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Water quality problems and control strategies in China

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Abstract China's development is severely limited by water shortage, whereby the per capita water resource is only about one quarter of the global average. The limited supply of water has been further aggravated by declining water quality over the past three decades. Almost all water bodies across China, i.e. rivers, lakes and groundwater, are polluted to some degree. According to the *Environment Bulletin of China*, 24.3% of the monitored sections of the seven major rivers were in water quality grade IV–V (meaning no longer suitable as drinking water) in 2009, and 18.4% below grade V, which means that the water cannot be used for any purposes. The water quality of rivers in northern China was found to be particularly impaired. For example, 42.2% of monitored sections along the Haihe River were classified as worse than quality grade V in 2009. Seven of the nine key lakes in China are also severely polluted and suffer eutrophication on account of elevated concentrations of nitrogen and phosphorus. The groundwater supplies for 97% of 195 cities investigated were also found to be polluted. Key pollutants are organic or inorganic nitrogen and active phosphate, which is sourced from not only industrial point pollution, but increasingly from agricultural diffuse pollution and domestic inputs. Although a substantial effort has been made to reduce water pollution from point sources, improvements have largely been offset by the increasing diffuse pollution caused by the over-use of fertilizers and pesticides in agriculture. Some strategic suggestions for more rigorous rules of environmental protection in China, particularly for controlling agricultural diffuse water pollution are presented.

Keywords water quality; water pollution; water body; environmental protection; China

INTRODUCTION

Water problems in terms of both quantity and quality are emerging as a limiting factor for society development and ecological stability worldwide (Falkenmark, 1990), and notably in the Asia and Pacific region including China, where rapid economic development and population growth bring extreme water problems and integrated water management strategies and techniques are urgently required. Understanding the water problem status in China will be helpful for solving the water problems not only in China, but also in many other countries and regions.

China is a country suffering from serious water shortage, and this has been increasingly aggravated by the widespread problem of water pollution (Cao *et al.*, 2006; Peng *et al.*, 2010; Li *et al.*, 2012), especially in the dry region of northern China (Wang, 2001; Zhang *et al.*, 2008). Almost all water bodies across China, i.e. rivers, lakes and offshore sea waters, including the groundwater, are polluted to some extent (MEP, 2010). Some water ecosystems have been so heavily impaired that fish and shrimps have suffered mass kills (MEP, 2010). Declining water quality has jeopardised the supply of safe drinking water to millions of people (MWR, 2010).

During recent years, China's Government has put substantial efforts and resources towards reducing the water pollution problem, especially the impairment derived from industrial point sources. However, progress was less than expected with regards to water quality improvement, and water pollution therefore remains a serious national problem. Given the enduring national water quality problem, it is important to understand the contributions from different sources and in conjunction with this evidence base, to improve current water management policy and catchment planning strategies for water pollution control.

Against the above background, this paper summarizes the current status of water pollution across China highlighting the key sources which are responsible for offsetting reduced point source pollution. Some suggestions for improving the current water policy and management strategies for water pollution control are provided.

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STUDY AREA

China is a country with an area of 9.6×10^6 km^2 and a typical continental monsoonal climate, i.e. the summer is warm and humid and the winter is cold and dry. The annual precipitation varies from 1600 mm in the southeastern region to less than 50 mm in the northwestern region. Across China, there are more than 10 000 rivers, of which 1500 have a catchment area of >1000 km^2. Seven major river systems can be identified namely, the Yangtze River, Yellow River, Pearl River, Haihe River, Huaihe River, Songhua River and Liaohe River (Table 1). Collectively, these seven major river systems cover a total drainage area of 2.5×10^6 km^2, with an annual runoff of 1.20×10^{12} m^3, accounting for 39.9% of total river discharge across China. Plenty of natural lakes exist in the Yangtze River Plain and on the Qinghai-Tibet Plateau. The total water storage of the four largest freshwater lakes, i.e. Poyang, Dongting, Taihu and Hongze lakes (Table 2), amounts to 51×10^9 m^3, which accounts for 1.8% of the total freshwater resources in China.

Table 1 Characteristics of the seven major river systems in China.

Name	Length (km)	Drainage area ($\times 10^3$ km^2)	Mean annual runoff ($\times 10^9$ m^3)	Remarks
Yangtze River	6300	1808.5	975.5	
Yellow River	5464	752.0	59.2	
Pearl River	2214	454.0	336.0	
Haihe River	1090	263.4	22.8	
Huaihe River	1000	269.0	61.1	Including the rivers Yi, Shu and Si
Songhua River	2309	556.8	74.2	
Liaohe River	1345	219.0	14.8	

Table 2 Characteristics of selected key lakes in China.

Name	Area (km^2)	Storage ($\times 10^9$ m^3)	Location	Remarks
Poyang Lake	3583	25.9	Southern bank of Yangtze River, northern part of Jiangxi province	China's largest freshwater lake
Dongting Lake	2740	17.8	Southern bank of middle Yangtze River, northern part of Hunan province	China's 2nd largest freshwater lake
Taihu Lake	2420	4.9	On the border of Jiangsu and Zhejiang provinces, south of the Yangtze River Delta	China's 3rd largest freshwater lake
Hongze Lake	2096	2.4	West of Hongze country of Jiangsu province, on the alluvial plain of middle reach of Huaihe River	China's 4th largest freshwater lake
Dianchi Lake	297	1.2	Southern part of Kunming, Yunnan province	

Water resources and arable land across China are very unevenly distributed. In the Yangtze River basin and southwards from it, there are more than 80% of the available water resources but only 35.2% of arable land. Conversely, in the basins of the Yellow River, Huaihe River, Haihe River and the northwest inland rivers, the land area and arable land account for 50% and 45% of the respective totals for China, but the available water resources only represent 12% of the corresponding national total. China is suffering from a serious water shortage; the volume per capita is only 2185 m^3/year, which is about one quarter of the global average. The water shortage amounts to over 40 billion m^3/year in China. About two-thirds of cities are water-needy and nearly 300 million rural residents lack access to safe drinking water. More important is that the water shortages are increasingly aggravated by widespread problems of water pollution.

METHODS

Water quality monitoring and its evaluation in China

In China, a national surface water quality monitoring programme has existed since the 1980s (Gao *et al*., 2006). As part of this national programme, 607 monitored sections were identified on the main rivers (e.g. the Yangtze and Yellow rivers), lakes (e.g. Poyang Lake, Taihu Lake) and large reservoirs. Key water quality parameters such as suspended solids, pH-value, dissolved oxygen, electrical conductivity, BOD, ammonium nitrogen, oils, volatile phenols, sulphate, residual chlorine, mercury and lead, have generally been sampled and measured twice per month since the instigation of this monitoring strategy. Water quality is evaluated according to the Environmental Quality Standards for Surface Water of the People's Republic of China (GB3838-2002) and classified into five levels (Table 3). If the water is graded I–II or III, water quality is very good or good, and consequently, it can be used as drinking water, for fishing and for recreation purposes. If, however, the water is graded as IV or V, meaning that it is lightly or moderately polluted, it can be used only for industry and irrigation, but not for domestic purposes. If the water is graded as below V, it means it is so severely polluted that it cannot be used by any sector.

Table 3 The basic parameters for surface water environment classification (mg/L) in China.

No.	Parameters	Grade I	Grade II	Grade III	Grade IV	Grade V
1	Water temperature (°C)	The man-made variations should be ≤1°C if increase or ≤2°C if decrease per week				
2	pH value	6–9				
3	Dissolved oxygen ≥	90% saturation (or 7.5)	6	5	3	2
4	Permanganate index ≤	2	4	6	10	15
5	COD_{Cr} ≤	15	15	20	30	40
6	BOD_5 ≤	3	3	4	6	10
7	NH_3-N ≤	0.15	0.5	1.0	1.5	2.0
8	Total P ≤	0.02 (0.01 for lake/reservoir)	0.1 (0.025 for lake/reservoir)	0.2 (0.05 for lake/reservoir)	0.3 (0.1 for lake/reservoir)	0.4 (0.2 for lake/reservoir)
9	Total N ≤	0.2	0.5	1.0	1.5	2.0
10	Cu ≤	0.01	1.0	1.0	1.0	1.0
11	Zn ≤	0.05	1.0	1.0	2.0	2.0
12	Fluoride (expressed in F^-) ≤	1.0	1.0	1.0	1.5	1.5
13	Se ≤	0.01	0.01	0.01	0.02	0.02
14	As ≤	0.05	0.05	0.05	0.1	0.1
15	Hg ≤	0.00005	0.00005	0.0001	0.0001	0.0001
16	Cd ≤	0.001	0.005	0.005	0.005	0.01
17	Cr (Cr^{6+}) ≤	0.01	0.05	0.05	0.05	0.1
18	Pb ≤	0.01	0.01	0.05	0.05	0.1
19	Cyanide ≤	0.005	0.05	0.2	0.2	0.2
20	Volatile phenols ≤	0.002	0.002	0.005	0.01	0.1
21	Oils ≤	0.05	0.05	0.05	0.5	1.0
22	Anionic surfactant ≤	<0.2	0.2	0.2	0.3	0.3
23	Sulfate (SO_4^{2-}) ≤	0.05	0.1	0.2	0.5	1.0
24	Coli-index (individuals/L) ≤	200	2000	10 000	20 000	40 000

* COD_{Cr} is chemical oxygen demand measured with potassium dichromate. BOD_5 is five-day biochemical oxygen demand.

Data sources

The water quality data used by this paper are cited from:

– the *China Environmental Status Bulletin of 2009* (http://jcs.mep.gov.cn/hjzl/zkgb/2009hjzkgb/201006/t20100603_190435.htm),
– the *Water Resources Quality Bulletin of the Yangtze River of 2009* (http://www.ywrp.gov.cn/szgb/News/Default.asp?cataid=A00070001),
– the *Surface Water Quality Bulletin of the Yellow River Basin of 2009* (http://www.yrwr.com.cn/cms/showsubpage.jsp?columnId=11),
– the *Taihu Basin and Southeastern Rivers Water Resources Bulletin of 2009* (http://www.tba.gov.cn:90/art/2010/11/25/art_41_34151.html),
– *Pollution Prevention and Control Planning of the Yangtze River Basin of 2011–2015* (http://www.zhb.gov.cn/gkml/hbb/bwj/201109/t20110920_217490.htm), and
– the *12th 5-year Plan for Environmental Protection* (http://gcs.mep.gov.cn/hjgh/shierwu/).

Some data were also extracted from published journal papers.

RESULTS

The national picture of water quality across China

All types of surface water across China, including rivers, lakes, groundwater, and offshore sea water, are polluted to some extent. In 2009, those rivers with a water quality grade of I–II only accounted for 32.2% of the rivers monitored. All of the seven major rivers were classified as having intermediate pollution. Lake eutrophication problems in China have become increasingly prominent over recent years, especially in the more developed regions. Equally, groundwater quality has deteriorated in many cities, especially those in northern China.

The water quality of rivers

According to official statistics, more than 850 rivers of the 1200 included in the national monitoring programme have been polluted over recent years (Fig. 1). Among 408 designated monitoring sections for surface water, in 203 monitored rivers which belong to the seven major river systems, 57.3%, 24.3%, and 18.4% were rated as grades I–III, IV–V, and below V,

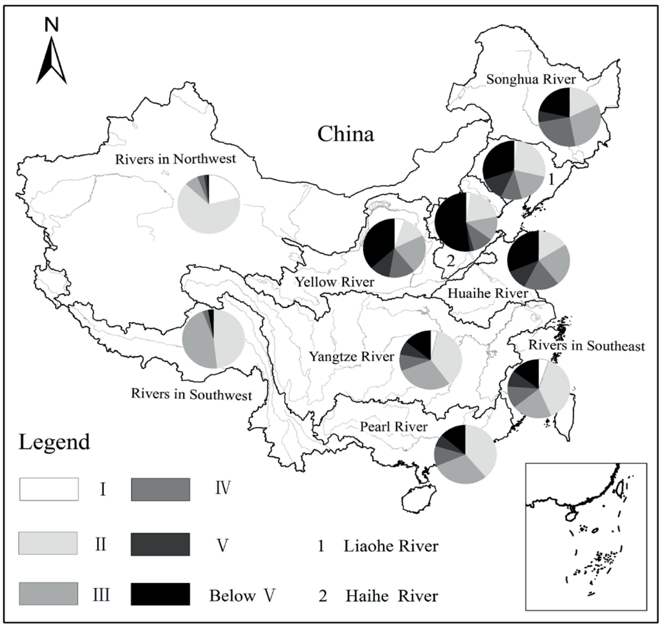

Fig. 1 The water quality grades for different river systems in China (2008) (Modified from the map at http://www.hydroinfo.cn/gb/szyzlnb/2008/).

respectively. In the case of the Yellow, Huaihe and Haihe rivers in dry northern China, the polluted river length exceeded 60% of their respective total lengths. Major pollutants included permanganate index, five day biochemical oxygen demand (BOD_5) and ammonium nitrogen.

The water quality of lakes

The pollution of lakes was much worse than rivers. Taking the Tai Lake as an example, the water quality was rated as grade V in 2009 although the rivers flowing into this lake were classified as just lightly polluted. Based on monitoring data, 36.3%, 33.0%, 11.4% and 19.3% of the 88 water quality monitoring sections were rated into the water quality grades of I–III, IV, V and below V, respectively. The water quality of 26 national key monitored lakes (and reservoirs) was assessed by the Ministry of Environmental Protection (MEP) in 2009 (Table 4). The data showed that 6, 6, 5 and 9 lakes (and reservoirs) met the water quality grades of I–III, IV, V and below V, respectively. Major pollutants were total nitrogen and total phosphorus. Excessive concentrations of nitrogen and phosphorus caused the outbreak of toxic cyanobacteria in Tai Lake in 2007 (Qin *et al*., 2007).

Table 4 The water quality of the key lakes and reservoirs in China in 2009.

Lake type	Lake number	Grade I	Grade II	Grade III	Grade IV	Grade V	Below grade V	Major pollutants
Three lakes*	3	0	0	0	0	1	2	Total N, total P
Large freshwater lakes	9	0	0	3	2	1	3	
Urban lakes	5	0	0	0	2	1	2	
Large reservoirs	9	0	1	2	2	2	2	
Total	26	0	1	5	6	5	9	
Proportion (%)	100	0	3.9	19.2	23.1	19.2	34.6	

*Three lakes include the Tai, Dianchi and Chao lakes.

Many lakes across China suffer from serious eutrophication. An assessment of lake eutrophication was completed in 2009 using the method of comprehensive nutrition state index (Wang *et al.*, 2002; Jing *et al.*, 2008). The evaluation indices included Chl-a, TP, TN, Transparent Degree (SD) and COD_{Mn}. The findings suggested that 57.7% of lakes were mesotrophic, with 30.8%, 7.7% and 3.8% suffering from light, middle and hyper-eutrophication, respectively.

Groundwater quality

Groundwater pollution has been reported in many urban aquifers throughout the world (Somasundaram *et al*., 1993). This is a serious water quality problem, firstly because no sufficient alternative water supplies exist in many parts of the world, and secondly because the restoration of groundwater pollution is very difficult. The outlook for groundwater pollution in China is not optimistic. Groundwater quality was monitored in 2009 using water samples from 641 groundwater wells distributed across eight provinces or municipal cities (Beijing, Liaoning Province, Jilin Province, Shanghai, Jiangsu Province, Hainan Province, Ningxia Hui Autonomous Region and Guangdong Province). The data showed that only 2.3% of monitored wells were rated in the water quality grade of I–II; while 23.9% and 73.8% were classified as grades III and IV–V, respectively. Major pollutants included total hardness, ammonium nitrogen, nitrite nitrogen, ferrum iron and manganese.

SOME KEY FEATURES OF WATER QUALITY ACROSS CHINA

More serious pollution in northern than southern China

River water quality is generally more degraded in the dry northern areas of China, because of lower river discharges. Taking northern China rivers as examples, the Yellow River and Liaohe River were moderately polluted, and the Haihe River was seriously polluted in 2009. Among the

44 monitoring sections of the Yellow River, 68.2%, 4.5%, 2.3% and 25.0% were rated as grade I−III, IV, V, and below V in 2009, respectively. Major pollutants included petroleum products, ammonium nitrogen and BOD_5. In the Haihe River, 12.5% and 42.2% of the monitoring sections were rated as grade V and below V, respectively. In comparison, for the Yangtze River in southern China, 87.4%, 5.8%, 2.9% and 3.9% of the 103 surface water monitoring sections were rated as grade I−III, IV, V, and below V in 2009, respectively. The major pollutants in this river system were ammonium nitrogen, BOD_5 and petroleum products.

Better water quality in main rivers than tributaries

In general, the water quality in the main stem of rivers was better than in the tributary streams because of the lower discharges characterizing the latter. For example, the water quality of the main stem of the Huaihe River was lightly polluted in 2009 (37.3% and 33.7% of the 86 surface water quality monitoring sections were, respectively, rated as grade I−III and IV; while 11.6% and 17.4% of monitoring sections were classified as grade V and below V), whereas its tributary streams were, in comparison, moderately polluted. The Guohe and Yinghe rivers, representing the first order branches of the Huaihe River, were severely polluted. The major pollutants in the Huaihe River were permanganate index, BOD_5 and ammonium nitrogen.

More serious pollution in river reaches flowing through cities

Generally speaking, cities contribute greatly to the pollution of rivers in China and elsewhere around the world. Based on the water quality monitored at 15 water supply sites for important cities along the main stem of the Yellow River (Table 5), river water was found to be more seriously polluted along the reaches flowing through cities or their suburbs. For example, the water quality at the water supply sites to Shizuishan City, Baotou City, Hohhot City and Sanmenxia City was rated as grades IV, IV, IV and V, respectively. The principal pollutants were ammonium nitrogen and COD.

Lower groundwater quality on the highly developed plains

The groundwater quality in southern China is better than in northern China. The area with groundwater quality grade I-III amounted to more than 90% of the total area in southern China, although the shallow groundwater on some plains was severely contaminated. The most serious groundwater pollution was identified in the highly developed delta of the Yangtze River (Wang *et*

Table 5 Water quality at 15 water supply sites to cities along the main stem of the Yellow River.

No.	Water supply sites	City	Annual water quality grade	Monthly ratio better than Grade III (%)	Major pollutants
1	Xinchenqiao	Lanzhou	II	100	
2	Shuichuandiaoqiao	Baiyin	II	100	
3	Shizuishan	Shizuishan	IV	0	NH_3-N, COD
4	Zhaojunfen	Baotou	IV	8.3	COD
5	Huajiangying	Baotou	IV	0	COD
6	Dengkou	Baotou	IV	8.3	COD
7	Toudaoguai	Hohhot	IV	8.3	COD
9	Gongluqiao	Sanmenxia	V	25.0	NH_3-N, COD
10	Huayuankou	Zhengzhou	III	91.7	
11	Kaifengdaqiao	Kaifeng	III	91.7	
12	Gaocun	Puyang	III	91.7	
13	Luokou	Jinan	II	100	
14	Binzhou	Binzhou	II	100	
15	Lijin	Dongying	II	100	

al., 2005), where many industries and cities exist. In some cities of this region, groundwater quality was rated as moderate, e.g. Yangzhou City in Jiangsu Province, and Changshu City, Lin'an City and Hangzhou City in Zhejiang Province.

In northern China, the groundwater quality in the hilly and mountainous areas and the piedmont plains is relatively good, but is worse in the plain areas and the coastal regions. In 2003, the groundwater quality was investigated twice in Beijing during the low-water period in April and the high-water period in September. It was found that only 22 wells (55%) met water quality grade III. The main pollutants included total hardness, turbidity and manganese (He *et al.*, 2005). According to the groundwater organic contamination survey finished by the Ministry of Land and Resources P.R.C. in 2000–2002, trace levels of toxic organic pollution were detected universally in the main cities and their environs, including the Beijing-Tianjin-Hebei Region, Yangtze River Delta, Pearl River Delta and the plain areas of the Huaihe River.

THE PRINCIPAL SOURCES OF WATER POLLUTION

The main sources of water pollution in China can be divided into the industrial sources, urban and rural residential areas and diffuse agricultural sources. The efficiency of treatments and their associated cost-benefit ratios for these key sources differ, as do their contributions to the water pollution problem. Understanding the key sources of water pollution is an essential prerequisite to improving future decision making and catchment planning. Generally speaking, the major pollutants of rivers include ammonium nitrogen, BOD, COD_{Mn} and volatile phenols. Lake pollution is dominated by eutrophication as well as issues associated with COD and COD_{Mn}. Industrial point pollution has been effectively reduced by the development of effective technologies and strategies. This has increased the relative contribution from the remaining pollution sources. As a result of the increasing living standards and population and food security pressures in China, the absolute magnitude of pollutant losses from urban and rural sewage and from diffuse agricultural sources have been continuously increasing, and these now represent the main sources of water pollution. The increased importance of diffuse sources makes water pollution control far more challenging.

As an example, in the middle and lower reaches of the Yangtze River, the amount of wastewater reached 10.48×10^9 tonnes in 2009, of which industrial wastewater and urban residential sewage represented 36% and 64%, respectively. The COD was 4.99×10^6 tonnes, to which the relative contributions from industrial pollution, urban residential sewage and agricultural diffuse pollution were 15.5%, 40.4% and 44.1%, respectively. The total loss of ammonium nitrogen amounted to 378 000 tonnes, to which the relative inputs from industrial pollution, urban residential sewage and agricultural diffuse pollution were 17.8%, 66.0% and 16.2%, respectively. Taking Tai Lake as another example, which is nearly entirely in Jiangsu and Zhejiang Provinces, and very seriously polluted, although the amount of wastewater originating from industry was much more than that from urban residential sewage, the total P and NH_3-N water pollution were mostly from non-industrial sources and especially agricultural diffuse pollution (Table 6).

Table 6 The amount and sources of main pollutants in Tai Lake Basin in 2000.

Pollutant export and key sources		COD	TP	NH_3-N
Total pollutant export from Jiangsu and Zhejiang Provinces (1000 tonnes/year)		491.5	14.4	130.0
Relative contribution from different sources (%)	Industrial pollution	44	7	5
	Urban residential areas	29	27	18
	Rural residential areas	11	28	20
	Diffuse agricultural sources	16	38	57

STATUS OF WATER POLLUTION CONTROL AND SUGGESTIONS FOR THE FUTURE

The current status of water pollution control

The main focus of water pollution control in China remains the industrial pollutants that are relatively easier to control. For example, more efforts will be directed in the 12th Five-Year Plan (2011–2015) to reducing the total emissions of COD and ammonium nitrogen from the paper-making, printing and dyeing, and chemical industries by more than 10%, compared with levels recorded in 2010. Increasing investments have also been directed towards the treatment of domestic sewage in China, after growing recognition of its major contribution to water pollution by sewage waste. For example, during the 11th Five-Year Plan (2006–2010), the treatment ratio of sewage in cities was increased from 52% to 72%. During the 12th Five-Year Plan, more investment will be focused on the construction of sewage treatment plants, sewage pipe networks, and both rainwater and sewage diversions. On this basis, it is intended that the treatment ratio of sewage in cities should be increased to 85% by 2015. This means that a significant proportion of sewage in Chinese cities is still not subjected to any treatment.

Agricultural diffuse pollution has increased dramatically in conjunction with the widespread over-use of chemical fertilizers and pesticides. Similarly, rural diffuse pollution has also been characterized by increasing rural residential garbage and untreated sewage. Thus, agricultural and rural diffuse pollution more generally play an increasingly important role in the deterioration of water quality across China. These sources require improved mitigation but pose a challenge given their diffuse nature in river catchments.

Suggestions for future control of agricultural diffuse water pollution

It is deeply embedded in Chinese traditional agriculture that higher applications of fertilizer always provide higher crop yields. This has severely limited the efficacy of control strategies for agricultural diffuse pollution. Moreover, there are no specific laws or regulations for controlling agricultural diffuse pollution and no active financial compensation mechanism for promoting environmentally-friendly applications of fertilizers and pesticides. Policy still requires a major effort to convince farmers to adopt new technologies for reducing agricultural diffuse pollution, but a financial compensation mechanism and extension service are also required urgently. Some key lessons can be learned from overseas, including the development history of agricultural best management practices for water pollution control in the USA (Logan, 1993), and the use of agri-environment schemes as financial incentives to farmers across the European Union (Pretty *et al*., 2001). The laws and regulations on controlling agricultural diffuse pollution should be developed and improved in detail. This requires more scientific studies to be carried out and more practical techniques to be developed (Logan, 1993) for promoting the rational use of chemical fertilizers and pesticides, for quantifying and utilizing the natural buffering capacity of soils for reducing pollution and for developing a system for promoting sustainable agriculture (Guo *et al.*, 2008). Pollution control also needs to be improved in the livestock and poultry agricultural sectors and this should go hand in hand with recycling organic wastes, such as livestock and poultry manure.

There is an urgent need to establish experimental and demonstration sites for promoting to farmers advanced mitigation options such as the adoption of low toxicity pesticides and rational fertilization techniques (Cui *et al.*, 2006). The extension system for land use and management should be further developed and supported to guide farmers in applications of organic fertilizers and standard fertilization techniques. The rational use of agricultural pesticides must be seen as critical for improving water quality in many areas (Wang *et al.,* 2008). Furthermore, demonst-rations are required to improve the treatment and recycling of rural residential garbage, sewage, and both human and animal excreta (Sun *et al*., 2010).

Besides engineering treatments for diffuse pollution, increased importance should be attached to the utilization of the water purifying functions of forest and vegetation. These types of land cover can play a unique role in agricultural diffuse pollution control. For example, vegetative filter strips (VFS) have already been accepted as one of the best management practices for helping to reduce diffuse water pollution (Verhoeven *et al*., 2006; Wang *et al*., 2008; Li *et al*., 2010; Deng *et* *al*., 2011). However, there continues to be a paucity of best-practice demonstrations for VFS across China. In addition, the shortage of farm land and the costs of transferring fertile land to VFS cause many farmers to discount this specific mitigation option for diffuse water pollution. In response to this resistance to adoption, the multifunctional benefits of VFS should be explored and emphasized to stakeholders as soon as possible.

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