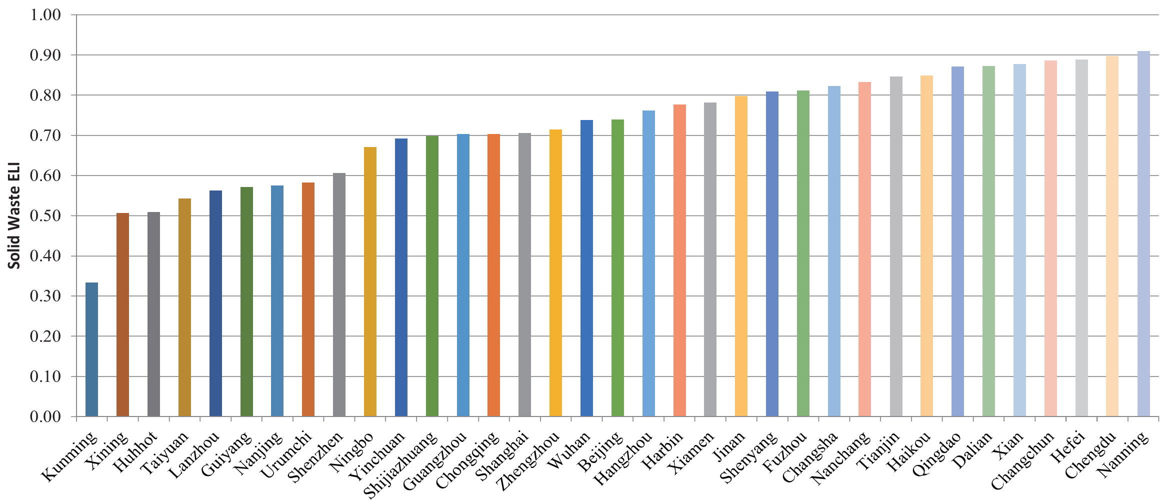


5.4 Solid Waste

City ranking

Figure 18 ranks solid waste livability indices: Nanning ranks the highest and Kunming the lowest. Of megacities, Beijing ranks higher than Guangzhou or Shanghai. In general, west cities such as Kunming, Xining, Huhhot, Taiyuan, Lanzhou, Guiyang, and Urumchi rank relatively poorly.

Figure 18 Ranking of Urban Solid Waste Livability Indices in China

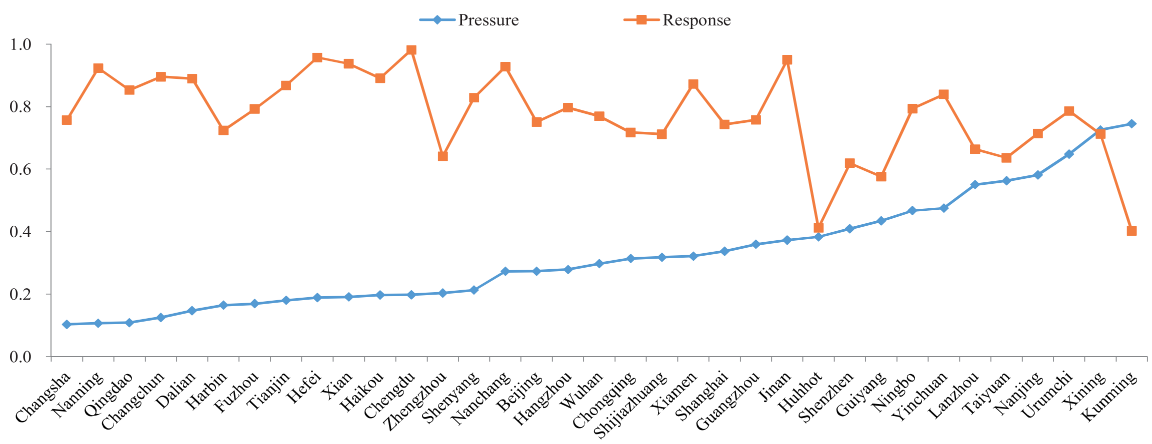


Pressure-state-response

According to Figure 19, Kunming has the highest solid waste discharge pressure and Changsha the lowest. Chengdu has the strongest disposal response and Hohhot the weakest. Of China's megacities, Shanghai's and Guangzhou's discharge pressure is higher than Beijing's, but their response are similar.

In general, as discharge pressure increases, environmental response capacity decreases. Some cities, such as Hohhot, Kunming, and Guiyang have substantial solid waste pressures but very weak response capacities. These cities must enhance their ability to use, treat and dispose of urban solid waste to improve their environmental livability index.

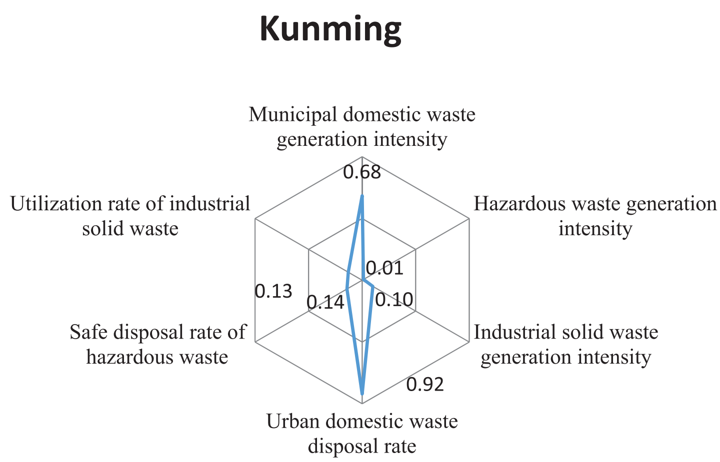
Figure 19 Pressure-Response Analysis of Livability Index in Urban Solid Waste in China



Case study

Solid waste problems in Kunming are main problem, as shown in Figure 20. This is because Kunming produces a lot of industrial and hazardous solid waste but is ill equipped to utilize, treat and dispose of it.

Figure 20 Identification of Major Issues for Kunming

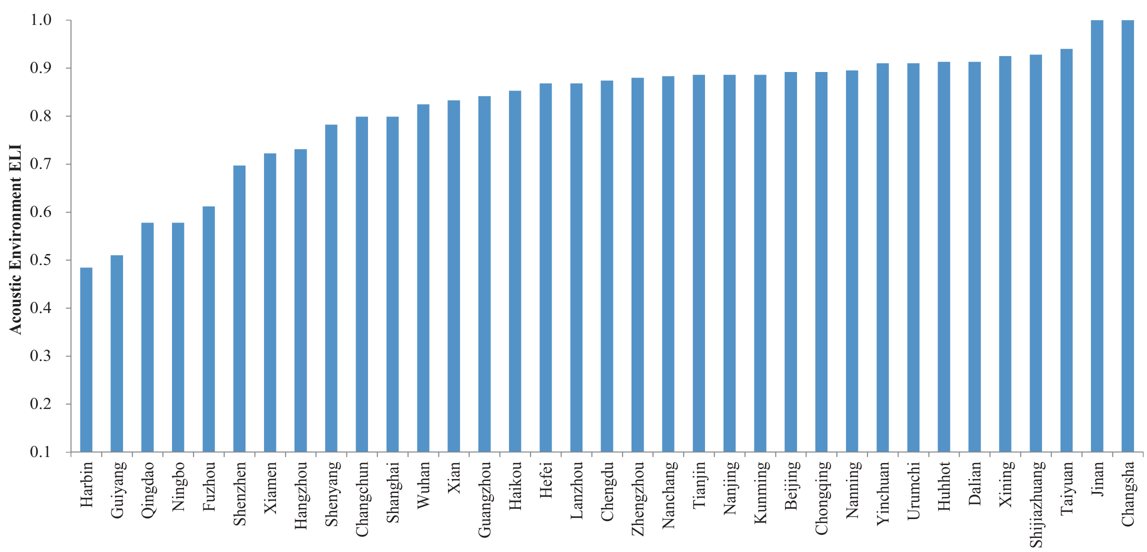


5.5 Acoustic Environment

City ranking

Figure 21 ranks noise levels for the cities studied. Jinan and Changsha rank the highest and Harbin the lowest. Of China's megacities, Beijing has a higher noise environmental livability index than Guangzhou or Shanghai. In general, compared with the other environmental indices discussed in this report, urban Acoustic environmental livability in China is high, with the index mostly above 0.6, indicating reasonably good livability in most cities except Harbin, Guiyang, Qingdao and Ningbo.

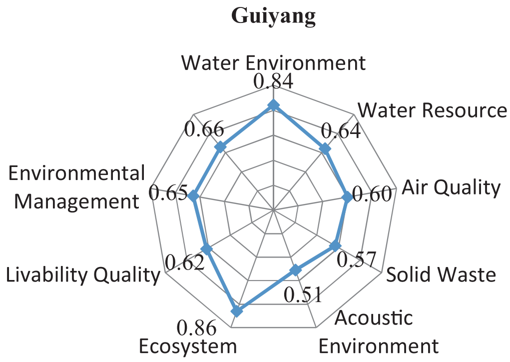
Figure 21 Ranking of Urban Noise Environmental Livability Indices in China

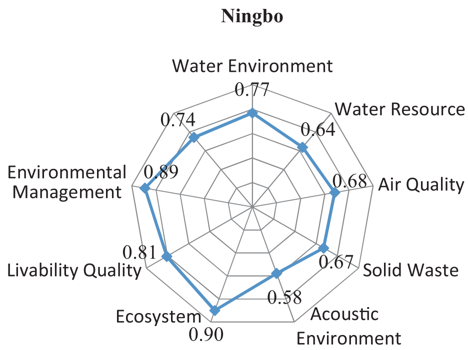


Case study

The main environmental problem in Guiyang and Ningbo, as shown in Figure 22, is noise pollution. To improve its overall environmental livability, Guiyang and Ningbo should therefore focus on treating urban noise pollution.

Figure 22 Identification of Major Issues for Guiyang and Ningbo



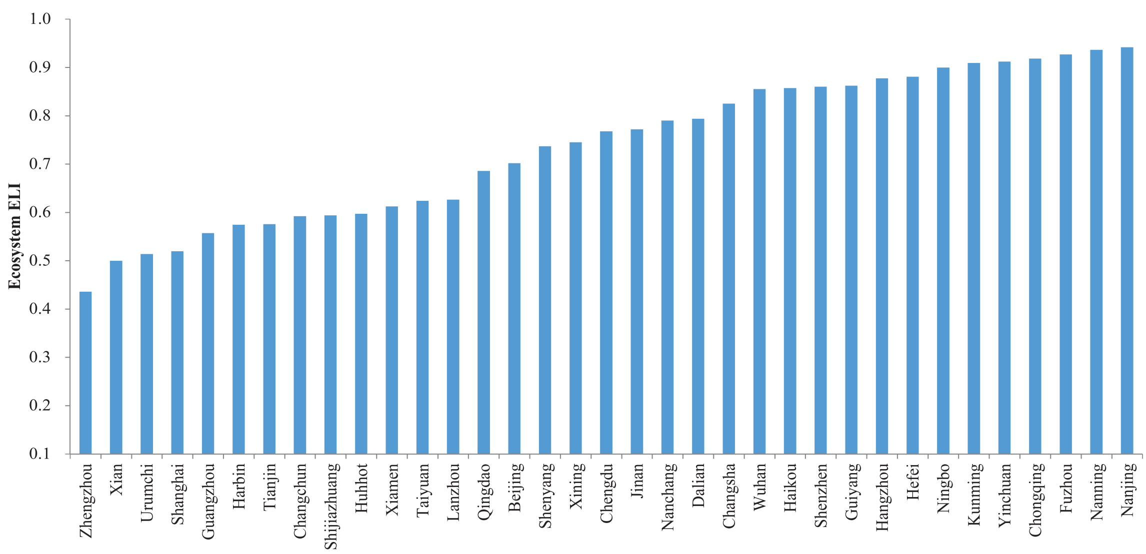


5.6 Urban Ecological Environment

City ranking

Figure 23 ranks cities by ecological environmental livability indices. Nanjing is ranked highest and Zhengzhou lowest. Of megacities, Beijing rank higher than Shanghai and Guangzhou.

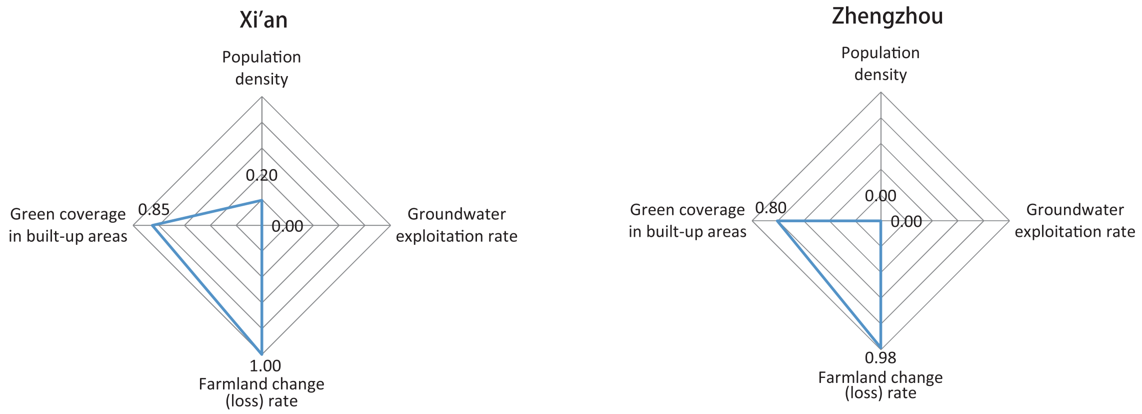
Figure 23 Ranking of Urban Ecological Environmental Livability Indices in China



Case study

Ecological environmental problems are serious in Xi'an and Zhengzhou, as shown in Figure 24, because of its high population density and ground water depletion.

■ **Figure 24 Identification of Major Issues for Xi'an and Zhengzhou**

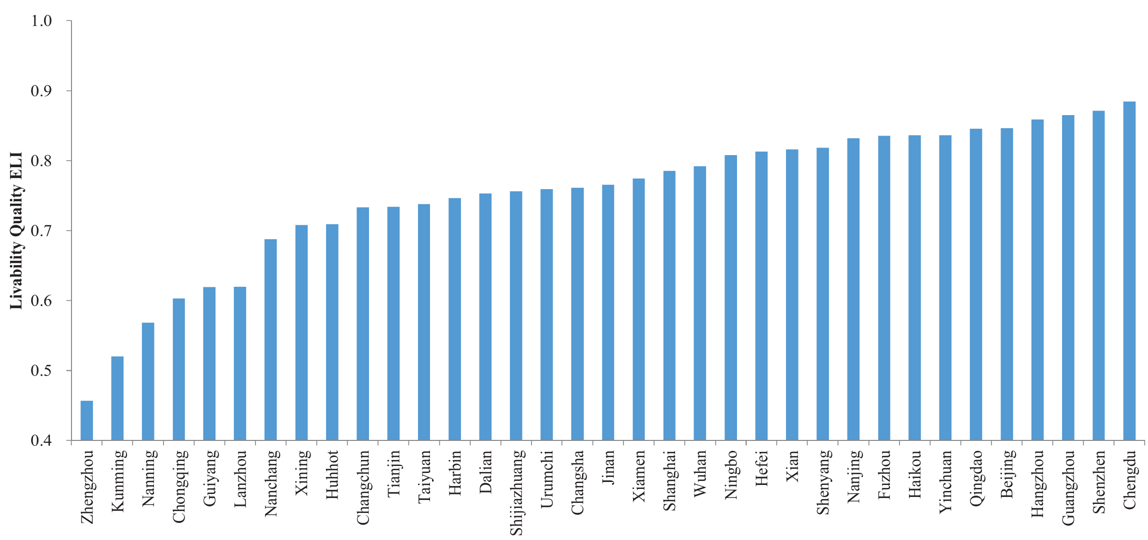


5.7 Urban Domestic Livability

Figure 25 ranks cities by domestic livability indices. Chengdu is ranked the highest and Zhengzhou the lowest. Of megacities, Guangzhou and Beijing have a higher domestic livability index than Shanghai.

In general, urban domestic livability in the economically developed east south regions (such as Hangzhou, Nanjing, Shenzhen, and Qingdao) is higher than in western cities (such as Kunming, Guiyang, Lanzhou, and Xining). For example, in Lanzhou the indicators of gas supply coverage rate and per capita park green area are lower than the economic well-developed region level.

■ **Figure 25 Ranking of Urban Domestic Livability Indices in China**



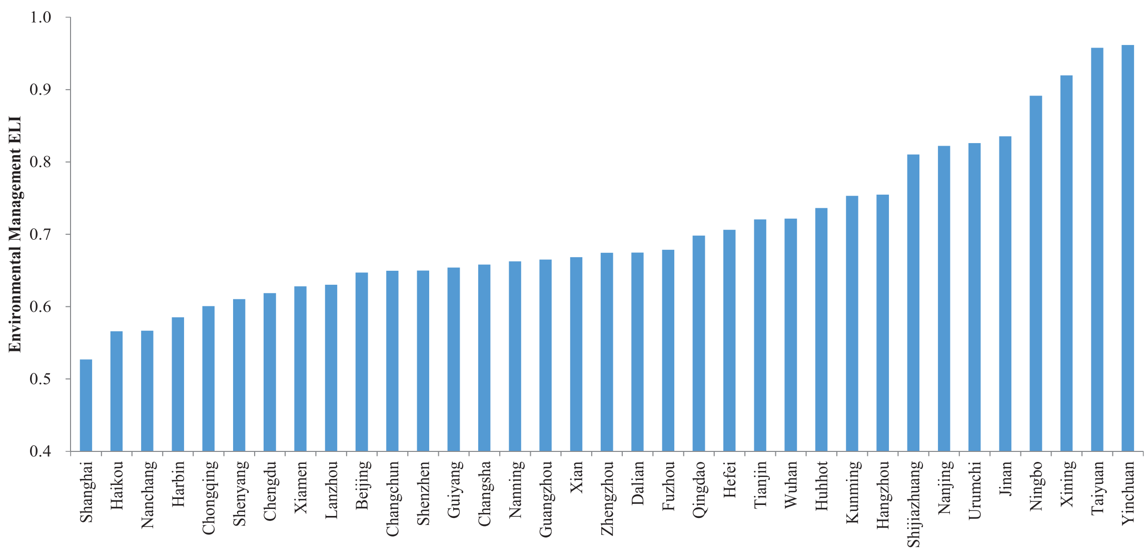
5.8 Environmental Management

City ranking

Figure 26 ranks cities by environmental management livability indices and shows that Yinchuan has the highest livability index in China and Shanghai the lowest. Shanghai mainly due to a lower environmental protection treatment personnel per 10,000 people, and proportion of treatment investment in GDP of megacities, Guangzhou and Beijing rank more highly than Shanghai.

In general, economically developed regions, such as Nanjing, Beijing, Tianjin, Chongqing, Dalian, Ningbo, Wuhan, and Guangzhou rank relatively well, indicating that they invest in environmental protection and attach importance to urban environmental management. Some cities (Nanning, Xiamen, Qingdao, and Haikou for example) that rank highly with regard to environmental livability rank poorly for environmental management. Such cities should increase investment in environmental protection and strengthen environmental management in order to raise overall urban environmental livability.

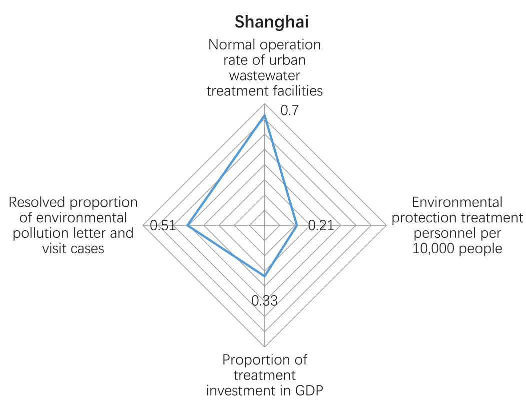
■ **Figure 26 Ranking of Urban Environmental Management Livability Indices in China**



Case study

According to Figure 27, environmental management is a major problem in Shanghai. This is the result of low investment in environmental protection and few staff dedicated to environment management. Therefore investment in urban environmental protection should be raised.

■ **Figure 27 Identification of Major Issues for Shanghai**

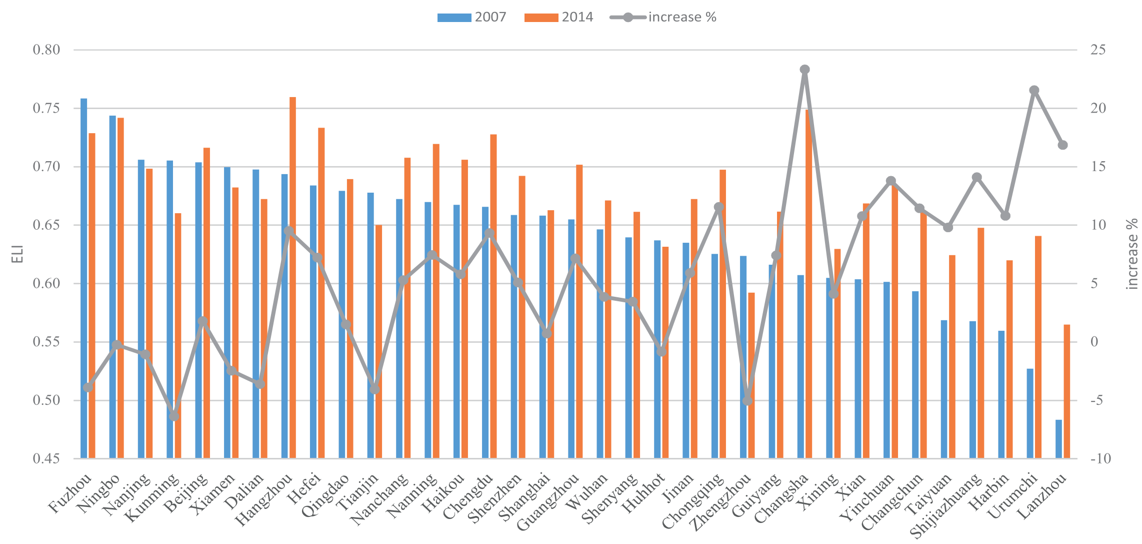


6. CONCLUSION AND PROSPECT

Conclusion

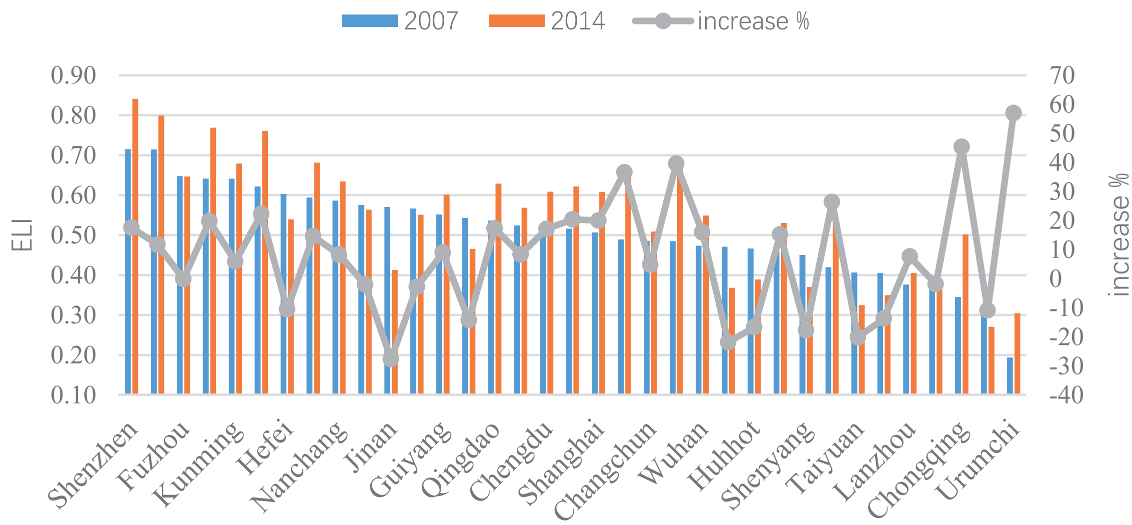
In 2007-2014 most cities have showing increase trends on their ELI, the city owning lowest ELI has the most potential on increment. During 2007-2014, ELI ranking has few changes in cities position, Fuzhou, Ningbo, Kunming, Xiamen, Beijing and Hangzhou has highest value of ELI, and Lanzhou Urumuqi, Shijiazhuang and Taiyuan with relative low value of ELI. Among those cities who have high ELI, Fuzhou, Ningbo, Nanjing, Kunming, Xiamen and Dalian have declined 3.9%, 0.3%, 1.1%, 6.4%, 2.5% and 3.6% respectively. Among those cities who have relative low ELI, Lanzhou, Urumuqi, Harbin, Shijiazhuang, and Changsha have the most increasing trend with 16.8%, 21.5%, 10.8%, 14.1%, 13.8% and 23.3% respectively. In the megacities, only Tianjin decline 4.1%, and Beijing and Guangzhou have increased 1.8% and 7.1% respectively.

Figure 28 2007-2014 ELI Changes in Major Cities



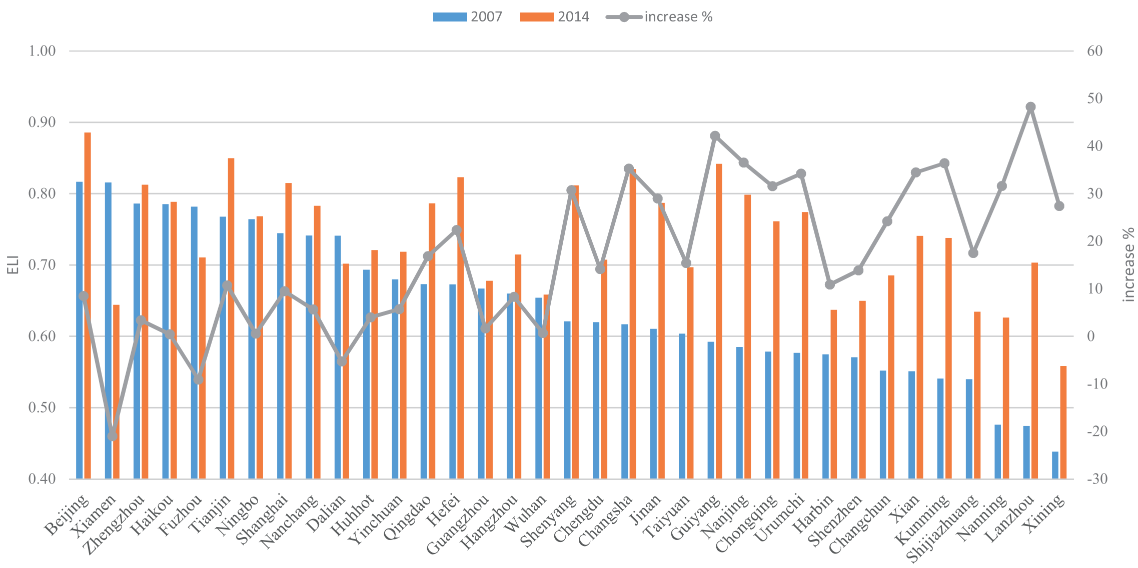
In 2007-2014 most cities have showing increase trends on their atmospheric environmental ELI the city owning lowest ELI has the most potential on increment. During 2007-2014, Shenzhen, Xiamen, Haikou, Kunming, Ningbo, Nanchang have the highest atmospheric environmental ELI, and Urumuqi, Xining, Shijiazhuang, Lanzhou, Taiyuan and Shenyang have the relative low atmospheric environmental ELI. In 2007-2014 Shenzhen, Xiamen, Haikou, Guangzhou and Ningbo's atmospheric environmental ELI has increased 17.6%, 11.8%, 19.8%, 22.3% and 14.6% respectively, and Xining, Shijiazhuang, Yinchuan, Taiyuan, Shenyang's atmospheric environmental ELI has decreased 10.9%, 1.9%, 13.7%, 20.1% and 17.7% respectively. Compare with 2007, the increase of Xining and Harbin in 2014 is because of high emitting intensity of SO2 and NOx which cause of days of achieving second grade air quality decrease, although the removal rate of SO2 and dust has decrease, but in overall atmospheric environmental ELI still has declined.

Figure 29 2007-2014 Atmospheric Environmental ELI Changes in Major Cities



In 2007-2014 most cities have showing increase trends on their water environmental ELI only Xiamen, Fuzhou and Dalian showing decline indication. During 2007-2014 Lanzhou, Guiyang, Kunming, Xian, Nanjing and Chongqing has increased its water environmental ELI 48.3%, 42.1%, 36.4%, 34.4%, 36.5% and 31.6% respectively. But Xiamen, Fuzhou and Dalian has declined the same index with 21%, 9.1% and 5.3% respectively. Compare with 2007 level, Xiamen has increased its intensity on waste water and heavy metal discharge, Fuzhou has increased its COD and heavy metal intensity, and Dalian has mainly increased its COD, wastewater discharge intensity. Although these three cities have increased their urban waste water treatment rate, but still their water environmental ELI has declined.

Figure 30 2007-2014 Water Environmental ELI Changes in Major Cities



PROSPECT

Although the test application shows that the ELI system can be used as a tool for environmental livability evaluation and policy analysis, but there are many methodological uncertainties regarding establishing ELI and institutional barriers for applying ELI for policy making. The methodological uncertainties include: (i) The aggregated ELI and its indicators are usually constructed in a manageable size by scarifying details. Further some aspects on environmental livability may not be measurable in a quantitative way. Policy analysis and making are normally required to fully understand the phenomenon or issues, which may require other qualitative and scientific information such as driving forces and natural conditions for explaining trends or issues, therefore the ELI system should be used as only one of tools, that is, as a tool for helping reveal trends and draw attention to problems that require further analysis and possible actions. (ii) Implicit assumptions in selection of indicators and calculation of weights. The determination of weights directly affects the evaluation results. These indicators and weights needs to be further tested and verified in the future applications, therefore the ELI system needs to be upgraded regularly. For example the improvement of the weight of water and atmospheric environment will make the evaluation result closer to the public feeling.

The institutional barriers are: (i) data availability and data quality. The data availability and data quality is a critical issue for applying the ELI system. For current testing application, data comes from different sources. Some of data are from research reports, that means these data are not regularly measured, also most of data are not available for medium and small cities. The data availability has made problems in selection of appropriate indicators, which may result in failing to measure important aspects of environmental livability and also it limits the possibility of applying it in small and medium cities. Lack of data availability and data quality will cause problems to give unbiased or complete picture of environmental livability, that may lead to serious problems on policy decision. (ii) benchmarks and targets. Environmental standards and national environmental planning target can be used as benchmarks and targets for some of the indicators, but it is difficult to define a common recognized benchmarks and targets for standardizing some of the indicators such as emission per GDP etc.

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