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Nonpoint Source Pollution, Environmental Quality, and Ecosystem Health in China: Introduction to the Special Section

Minghua Zhang* and Jianming Xu

The rapid economic and industrial growth of China, exemplified by a 10-fold increase in its gross domestic product in the past 15 years, has lifted millions of its citizens out of poverty but has simultaneously led to severe environmental problems. The World Health Organization estimates that approximately 2.4 million deaths in China per year could be attributed to degraded environmental quality. Much of China's soil, air, and water are polluted by xenobiotic contaminants, such as heavy metals and organic compounds. In addition, soil quality is degraded by erosion, desertification, and nutrient runoff. Air quality is further compromised by particulates, especially in heavily populated areas. Research shows that 80% of urban rivers in China are significantly polluted, and poor water quality is a key contributor to poverty in rural China. Economic and industrial growth has also greatly expanded the demand for water sources of appropriate quality; however, pollution has markedly diminished usable water resource quantity. Desertification and diminishing water resources threaten future food security. In recent years, China's government has increased efforts to reverse these trends and to improve ecosystem health. The Web of Science database showed that the percentage of articles on China devoting to environmental sciences increased dramatically in recent years. In addition, the top 25 institutes publishing the papers in environmental sciences were all in China. This special issue includes seven articles focusing on nonpoint source pollution, environmental quality, and ecosystem health in China. The major issues, and results of these studies, are discussed in this introduction.

THE UNPRECEDENTED ECONOMIC AND INDUSTRIAL GROWTH of China, exemplified by a 10-fold increase in its gross domestic product (GDP) in the past 15 years, has lifted millions of its citizens out of poverty but has simultaneously led to severe pollution of the soil, air, and water. The World Health Organization estimated that annually, 2.4 million deaths in China could be attributed to environmental problems (J. Zhang et al., 2010). Due to the rising population in China, soil erosion, desertification, nutrient runoff, and residual xenobiotic contaminants (e.g., heavy metals, organic pollutants) have become major issues in soil quality (Li et al., 2009; Bolan et al., 2010; Wang et al., 2010; Xiong et al., 2010). Currently, many of China's cities have severe air quality issues, including ozone, acid deposition, and volatile organic compound emissions (Hu et al., 2010). In addition, China also faces many water quality issues (e.g., nutrients runoff, pesticide runoff, heavy metals, pharmaceuticals, pathogens). Economic and industrial growth have greatly expanded the demand for water sources of appropriate quality; however, pollution has markedly diminished usable water resource quantity. Qu and Fan (2010) reported that 80% of urban rivers in China are significantly polluted, and studies have shown that poor water quality is a key contributor to poverty in rural China (Cohen and Sullivan, 2010). Desertification and diminishing water resources have threatened future food security (Khan et al., 2009; Mu and Khan, 2009).

In recent years, the Chinese government has focused great efforts on mitigating these problems while maintaining economic growth throughout the country, by means of increasing scientific funds for basic and applied research and implementing policies designed for environmental quality and ecosystem health protection. For example, the percentage of articles on China in the Web of Science database that are devoted to environmental sciences has increased dramatically in recent years, after remaining stagnant through the mid-1990s (Fig. 1). While 26% of the articles did not include any authors with Chinese addresses, the top 25 institutes were all in China (Table 1). Other governmental measures include elevating the primary environmental agency in China to the ministry level in 2008, as the Ministry of Environmental Protection (Lin and Swanson, 2010), and

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*Corresponding author (mhzhang@ucdavis.edu).
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5585 Guilford Rd., Madison, WI 53711 USA

M. Zhang, Wenzhou Medical College, Wenzhou, Zhejiang 325001, China, and Dep. of Land, Air and Water Resources, Univ. of California, Davis, CA 95616; J. Xu, Institute of Soil and Water Resources and Environmental Science, Zhejiang Univ., Hangzhou, Zhejiang, 310058, PR China. Assigned to Editor Dennis Corwin.

Abbreviations: BMP, best management practice; CCFGP, Conversion of Cropland to Forest and Grassland Program; EDC, endocrine disrupting chemical; HA, humic acid; NPS, nonpoint source; OC, organic compound; PAH, polycyclic aromatic hydrocarbon; PCP, pentachlorophenol; SOM, soil organic matter; TIE, toxicity identification evaluation; TOC, total organic content.

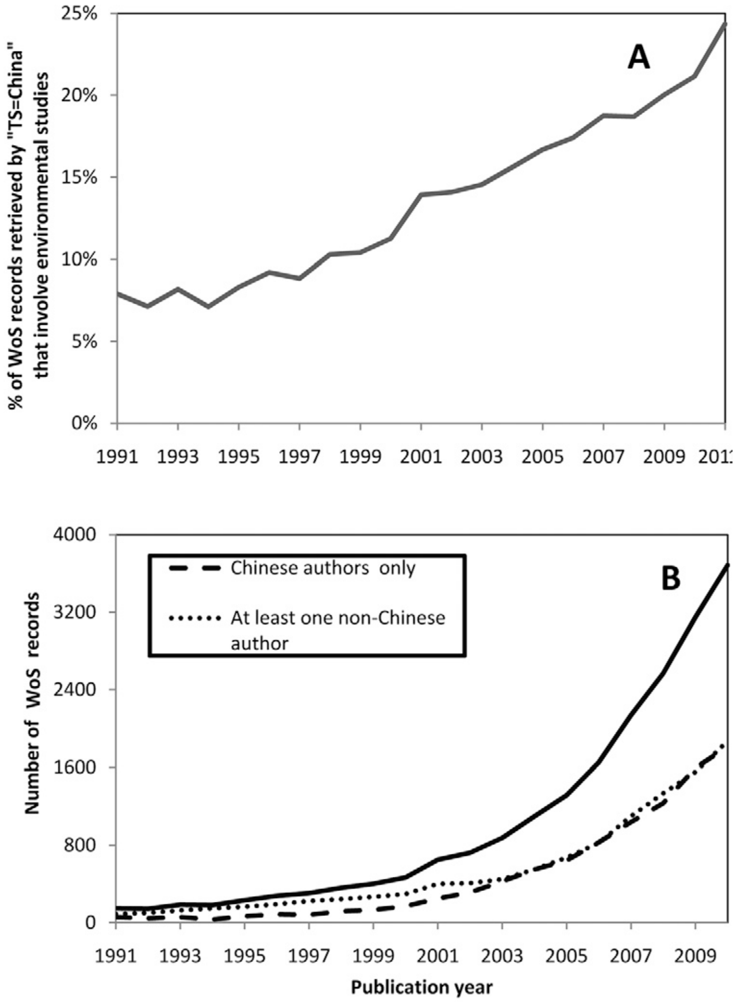

Fig. 1. Crude estimate of growth of published research literature on environmental issues in China. (A) Percentage of Web of Science (WoS) records retrieved with "TS = China" that also include (TS = environment* or Subject = "Environmental Sciences"). Data for the partial year of 2011 are included here because the value represents a ratio –1271/5242 records for 2011 on 29 Apr 2011. (B) Number of records retrieved with the same search query. The high percentage of articles with non-Chinese authors attests to the international interest in China's environmental issues.

establishing one of the largest scientific networks in the world, the Chinese Ecosystem Research Network (CERN) in 1999, to coordinate a broad spectrum of ecological studies throughout the country (Fu et al., 2010).

Pollution that originates from spatially discrete sources, such as a petroleum refinery, is often termed *point source pollution*, whereas that derived from spatially diverse sources, such as contaminated runoff from agricultural land, is referred to as *nonpoint source pollution*. Despite some debate over precise definitions of these two somewhat artificial categories, nonpoint source (NPS) pollution is generally considered to be the major type of pollution in China and many other parts of the world (Ongley et al., 2010). Point source pollution is often relatively simple to control through legislation and compliance monitoring. The mitigation of NPS pollution, however, has proven to be much more difficult due to its widely diffuse sources. Therefore, in recent years, NPS pollution has become a major focus of environmental research.

Nonpoint source pollution yields a broad spectrum of concerns for environmental quality and ecosystem health. For example, agricultural runoff often contains pesticides, fertilizer residues, and sediment. Urban and transportation corridor runoff is often contaminated with petroleum products. Inadequately treated sewage and livestock yard runoff are sources of pathogens and pharmaceutical products. Heavy metals and sediment (which is intimately involved in pollutant transport and degradation dynamics) originate from a variety of natural and anthropogenic sources. Each of these pollutants degrades environmental quality and threatens the sustainability of ecosystem health and ecosystem services.

Improving NPS pollution control in the future will require continuing advances on all fronts (Fig. 2):

- *source apportionment* for awareness of the various NPS pollutant sources
- an improved understanding of the *fate and transport processes and mechanisms* by which the pollutants reach their environmental destinations
- robust *analytical tools* for monitoring, modeling, and accurately assessing pollution levels at specific sites
- effective *remediation* strategies that are optimized for the unique circumstances surrounding a particular instance of pollution
- *policies and regulations* that are effective, practical, and enforced

This special section is devoted to a group of seven articles, each article focusing on one or more of these aspects of NPS pollution, specifically as they relate to environmental quality and ecosystem health in China. Although a detailed review of the interrelated aspects of NPS pollution in China is beyond the scope of this introduction, recent major developments in the field are addressed here as they relate to the issues relevant to the case studies presented in these seven articles.

NPS Pollutant Sources: Heavy Metals in Animal Manure Fertilizer

Among the myriad of sources of NPS pollution, agricultural activity is often considered to be a major contributor (Ongley et al., 2010). Chemicals in agricultural soils can potentially contaminate crops grown in that soil, and their food residues can adversely affect human health. The application of animal manures to agricultural soils as a cost-effective method to improve soil fertility and dispose of waste has been increasing worldwide (Min et al., 2003). Increasing levels of heavy metals such as copper (Cu) and zinc (Zn) are being added to commercial animal feeds in China as supplements and growth stimulants (Xiong et al., 2010). Because these heavy metals are excreted in manure, soil heavy metal pollution is expected to increase from applications of manures to soil. Thus, the food chain could become contaminated with heavy metals, threatening human and ecosystem health. Indeed, several recent studies have found high concentrations of Cu, Zn, cadmium (Cd), and arsenic (As) in pig manure samples in China (Hao et al., 2008a; Li et al., 2010; Xiong et al., 2010) and in the tissues of plants grown in such soils (Zhou et al., 2005).

Table 1. Characteristics of 21,953 Web of Science records retrieved by [TS = (China) and (TS = environment or Subject = "Environmental Sciences")] on 29 Apr. 2011.

Country	No.	Institution	No.	Journal	No.	Broad subject	No.	%‡
China	16,143†	Chinese Acad. Sci.	5944	Atmos. Environ.	747	**Natural and applied sciences**		
USA	4523	Peking Univ.	903	J. Environ. Sci. (China)	472	Environmental sciences	10,914	50%
EU-27	3353	Nanjing Univ.	604	Chemosphere	413	Earth sciences	5,866	27%
Japan	1355	Beijing Normal Univ.	562	Environ . Sci. Technol.	413	Engineering	3,752	17%
England	964	Tsinghua Univ.	546	Energy Policy	400	Medicine	2,771	13%
Canada	902	Zhejiang Univ.	447	Environ. Geol.	373	Biology	2,730	12%
Australia	854	China Univ. Geosci.	429	Sci. Total Environ.	348	Water resources	2,548	12%
Germany	766	Lanzhou Univ.	406	Chin. Geo. Sci.	338	Agriculture	1,804	8%
South Korea	420	Univ. Hong Kong	360	Environ. Monit. Assess.	318	Ecology	1,560	7%
France	365	Hong Kong Polytech. Univ.	325	Environ. Pollut.	293	Chemistry	998	5%
The Netherlands	303	Acad. Sinica	295	Chin. Sci. Bull.	273	**Social sciences & humanities**		
India	239	China Agric. Univ.	295	J. Hazard. Mat.	273	Economics and business	884	4%
Sweden	211	Fudan Univ.	257	Sci. China Ser. D Earth Sci.	222	Other social science/humanities	1,306	6%
Switzerland	200	City Univ. Hong Kong	248	Bull. Environ. Contam. Toxicol.	221			
Italy	197	E China Normal Univ.	224	J. Arid Environ.	208			
Norway	184	Chinese Univ. Hong Kong	210	Mar. Pollut. Bull.	194			
Singapore	156	Shanghai Jiao Tong Univ.	200	Water Air Soil Pollut.	188			
Spain	139	Tongji Univ.	199	J. Environ. Manage.	182			
Thailand	132	Chinese Acad. Agric. Sci.	193	Acta Petrologica Sinica	174			
Russia	128	Sun Yat Sen Univ.	191	Biomed. Environ. Sci.	165			

†10,304 (47% of 21,953) records included only authors with Chinese addresses, and 5810 (26%) records had no authors with Chinese address.

‡ Percentages add up to >100% as many records are classified into more than one category in the database.

Shi et al.'s (2011) paper in this special section examines the levels of Cu, Zn, and Cd in pig manure applied to a rice (*Oryza sativa* L.) crop system, and subsequent levels of these metals in the rice straw, brown rice grains, and soil samples. The authors found that average levels of Cu and Zn in pig manure exceeded the appropriate standard levels, as did many of the soil samples for Cu and Cd. At current application rates, Zn levels in the soil are expected to exceed acceptable standard levels in 9 yr. Despite elevated levels in the soils, however, none of the metals exceeded the Chinese Food Hygiene Standard levels in the brown rice samples. Repeated long-term use of heavy metal–rich manures will continue to increase the soil concentrations of these pollutants and may eventually lead to levels in food crops that exceed health standards.

Future research on the dynamics of heavy metals in agroecosystems from applied manure must also consider the bioavailability of the metals. In addition to heavy metals, animal manures often contain high levels of pathogens, phosphorus (P), and endocrine disrupting chemicals (EDCs) (Bolan et al., 2010). However, to date relatively few studies have examined the potential impact of these manure-borne contaminants on the receiving soil environment. Manure application loading rates are typically gauged by N concentration, leading to potential P runoff and eutrophication of water bodies in agricultural areas. The impacts of manure treatment processes before application should also be examined in relation to pathogen survival (Han et al., 2011) and the transformation and degradation of EDCs. Studies have shown that the contamination risk of manure-derived heavy metals in cultivated plants varies with soil characteristics (Hao et al., 2008b; Li et al., 2009). Therefore, soil type may be one of the main attributes to consider in animal manure application management. A better understanding of these aspects will help minimize the adverse effects of these contaminants on the quality of receiving soil and water environments.

NPS Pollution Transport: Soil Sorption

By definition, NPS pollution is that derived from numerous geographically dispersed sources. Various transport mechanisms often deliver pollutants from their sources to their environmental destinations. Transport mechanisms may decrease pollutant concentrations, such as diffusion of methane from livestock herds through the air. Alternatively, transport may increase pollutant concentrations—such as runoff from many square miles of farmland treated with heavy metal–rich manure draining into a single body of water. Thus, pollutant transport is a key factor for understanding and mitigating many pollution situations.

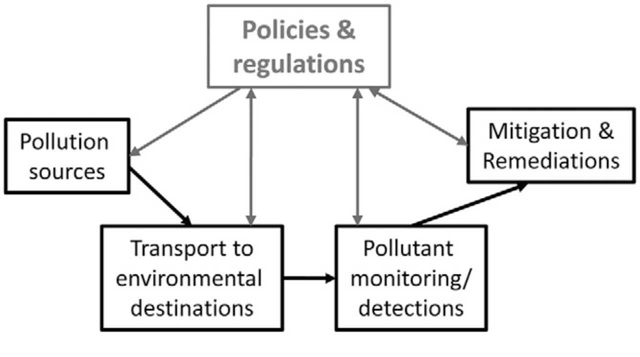

Fig. 2. Pollution control pathway. Pollution control requires knowledge of the relevant sources and transport mechanisms, diligent environmental monitoring, and (when necessary) effective remediation protocols. Policies and regulations influence each of these components.

The sorption of organic compounds (OCs) in soil is important in determining their environmental fate, including leaching potential (Farenhorst, 2006). Sorption is mainly controlled by soil organic matter (SOM) and clay minerals, although the relative contributions of these two factors remain a subject of much debate (Bronner and Goss, 2011a,b). Many studies indicate that the polarity of a compound dictates the contribution of mineral-phase sorption (Sheng et al., 2001; He et al., 2006; Liu et al., 2008, 2010a). Soil organic matter is believed to provide a partition phase for hydrophobic OCs, and for OCs containing nonpolar or slightly polar functional groups, such as –Cl, the SOM partition model appears valid. This model, however, is frequently extended to OCs in general, including those with polar functional groups such as many pesticides. For example, this extension is the basis for using K_{OM} or K_{OC}, the soil-organic-matter and carbon-normalized sorption coefficients, to predict pesticide mobility in soils.

The paper by He et al. (2011) examines sorption of butachlor by six purified clay minerals, four soil alkali-extractable pure humic acids (HAs), four unmodified HAs, and four soils treated with H_2O_2 to reduce total organic content (TOC). The results indicate a major role for HAs in butachlor sorption and that the lesser role played by the minerals may involve their enhancement of the availability of the HA sorption domains. Results of butachlor sorption by soils in which the TOC/clay ratios were altered by H_2O_2 treatment further supports the contribution of the interaction of these two components in their native states in the soil.

Future work on soil sorption characteristics should continue to focus on experimental systems that approximate the complexity of real soil matrices. Although many studies have explored sorption mechanisms using only pure clay minerals (e.g., He et al., 2006) or separated SOM fractions (Gunasekara and Xing, 2003; Xu et al., 2005; Pan et al., 2006), the separated fractions are unlikely to reflect the sorption characteristics of the original soils. Soil is composed of organo-mineral complex aggregates; it is not simply a mixture of discrete organic and mineral components. Thus, differences in chemical composition and content of the SOM in aggregates may affect OC sorption as a function of aggregate size, particle size, and the physical associations among different components.

NPS Pollutant Monitoring and Detection: Toxicity Identification Evaluation Protocol

Regardless of the sources, and potential transport mechanisms by which pollutants arrive at their environmental destinations, the starting point for understanding and mitigating any pollution situation is the accurate identification and quantification of pollutants in environmental samples. Instrumental techniques, such as gas chromatography, liquid chromatography, mass spectrometry, and atomic emission spectrophotometry, can identify the specific molecules present in environmental samples, but they require expensive equipment and are often unsuitable for the rapid analysis of large numbers of samples (VanLoon and Duffy, 2011). Traditional wet chemistry techniques, such as electrochemistry and titration, are still widely used in environmental chemistry due to the low cost and easy adaptation to batch-scale processing.

Identifying the main toxic component(s) of environmental samples is necessary for designing the most effective and cost efficient means of remediation (Landis, 2011). The "toxicity" of a complex environmental sample matrix or its individual components can only be determined by observing their effects on biological systems using bioassays or immunoassays. The use of multiple indicator organisms typically provides a more comprehensive toxicological profile of environmental samples. In some cases, specific symptoms elicited by a particular class of toxic compounds can provide evidence that sample toxicity is due to a specific suspected agent (Ho et al., 2009).

In the 1990s, the USEPA designed the toxicity identification evaluation (TIE) protocol to pinpoint the toxic component(s) in environmental samples using a series of simple and inexpensive chemical tests and biological assays that are suitable for batch sample processing (Ho et al., 2007). Together, this series of tests identifies the most commonly encountered classes of toxic environmental contaminants, and many remediation methods can be applicable to most chemical species in a given toxicant class. Toxic components in the broad classes of "metals" or "oxidizers," for example, can be removed by the addition of ethylene diamine tetraacetic acid (EDTA), which precipitates most metal ions, or the reducing agent sodium thiosulfate, respectively.

The study by Li et al. (2011) identifies the toxic components in chemical industrial wastewater from the Hangu Reservoir in Tianjin, China, and assesses several possible treatment options. This reservoir received effluents from a chemical industrial park for decades. Using both the *Daphnia magna* acute toxicity test and wheat seedling root elongation test, TIE analysis indicated that the primary toxic components were Cl^-, Cu^{2+}, Pb^{2+}, and Zn^{2+}. Given its high salinity, modeling analysis suggested that the most efficient and cost effective method to treat this wastewater would be dilution with municipal wastewater at a 10:1 volume ratio before any treatment. The simulated treatment process, involving aeration, sedimentation, and drainage steps, reduced the levels of toxic components, i.e., chemical oxygen demand and total nitrogen and phosphorus by about 85 to 96%, and reduced the toxicity to 0.50 toxic units.

The TIE protocol allows the determination of today's most significant pollutant classes. Future refinements will likely include a wider range of biologically based assay systems with improved sensitivity and specificity. As new substances are found for industrial uses, new pollutants will likely emerge, necessitating the expansion of the TIE's repertoire of methods. New chemical substances are being discovered at a phenomenal rate. For example, 10 million new substances were added to the Chemical Abstracts Service *CAS Registry* in the first nine months of 2009 (Toussant, 2009), and the lack of toxicological information for most of them is a growing problem (Binetti et al., 2008).

NPS Pollution Mitigation and Remediation: Three Case Studies

When monitoring reveals pollutants at unacceptable levels in the environment, they must be removed, mitigated, or degraded. A broad spectrum of methods has been developed to deal with a wide range of pollutant chemistries and environmental matrices (VanLoon and Duffy, 2011). There is an increasing awareness that mitigation and remediation actions can sometimes yield unintended negative environmental consequences. Therefore, the overall health of the entire ecosystem involved must be considered in the mitigation and remediation managements (Dawson and Smith, 2010).

Case Study 1: Phytoremediation Using Rice Paddy Rhizosphere System

Environmental oxic/anoxic interfaces are the true hotspots of the biogeochemical redox reactions that control element and compound cycles. An understanding of the biogeochemical processes at environmental redox interfaces is crucial for protecting many aspects of ecosystem health and environmental quality. Minerals (including Fe, Mn, P, N, S) and humic substances are the major redox-active elements in soils that affect the biogeochemical cycles of environmental contaminants (Borch et al., 2010). The roles of these redox processes in conversions of chemical contaminants have been more thoroughly investigated in either fully oxic soils or permanently reducing environments (e.g., Trebien et al., 2011) than in fluctuating redox environments. In the latter, the relevant microbial and mineral components are likely to differ from those of static oxic or anoxic environments (Borch et al., 2010).

Phytoremediation is an inexpensive, environmentally friendly method for reducing organic and metallic contaminants from soils, particularly using plants with a microbially rich rhizosphere (Ma et al., 2011). In China, wetland paddy soil is a popular phytoremediation option that exhibits an oxic-anoxic gradient in the root–soil interface and a diverse rhizobacterial community. The oxidative state of the rhizosphere and formation of iron plaques on root surfaces provide an environment that is radically different from the bulk soil (Liu et al., 2006). These unusual properties are expected to affect the dissipation of OCs near the rice root surface.

In their research presented here, Hayat et al. (2011) found that the dissipation of pentachlorophenol (PCP), either by reductive dechlorination or aerobic catabolism, in the dynamic redox environment of the rice rhizosphere system is influenced by organic root exudates, a rich microbial flora, and oxygen release from the aerenchyma tissue of the plant. Pentachlorophenol dissipation was strongly affected by its proximity to the roots, although reductive dechlorination was the main PCP removal pathway. Correlations of PCP dissipation with concentrations of common electron acceptors and donors suggest that oxidation or reduction of soil constituents influences the aerobic or anaerobic PCP degradation processes, respectively.

Many aspects of the complex rice paddy remediation system, such as the kinetics of the redox processes and effects of redox reactions on soil minerals (Borch et al., 2010), remain largely unstudied. We are only beginning to understand the importance of rhizobacteria and other soil microbes in phytoremediation systems, and relatively few studies have investigated the roles of these microbial components under field conditions (Glick, 2010). Further research is also needed to understand the specific roles of plant–microbe interactions and organic root exudates on remediation efficiencies for organic and metal pollutants (Ma et al., 2011). Given its low cost and, in many cases, high efficiency, phytoremediation will likely remain a widely used method for improving ecosystem health in China and around the world.

Case Study 2: Mitigation and Remediation by Constructed Wetlands

Constructed wetlands are often used to remove sediment and pollutants by physical, chemical, and biological means from agricultural runoff and other wastewaters (O'Geen et al., 2010). They may be either *free water surface* systems, with vegetation rooted in soil on the bottom and the free-standing runoff water flowing through the leaves and stems, or *vegetated submerged bed* systems, with plants rooted in beds of soil or gravel and runoff water flowing only through the roots and rhizomes. The water flow rate, water depth, and dimensions of the wetland affect the settling of sediment. The plant and microbial communities metabolize organic pollutants, bioaccumulate heavy metals, and incorporate nitrogen and phosphorus-based nutrients into their biomass (Marchand et al., 2010). Thus, the effluent of the constructed wetland often has dramatically reduced levels of a variety of pollutants relative to the wastewater source. Because they are low cost and low tech, and may provide horticultural income depending on plant choice, constructed wetlands are widely used for wastewater treatments in developing countries where land is available (Zurita et al., 2011).

Along the flow-path of a wetland, the levels of nutrients and pollutants gradually decrease due to their removal and metabolism by the plants and microbes. This gradient, coupled with the release of oxygen from submerged roots and rhizomes, produces a diverse ecological matrix within the constructed wetland, leading to localized differences in the microbial communities (e.g., Zhang et al., 2011). The metabolic activity of microbial communities is a major factor influencing the pollution mitigation and remediation functions of the constructed wetland, particularly in the removal of OCs by degradation (O'Geen et al., 2010). Although culture-based and molecular methods can reveal the diversity of these localized microbial communities (e.g., Iasur-Kruh et al., 2010), these methods do not provide information on their metabolic capabilities.

In their contribution to this special section, Deng et al. (2011) demonstrate a highly rapid, inexpensive, and universally applicable method for characterizing the diversity and metabolic profiles of microbial communities in different portions of a horizontal subsurface-flow constructed wetland. Biolog-ECO plates contain triplicate samples of 31 different carbon sources in individual wells. Each well also includes a pH-sensitive dye to indicate microbial metabolic activity (i.e., growth). The pattern of utilization of the 31 carbon substrates by water samples provides a metabolic "fingerprint" of its microbial community. Using this method, the authors demonstrate quantitative and qualitative metabolic differences in the microbial communities at different points along the flow path in the constructed wetland. This study follows a similar report by the same group (Deng et al., 2010), which used a different plant species, *Typha angustifolia* in the constructed wetland.

The Biolog-ECO plate assay may facilitate future studies on the effects of manipulation of various parameters, such as depth and flow rate of the water, plant density, or plant species choice, on the metabolic activity of the microbial communities. Because of their large sample throughput, the various Biolog carbon source microplates are gaining widespread use for profiling microbial communities from a variety of matrices, such as soil (e.g., Z.Y. Wang et al., 2011), sewage/domestic wastewater (Biggs et al., 2011; Zhang et al., 2011), marine samples (Sala et al., 2011), and various types of industrial bioreactors (Papaspyridi et al., 2011). Based on the literature, this type of constructed wetland can clearly be one of the most effective mitigation and remediation treatments for improving water quality.

Case Study 3: Mitigation and Remediation by Adsorbent Material

A wide range of methods has been tested for the physical or chemical removal of pollutants from NPS pollution-contaminated wastewaters. Methods based on ion exchange, electrochemistry, or chemical coagulation have high costs, whereas ultrafiltration and zeolite adsorbents are not efficient for processing large volumes of contaminated water (Farooq et al., 2010). Many adsorbents produced from various industrial and agricultural wastes offer a low-cost, low-tech alternative to the above methods and have demonstrated excellent adsorption-based removal of pesticides, heavy metals, dyes, and other toxic substances from contaminated water sources (Demirbas, 2009; Ahmad et al., 2010; Bhatnagar and Sillanpaa, 2010).

A material derived from soybean [*Glycine max* (L.) Merr.] straw has shown high adsorption capacity of copper ions from experimental aqueous solutions (Zhu et al., 2008). In their article, Kong et al. (2011) demonstrate the removal of polycyclic aromatic hydrocarbons (PAHs) from aqueous solution by phosphoric acid-activated carbonized soybean stalk waste product. With PAH removal rates >95%, the soybean stalk-derived adsorbent outperformed commercial activated charcoal. The use of this and other agricultural wastes for NPS pollution remediation could potentially provide an additional source of income for farmers if these applications achieve large-scale commercialization. Future studies using this material should examine its ability to remove contaminants of other chemical classes from actual wastewater samples and compare the adsorptive capacities of the soybean straw-based material to other agricultural waste materials processed for optimal adsorption.

An important issue to consider for any adsorbent material is the disposal of the contaminated adsorbent. Future research should focus on the development of adsorbents that can be easily regenerated by desorption of the pollutants, such as by altering pH or salt concentrations (Zhou and Haynes, 2010). This feature would allow subsequent reuse of the adsorbent material and achieve maximal concentration of contaminated material for ultimate disposal. Nanomaterial adsorbents are receiving increasing attention for their ability to remove the various pollutants from wastewater, such as heavy metals (Fu and Wang, 2011), polychlorinated biphenyls (PCBs) (Shao et al., 2010), and other environmental xenobiotics (Shan et al., 2009).

Environmental Policy: Environmental Successes of the "Conversion of Cropland to Forest and Grassland Program" in China

Because NPS pollution comes from vast, widely dispersed natural and anthropogenic sources, its control by traditional policy and compliance monitoring methods has proven much more difficult than the control of point source pollution (Liu et al., 2010b). One of the world's most ambitious ecological restoration projects, the "Conversion of Cropland to Forest and Grassland Program" (CCFGP)—also known as "Grain for Green Program" or "Sloping Land Conversion Program"—has been underway in China for more than a decade. This program includes a significant NPS pollution controlling objective (Cao, 2011). The program is designed to protect certain vulnerable ecosystems in China from damaging agricultural activity, while lifting millions of people in marginal agricultural areas out of poverty. The expected environmental benefits include reductions in soil erosion, sediment runoff to waterways, and water loss from soil due to evaporation; and increases in soil moisture retention, biodiversity, and carbon sequestration in soil and vegetation.

To reach these goals, cultivation and livestock grazing on marginal and steep-sloped agricultural land are being reduced by converting these marginal lands, as well as abandoned agricultural lands, to either forest or grassland. The CCFGP plans to eventually convert 14.7 million ha of marginal cropland and 17.3 million ha of degraded land to forest or grassland (Wang and Lu, 2010). The total cost for the program is projected to reach about US$48 billion, and approximately 68% of the money spent to date has gone to grain and cash subsidies to compensate the farmers for income lost due to cropland conversion (Xu et al., 2010).

Various studies have documented beneficial effects of the CCFGP on soil erosion (Zhou et al., 2009), soil organic carbon sequestration (L.F. Wang et al., 2011), and flood reduction in the Yellow River Basin (Qiu et al., 2010). In their research presented here, Qiu et al. (2011) used the Soil and Water Assessment Tool (SWAT model) to simulate a variety of hydrological benefits of the CCFGP in the Jinghe River Catchment, Loess Plateau, China. Increases in stream flow and soil water content, and decreases in both evapotranspiration and runoff were clearly demonstrated. Although this study did not directly measure sediment, runoff typically contains sediment.

Some researchers have questioned the future sustainability of the CCFGP. Qiu et al. (2011) warn that the environmental gains they found may be lost if land is converted back to farmland when the "payment for environmental services" program ends. Indeed, about one-third of farmers surveyed in Shaanxi, Guizhou, and Ningxia Provinces indicated that they would convert their land back to farmland without these subsidies (Cao, 2011). The subsidies expired in 2006–2007 but were extended for another 5 to 8 yr, depending on the subsidy category. Wang and Lu (2010) suggested that factoring in the value of the carbon sink differential between agricultural reversion and long-term forest/grassland maintenance may provide the necessary financial incentive to prevent large-scale agricultural reversion. Despite the sometimes negative press surrounding the ambitious CCFGP, it is clearly achieving important environmental benefits. Future funding to continue CCFGP may be necessary to maintain the achieved benefits.

Gaps in Knowledge and Future Directions

The articles published in this special section advance our understanding of pollution, environmental quality, and ecosystem health by examining specific issues related to sources, transport dynamics, pollutant monitoring and detection methods, mitigation and remediation protocols, and policies, focusing on cases and issues relevant to the NPS pollution problems in China. A systematic review on the current research needs and suggestions for future policies related specifically to NPS pollution in China was recently published (Ongley et al., 2010). Because NPS pollution is distinguished by its source, many relevant issues, such as analytical and some remediation techniques, do not really differ between nonpoint and point source pollution. Thus, speculations on the future developments for NPS pollution control often apply equally to environmental pollution in general.

Sources

In addition to the well-known primary NPS pollution sources, new or underappreciated sources will continue to come to light in the future. Problems that did not exist in the past may arise due to changes in environmental or agricultural practices and products. For example, the addition of increasing amounts of nutritional heavy metals to animal feed will lead to increased heavy metal contamination of manure-fertilized soils (Shi et al., 2011). Tools such as remote sensing, modeling, and geographic information systems (GIS), which are crucial for understanding the spatially diffuse sources contributing to NPS pollution, will continue to be developed (e.g., Wu et al., 2010; Zhang and Huang, 2011). In addition, if climate change alters future temperature and hydrological patterns, these changes are expected to alter future NPS pollution sources and patterns in many ways (Praskievicz and Chang, 2009).

Fate and Transport

Nonpoint source pollutant fate and transport is a complex and interactive process that depends on many dynamic environmental variables and the physical and chemical properties of individual pollutants. Air- and water-borne pollutants are known to travel thousands of miles in some cases (Zhang, 2010). Transport of pollutants through the air and water is often temperature- and precipitation-dependent (Ficklin et al., 2010). The potential role of climate change in the overall volatility and/or solubility of pollutants in these ecosystem compartments has not been extensively studied, but it may influence the transport and toxicological properties of pollutants in the future. Pollutant fate in the complex soil matrix will continue to be a particularly exciting area of investigation, as our understanding of the roles of soil components and their interactions are far from resolved. In modeling transport in aqueous environments, the interactions of pollutants with the substratum and sediment particles must always be taken into account as accurately as possible.

Monitoring and Detection

Inexpensive and low-tech techniques suitable for batch sample processing are often sufficient to identify relevant pollutant classes in environmental samples, and in many cases this level of information is adequate to guide remediation decisions (Ho et al., 2007, 2009). Thus, analytical techniques with these features will likely continue to be developed and widely used. As our knowledge on toxin class-specific symptoms among potential indicator organisms increases, more selective and sensitive bioassays for pollutant identification will become available. Analytical instrumentation will continue to provide ever greater sensitivity and specificity. Many nanotechnology-based systems show improved detection of pollutants in environmental samples relative to traditional technologies, although few nanomaterial-based products have been commercialized thus far (Savage, 2009). Monitoring will directly provide not only the real-world information for policymakers but also the essential observed data for the calibration and validation of the models necessary for future environmental predictions.

Mitigation and Remediation

Most pollution mitigation and remediation techniques involve the removal of pollutants by chemical–physical–biological interactive effects that may include means of binding, occluding, and degradation. Low-tech and low-cost remediation options that are easily scalable to treat large amounts of polluted materials will continue to be developed in the future (Zhou and Haynes, 2010). Novel emerging technologies, such as nanomaterials, are attracting increasing attention for potential use in the remediation of NPS pollution in China and worldwide (Pradeep and Anshup, 2009; Shan et al., 2009). The constructed wetlands, as complete ecosystems, offer many potential ways to optimize the remediation capacity of the system for a particular pollution matrix. New species of microbes with unique metabolic properties suited for pollution remediation are still being discovered (e.g., Teramoto et al., 2011).

Policy and Regulations

Effective and comprehensive policies that are properly enforced are crucial for preserving environmental quality and ecosystem health by reducing pollutant inputs from both nonpoint and point sources in China. For NPS pollution, these may involve land-use shifts, like the CCFPG program, or agricultural best management practices (BMPs) such as stricter regulation of pesticide use or the heavy metal content of manure used as fertilizer (Shi et al., 2011). Many studies have documented the effectiveness of BMPs in reducing agricultural runoff (X. Zhang et al., 2010). Therefore, the implementation of BMPs designed to reduce pollution in agricultural settings can be improved by streamlining technology transfer. When appropriate, policies should include sensible incentives to the stakeholders involved in addition to restrictive regulations. Ongley et al. (2010) suggest many future policy options that are related to NPS pollution issues and environmental quality and that would generally enhance the research, information gathering and distribution, and institutional infrastructures of China.

Because its sources are so widely dispersed, NPS pollution problems are often governed by factors that operate on very large scales and interact with many other factors to negatively impact ecosystem health. Thus, today's focused, often disjointed, research efforts must be properly synthesized to achieve a comprehensive understanding of the complexities of individual pollution situations and to avoid creating new problems while solving existing problems (Dawson and Smith, 2010). Most important, effective solutions to the pollution problems in China must be tailored to the unique combination of factors at work in any given locality. Policies and regulations should ensure the source control, utilize currently available research outcomes, and adopt successful methodologies from other countries. Given that the Chinese government has paid more and more special attention to the environment in recent years, it is trusted that in time NPS pollution will be mostly controlled in China and the environmental quality and ecosystem health will be much improved.

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