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A review of diffuse pollution modeling and associated implications for watershed management in China

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Abstract

Purpose Diffuse pollution has been extensively studied in China from loading assessments to watershed management, which are important in international research. However, few studies that assess the advances of diffuse pollution modeling and studies of trace diffuse pollutants have been conducted. The adaption and development of imported model systems based on local observations and climatic features have improved study skills and presented unique characteristics. In addition to traditional diffuse pollutants (e.g., nitrogen and phosphorus), modeling trace heavy metals and pesticide also provides insights for watershed management.

Materials and methods We reviewed existing literature on diffuse pollution model applications and developments in China, attempting to provide a better understanding of the advances of diffuse pollution and new research directions for pollution modeling.

Results and discussion Diverse methods have been adopted to express diffuse pollution formation, transport and environmental impacts using modeling as an effective tool for developing management guidelines in China. Model applications at different temporal–spatial scales, development of diffuse pollution modeling for emerging pollutants, and impacts of diffuse pollution on water quality in China were analyzed. Pollution loading decreased from east to west, coinciding with farmland distributions, tillage intensity, and economic levels. The temporal patterns of pollution loading have increased in recent decades due to increased fertilizer additions and climate warming which has put more pressure on water quality. This analysis indicated that enhancing existing models, with more field observations, is key for future diffuse pollution studies of trace organic pollutants and heavy metals. Establishing national databases and validating standard model parameters are essential and currently weak points at the national scale with respect to diffuse pollution modeling.

Conclusions Diffuse pollution has become a challenging issue in watershed management, and agricultural diffuse pollution poses the greatest risk to watershed management in China. However, the mechanisms involved in trace pollutant transport and the environmental consequences of these pollutants are largely unknown in China, where complicated tillage methods are used and climatic conditions vary throughout the country. Accumulated field observations at diverse temporal–spatial scales are important to accurately model and perform water risk assessments.

Keywords China · Diffuse pollution · Modeling · Watershed management

1 Introduction

Diffuse pollution, also known as non-point source pollution, is the main source of water quality degradation worldwide (Collins et al. 2014). According to Chinese Environment Quality Bulletin in 2015, over 9.0% of the 131 national basic stream water quality monitoring locations received grades worse than V and approximately 25% of the lakes were seriously eutrophic. Agricultural diffuse pollution contributes up to 53% of total nitrogen (N) loading and 85% of total phosphorus (P) loading in China's waterways (Edwin et al. 2010). Diffuse

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pollution is characterized by random discharge locations and complex mechanisms, which present additional challenges for watershed management. Diverse methods have been adopted to study diffuse pollution loading and to provide better information for management decisions. Modeling has proved to be an effective tool that can express waterway risks at different temporal–spatial scales (Li et al. 2014).

Diffuse pollution studies were firstly conducted in the 1960s. The Chemicals Runoff and Erosion from Agricultural Management Systems (CREAMS) integrates hydrology, soil erosion, and contaminant migration (Knisel 1980), which became the landmark model for improving understanding of diffuse pollution. After the 1990s, the combination of geographic information systems and remote sensing technology advanced the model's ability to make predictions, evaluate management decisions, and perform risk assessments at watershed scales (Montzka et al. 2008; Panagopoulos et al. 2011). Many diffuse pollution models have been developed and applications due to much more available observation database in the developed countries (Gömann et al. 2005; Fonseca et al. 2014). These models were used to quantitatively descript the complicated pollution generating process, analyze spatial and temporal patterns of diffuse pollution, identify the main source and migration path, and assess the impacts of climate and land use change on diffuse pollution.

Diffuse pollution research in China started in the 1950s, and comprehensive understanding of agricultural diffuse pollution began in the late 1980s. Before the use of models, relationships between pollution loads and runoff volumes from rainfall events were analyzed and summarized for different locations. Since the 1990s, the distributed model was employed to understand the progress of diffuse pollution at watershed scales (Edwin et al. 2010). As the understanding and field observations have advanced, models developed by Chinese researchers have received more citations and have been used in more applications (Huang et al. 2017). Previous review papers mainly concentrated on applications and improvements of diffuse pollution modeling (Edwin et al. 2010; Shen et al. 2012). Whereas, this paper summarizes diffuse pollution model applications at different spatial–temporal scales, modeling advances with emerging pollutants, and identifies the pollution status at national scale based on previous studies. The information about spatial–temporal distribution of typical diffuse pollutants at national scale is useful when compared to the other countries. The application in watershed management is critical for environmental administration, and it is highlighted in this paper.

2 Diffuse pollution modeling at different spatial scales

2.1 Empirical modeling at field scales

Diffuse pollution simulations in China are mainly based on direct applications of mature models developed abroad between 1983 and 1987 (Liu 1985; Zhang 1987). By the end of 1980s, Chinese scholars started to develop models at field scales considering local environmental conditions. The earliest diffuse pollution model was a lumped model (Hao et al. 2006). The landmark model CREAMS, which combined Green-Ampt with the nutrient loss equation, was used to estimate runoff and erosion from a small experimental plot (Zhang 1995). Detailed field observations with different slopes enhanced understanding of the erosion process in China. Later, based on CREAMS, the Erosion Productivity Impact Calculator (EPIC) developed by Williams et al. (1983) for field-scale applications was introduced in China and used to simulate N and P losses from croplands under diverse tillage.

Statistical models, such as USLE, can estimate diffuse pollution loading for small watersheds with sufficient basic information (Shen et al. 2011a, b. The nutrient empirical loss equation has been widely applied to quantitatively study diffuse pollution in China over the last three decades (Liu et al. 1988; Du 1991). However, this type of modeling is data-intensive considering the large amounts of field-sized experiments conducted. In contrast to empirical models, other types of models have been developed such as the export coefficient model (ECM), which has evolved from the unit load approach (Edwin et al. 2010). The modified EMC takes into account the spatial distributions of precipitation and runoff, which improves accuracy with data availability (Li et al. 2009a).

2.2 Physically based models for watershed scales

The applications of distributed hydrology models become popular, and several types of models have been improved upon in China since the 2000s. AnnAGNPS was the popular one due to its applicability (Hong et al. 2005; Wang et al. 2009; Huang and Hong 2010). HSPF is mainly used to simulate nutrient pollution loads and respond to different hydrological scenarios (Mei et al. 2007; Hayashi et al. 2015), but it is not used widely in China because it requires extensive calibrate parameters. Soil and Water Assessment Tool (SWAT) is widely used to evaluate diffuse pollution loading, and it can highlight the impacts of policy-induced land management practices (Jiang et al. 2014). The SWAT model identified that farmlands in China contribute the highest amount of the diffuse pollution load (Wang et al. 2008). However, the application of these models presents some uncertainties due to the limited timeframe of regular monitoring data. The models are also affected by complex topography, high spatial variability of land use, and uncontrolled point source pollution.

The Soil Conservation Service (SCS) method used in SWAT is not suitable for runoff calculations due to diverse geographical and hydrometeorological conditions. Coupling the Xin'anjiang model with SWAT to simulate diffuse pollution can provide more accurate results (Yang et al. 2011), which has been the case in south China watersheds. Based on the Conversion of Land Use and its Effects at Small Regional Scales (CLUE-S) and SWAT models (Liu et al. 2014), diffuse pollution loading based on urban planning and historic land use trends was simulated. Chinese scholars recently developed physically based models to estimate diffuse pollution at watershed scales (Lei et al. 2009). The IMPULSE developed by Wang et al. (1995) can simulate hydrological conditions, soil erosion, and sediment and pollutant transportation, which is more effective than AnnAGNPS because it can simulate BMPs and provide uncertainty analysis. The EasyDHM is the GIS-distributed hydrocycle evaluating model, and it can distinguish between territorial differences. These developed models have better interfaces and can import and analyze data effectively, which is beneficial for model advocates.

2.3 Modeling at national scale

Under the mandate to control water pollution in China, quantitative assessments at national and regional levels have been sought to support decision-making (Wang et al. 2012a). By simulating diffuse pollution loading of independent watersheds, it is possible to infer pollution loading at national levels with diverse natural and economic conditions (Wu et al. 2012; Ouyang et al. 2013; Wang et al. 2014a). Nevertheless, the results of these studies have not been merged with the national database. The ECM can be scaled up to large watersheds or even national databases (Ma et al. 2012), but as a statistical method, it cannot explain transport mechanism of diffuse pollution. Given the situation in China, it is desirable to have access to a model that combines simple, approximate models with detailed, computationally intensive models.

Chinese scholars have developed several models that are applicable at national and regional scales. Estimating nonpoint source pollutant loads in a large-scale basin (ENPS-LSB), a model for estimating diffuse pollution loads in a large-scale basin, was developed in 2006 (Hao et al. 2006), which combined an empirical model and a mechanical model. The model has a flexible spatial scale, making it appropriate for large basins spanning millions of hectares. The analysis befits decision-making with respect to reducing diffuse pollution at large-scale basins (Wang et al. 2011a). The improved ENPS-LSB model was built to capture the spatial–temporal process of diffuse pollution loads, which provides a method to estimate diffuse pollution loads at national scales using spatial pixel-based modeling (Wang et al. 2014b). Eubolism (elementary unit-based nutrient balance modeling in agroecosystem), an extended framework substance flow analysis model similar to the improved ENPS-LSB model, was built to estimate nutrient emissions from agricultural and rural activities in China at national scale (Chen et al. 2010).

2.4 Modeling at ungauged basin

A common constraint in diffuse pollution model development and verification is the limited availability of hydrological and water quality data with satisfactory resolution (Zhao et al. 2011). The statistical method is frequently adapted to estimate diffuse pollution in ungauged basins, which can be applied to most basins. The mean concentration method can estimate diffuse pollution loads based on surface runoff, underground runoff, and average concentrations of N and P (Hong and Li 2000). The rainfall deduction method proposed by Cai et al. (2005) can calculate the contribution of atmospheric deposition to watershed diffuse pollution loading. A correlation method of water quality and quantity developed by Hong and Li (2000) is used for estimating the annual load of rainfall-runoff pollution with limited monitoring data. These methods have been successfully used in many ungauged watersheds, which also provide a diffuse pollution load estimation, a watershed hydrological model, a pollutant-yielding model, and a pollutant-converging model.

Another solution for modeling ungauged basins is to reference validated parameters from watersheds with similar natural characteristics (Ouyang et al. 2014). This method has the ability to make stream flow predictions and N and P load predictions in poorly monitored catchments (Panagopoulos et al. 2011; Ouyang et al. 2012). The basins' hydrological similarity evaluation index system was set up to fill in the gaps by transferring parameters between two different watersheds with similar hydrological mechanisms (Pan et al. 2009). For simplicity, the topographic frequency distribution index was selected as an evaluation tool for runoff and sediment yield simulation in ungauged watersheds (Wang et al. 2014b).

3 Diffuse pollution dynamics and risk assessment in China

3.1 Spatial patterns of diffuse nutrient pollution in China

In China, the spatial distribution of diffuse nutrient pollution is non-uniform due to varying climates and land use patterns (Hao et al. 2006). In recent years, limited pilot studies about spatial patterns at national or large basin scales have been conducted (Table 1). The ENPS-LSB model was applied to 10 primary basins in China. The analysis showed that diffuse TN load in the south Pearl River Basin was the highest. The

Table 1 Reported spatial pattern of diffuse nutrient pollution load at large basins or national scales in China

Model	Spatial patterns of diffuse nutrient pollution in China		Content	Source
	Difference between south and north	Difference between east and west		
ECM	South (129–307 × 10^4 t) > north (77–134 × 10^4 t)	East (384–467 × 10^4 t) > west (204 × 10^4 t)	Diffuse nutrient (TN, TP, COD) pollution loads of all provinces in China, 2007	Ma et al. (2012)
ENPS-LSB	–	TN: middle and lower reaches (127–170 t/km^2) > upper reaches (42–85 t/km^2) TP: middle and lower reaches (31–41 t/km^2) > upper reaches (10–21 t/km^2)	Diffuse TN and TP loads of the Yangtze River, 2000	Wang et al. (2011b)
	–	TN: middle and lower reaches (3387–9761 t) > upper reaches (1348–8901 t) TP: middle and lower reaches (1498–4773 t) > upper reaches (457–3404 t)	Diffuse TN and TP loads of the Yellow River, 2000	Cheng et al. (2006b)
	TN: south (69–130 × 10^4 t) > north (11–25 × 10^4 t) TP: south (30–57 × 10^4 t) > north (7–14 × 10^4 t)	TN: east (11–31 × 10^4 t) > west (1.2–9.8 × 10^4 t) TP: east (7–14 × 10^4 t) > west (0.3–3.4 × 10^4 t)	Diffuse TN and TP loads of 10 super-large basins in China, 2000	Hao et al. (2006)
Improved ENPS-LSB	TN: south (3.5–61 t/km^2) > north (0–3.5 t/km^2) TP: south (0.1–2.62 t/km^2) > north (0–0.05 t/km^2)	TN: east (2.5–45 t/km^2) > west (0–2.5 t/km^2) TP: east (0.05–1.5 t/km^2) > west (0–0.05 t/km^2)	Diffuse TN and TP loads of 10 super-large basins in China, 2010	Wang et al. (2014c)
SFA framework	TN: south (0.4–1.6 t/km^2) > north (0.1–1.6 t/km^2) TP: south (0–0.2 t/km^2) > north (0–0.1 t/km^2)	TN: east (0.4–2.5 t/km^2) > west (0.1–0.8 t/km^2) TP: east (0.1–0.3 t/km^2) > west (0–0.1 t/km^2)	Diffuse TN and TP pollution loads of all provinces in China, 2004	Chen et al. (2010)

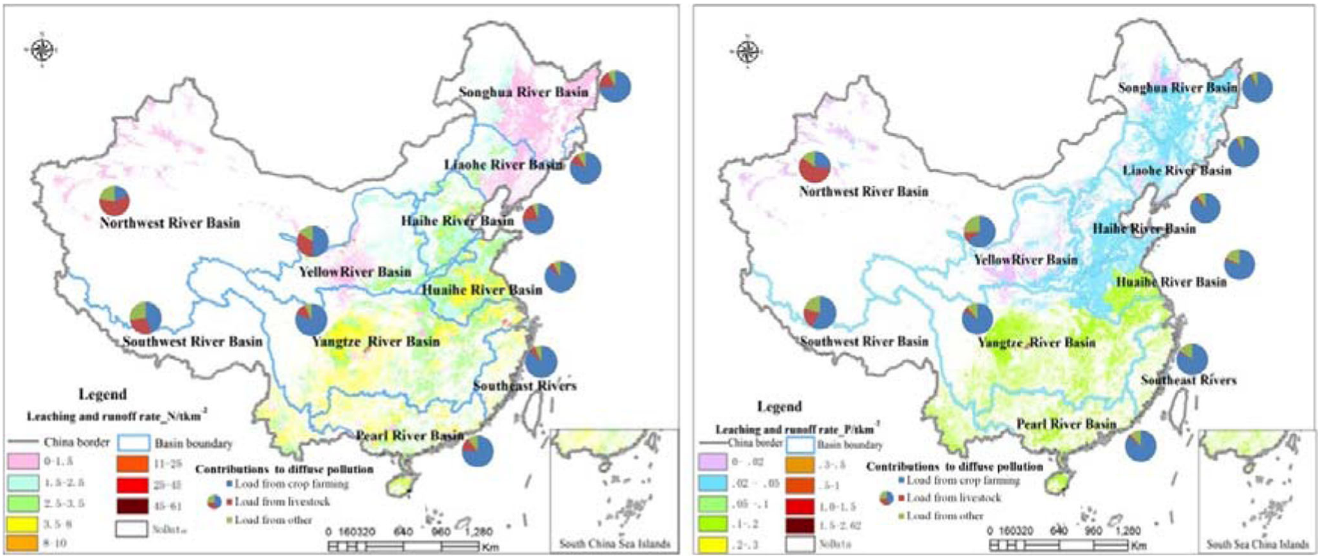
values estimated by EMC were larger than the simulated values of the watersheds, on average. The range of the pollution loading values produced by two models over large watersheds indicates that differing territorial and climatic conditions have direct impacts on diffuse pollution loading. Diffuse TN and TP loads in the middle and lower reaches of Yellow River Basin (Cheng et al. 2006a) and Yangtze River Basin (Wang et al. 2011b) are higher than those in the upper reaches. This is likely due to intensified fertilizer applications and the density of mature livestock excrement in east China compared to west China (Li et al. 2009b; Zhang 2011).

The increasing concerns about diffuse pollution in China highlight the need for national-level assessments. The improved ENPS-LSB (Wang et al. 2012a) model estimated potential diffuse pollution for the entire country. The spatial load observed a declining pattern from south to north and from east to west, which coincides with climate, farmland distribution patterns, and even economic distributions. The main reason is that precipitation in the south is higher than in the north and crop rotation in more intensive in the south (Fig. 1) (Hao et al. 2006; Wang et al. 2014c). The extended substance flow analysis (SFA) framework and Eubolism model were applied to estimate diffuse load from agricultural and rural activities in China. Similar spatial patterns of higher diffuse TN and TP loading occurred in south and east China, which suggested that these areas should be given priority for agricultural pollution management (Chen et al. 2010). In China, large-scale livestock production is also a key contributor (Ouyang et al. 2013) that affects the national nitrogen balance, which is above the acceptance levels of the tillage system. ECM can be applied at large watershed or at the national level, but it cannot provide detailed loading information about different sources of nitrogen or phosphorus. With the rapid development of intensive farming in the west, spatial differences of diffuse nutrient pollution in east and west China are beginning to lessen.

3.2 Temporal patterns of diffuse nutrient pollution loading in China

Daily and seasonal climate patterns and tillage practices are direct factors in diffuse pollution formation, which can be expressed by the distributed model systems (Yu et al. 2013). Studies conducted in the humid south indicate that temporal patterns of diffuse pollution loads exhibited a single peak (Wu et al. 2011; Wang et al. 2014d). However, simulations in the freeze-thawing agricultural watershed showed twin pollution loading peaks resulting from the combination of precipitation and temperature (Tang et al. 2012; Ouyang et al. 2013). In spring, soil thawing impacts hydrological processes and pollution transformation which makes diffuse pollution control more challenging. Improved snowmelt algorithms merged with SWAT have led to better performance using temporal patterns of daily runoff in cold areas (Yu et al. 2013; Ouyang et al. 2015). The migration and transformation of diffuse pollution in freeze-thaw areas can be analyzed using temperature and precipitation simultaneously (Ouyang et al. 2017).

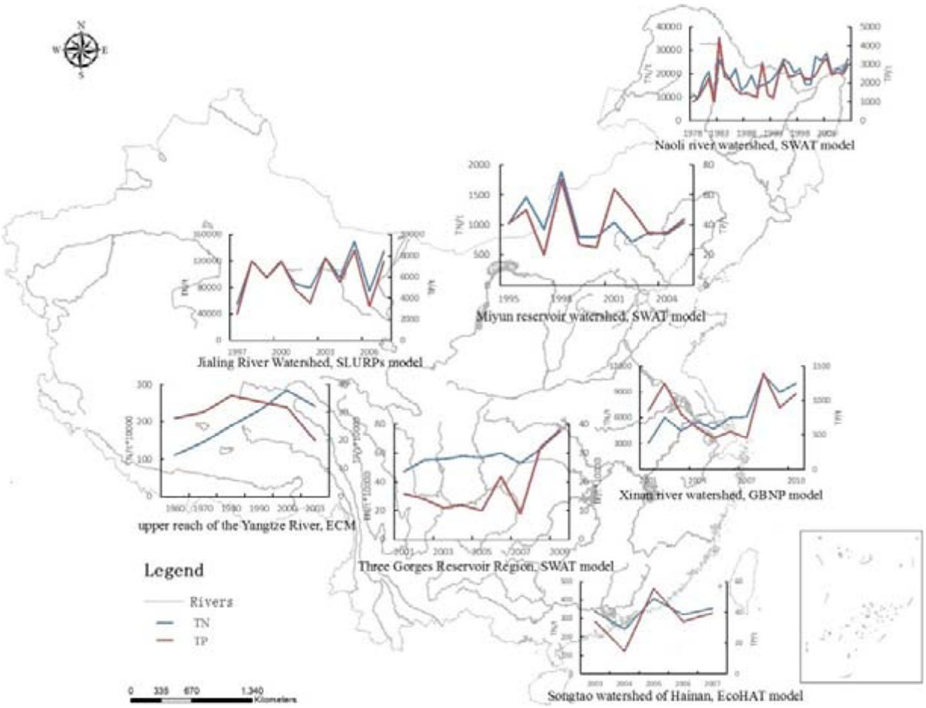
The intern-annual modeling of diffuse pollution loading indicated that many of China's watersheds have recently faced challenges (Fig. 2). After the control of point source discharges, it may be hard for the water quality to recover (Ouyang et al. 2013; Li 2014c; Wang et al. 2014d). With the advances in tillage practices and crop rotation, diffuse nutrient pollution loading in Miyun Reservoir watershed in the north and upper stream of Yangtze River watersheds in south China



(a) (b)

Fig. 1 Spatial patterns of monthly averaged diffuse N (**a**) and P (**b**) loading in China (after Wang et al. 2014c; Hao et al. 2006)

Fig. 2 Temporal trends of diffuse TN and TP pollution loads in different Chinese watersheds



decreased. Having the capability to address long-term pollution composition trends in large watersheds or on a national scale is fundamental and can improve pollution control efficiency. The national averaged diffuse pollution load has increased over the past decade because of intensive tillage, varying soil properties, land use distribution, increased use of fertilizers, and global warming. Considering food security and rural economic development, diffuse pollution in China will increase unless more effective measures are utilized (Ma et al. 2012).

3.3 Watershed diffuse organic chemical pollution assessment in China

Intensive tillage causes diffuse organic chemical pollution (OCP), and it is a risk for watershed water quality (Ouyang et al. 2016; Li et al. 2014d). The occurrence, fate, and sources of OCP in farmland soils and their impact on water quality have increased significantly in China (Fig. 3). With modeling advances and more references from field observations, OCP studies about distribution and sources have advanced knowledge and documented improvements. The laboratory experiment approach shows credibility, but it is time-consuming and limited by the ability to sample (Wang et al. 2012b). Recently, Chinese scholars have improved models to estimate diffuse OCP by sorption mechanisms or ratios comparing other regular pollutants at multiple watersheds (Mackay and Paterson 1982; Chu and Marino 2007). Increased modeling results at different temporal–spatial scales provide more detailed assessments of diffuse OCP distribution and sources. The rapid forecasting model approach for pollutant fate and transport is a viable option to assess the effects of diffuse OCP with limited monitoring data (Boulange et al. 2014).

Models were mainly used to assess the source, the fate, and the transport of OCP in various environmental mediums such as air, water, and soil in China (Dong

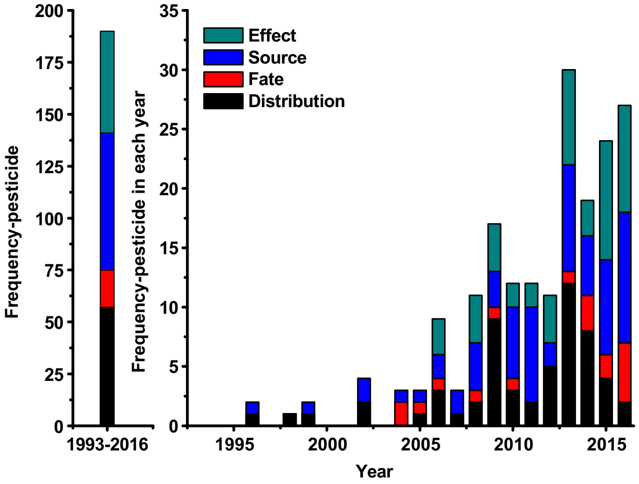


Fig. 3 The frequency of research conducted in China about diffuse pesticide pollution over the last two decades

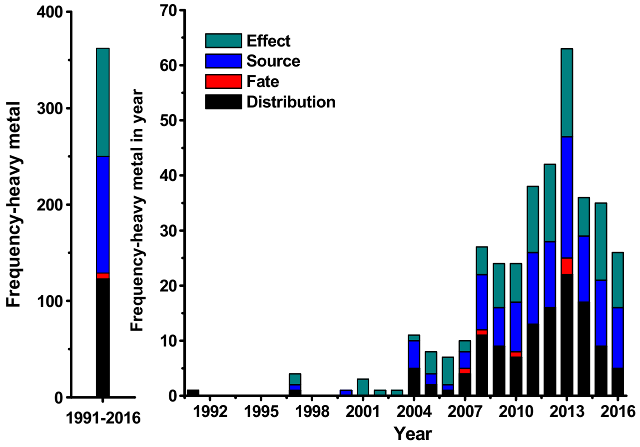


Fig. 4 The frequency of research conducted in China about diffuse heavy metal pollution over the last two decades

et al. 2010). The level IV fugacity model is appropriate when continuous concentrations of typical OCP are available, which has been used in a number of cases to simulate the fate of OCP (Cao et al. 2007; Kong et al. 2012). The distributed hydrology model, which uses spatial–temporal variability of regular nutrient pollutants, has been developed to simulate diffuse OCP in Chinese rivers. The one-dimensional dynamic contaminant fate model, which couples kinematic wave flow options with the advection–dispersion–reaction equation, was developed to assess the spatial–temporal variability of OCP fate in watersheds (Wang et al. 2012b). The watershed diffuse pesticide pollution model (ESSI-2), combined with soil and land use properties, takes each grid of the DEM dataset as a simulating unit for daily steps. The distributed model is a preferred tool to simulate the process of pesticide transportation in terms of tillage patterns and local climatic features. For supporting decision-making at the national scale, the ChnGPERM was developed based on Gridded Basin-Based Pesticide Mass Balance Model (Tian et al. 2009), which can express spatiotemporal variations of α-HCH concentrations (Tian et al. 2011).

3.4 Watershed diffuse heavy metal pollution assessment in China

The heavy metal balance in the soil is influenced by tillage practices, fertilizer applications, and contamination by depositions (Dœlsch et al. 2006). An increased number of studies have addressed spatial patterns of heavy metal variations during agricultural development and land use conversions (Fig. 4). Compared to the OCP studies, the published papers of heavy metals deceased in the recent years. Advances in models based on traditional field investigations have fueled the increase in heavy metal studies over the past decade. There have been attempts to develop a physically based distributed model for simulating diffuse heavy metal pollution based on previous achievements (Velleux et al. 2008). By coupling SWAT and the simplified ECM, the model can quantify particulate and dissolved cadmium loading (Lin et al. 2012). This research could be used to further analyze the characteristics of heavy metal transfer and the methods for adjusting land use structures reasonably (Zhang et al. 2014). However, the aforementioned models estimate the load and not the transport processes of heavy metals.

An option for simulating the transport process of heavy metals to water is by coupling field transport observations and vertical sediment cores with a hydrodynamic model. The sediment-heavy metal transport model for Taihu Lake was established based on the Environment Fluid Dynamics Code (EFDC), which is used to solve three-dimensional turbulent averaged equations (Wang et al. 2013). The two-dimensional models are a more efficient tool to study heavy metal transport processes. A two-dimensional depth-average numerical model, which couples RMA2 (Norton et al. 1973) and TOXIWASP (Ambrose et al. 1983) models, was developed to simulate hydrodynamics and to track the fate of heavy metals (Yang et al. 2012). The hydrodynamic results obtained from the RMA2 model can provide simulated flow fields and water-level information for this water quality model. A diffuse heavy metal model for watersheds was developed to simulate transformations in the soil, movement, and sedimentation in rivers and reservoirs based on SWAT (He et al. 2013). The diffuse heavy metal is primarily simulated by coupling statistical runoff and sediment-heavy metal ratios with typical diffuse pollutant loading in China. An alternative way to estimate the temporal–spatial variability of heavy metals is to combine SWAT with sediment geochemistry, which establishes correlativity between heavy metal and typical diffuse pollutant simulated by SWAT model (Jiao et al. 2015). This innovative approach was used to assess temporal–spatial variability of particulate Pb, Cu, Cr, and Ni losses within an agricultural watershed. The results showed that the watershed particulate heavy metal loadings displayed an obvious increasing trend from 1981 to 2010; Pb ranged from 18.85 to 21.81 g/ha; Cu ranged from 19.57 to 24.32 g/ha (Jiao et al. 2014).

3.5 Risk of diffuse pollution for Chinese water quality

As one of the main factors causing eutrophication, diffuse pollution is a key component in risk assessment and catchment management (Orr et al. 2007). Recently, diffuse pollution modeling research has shifted from ordinary applications towards risk assessments (Wu and Chen 2013; Fonseca et al. 2014). However, some of these assessments were based on a one-dimensional water quality equation, which cannot accurately reflect migration and transformation of pollutants in water for large reservoirs and lakes (Zhu et al. 2012; Liu et al. 2013). A few studies have attempted to link diffuse models with two-dimensional or three-dimensional water quality models in order to fill this gap. SWAT has been integrated with an aquatic ecological-hydrodynamic model (Wang et al. 2006), which was developed by coupling a water quality analysis simulation program (WASP) with EFDC, a three-dimensional model. With the distributed model, water safety of most watersheds in China can be predicted even with diverse water resource conditions. The updated river water quality model can simulate the response of different diffuse pollution reduction schemes.

Reservoirs provide drinking water for most Chinese cities, so upstream watershed management considering diffuse pollution is of prime concern. The CE-QUAL-W2 is a two-dimensional hydrodynamic, water quality model, which has been coupled with SWAT or AnnAGNPS to simulate the impact of diffuse pollution on water quality of narrow and long reservoirs (Zhu et al. 2012). The CE-QUAL-W2 performs well in relatively narrow and long reservoirs or lakes (Yuan et al. 2007; Yin et al. 2008). The disbursed water quality model combined with traditional reservoir fluid tools can indicate channel processes between two adjacent reservoirs, which can be influenced by outflows of the upstream reservoir (Zhang et al. 2012).

4 Conclusions and future perspectives

Previous studies of diffuse pollution in China have highlighted national water safety issue and provided pollutant fate insights. Future work on diffuse pollution modeling may focus on the following three aspects. The combination of modeling and monitoring at similar spatial–temporal scales can serve as an effective tool to manage diffuse multi-scale pollution. The hydrological and water quality monitoring networks in China are insufficient, which is not plenty for diffuse pollution load estimation at national and regional scales. The validated values of sensitive parameters in different watersheds need to be established as a national database, in order to avoid uncertainty of models. Conversely, using a remote sensing data-derived model is an alternative solution to national diffuse pollution modeling.

There is also a need to improve existing models to describe diffuse pollution processes more accurately with respect to China's tillage practices. Tillage patterns of a single crop may vary intensively across the country, which directly affects the design of Best Management Practices (BMPs). Coupling large basin management designs with diffuse pollution models will become an important topic, and these combinations will be useful for pollution management. With the deepening understanding of diffuse pollution and agricultural development situation in China, the guideline for the Chinese agricultural system has been shifted from yield priority to green agriculture. Therefore, the environmental consequence can be assessed by the diffuse pollution models for the diverse policy scenarios with the orientation of green agriculture in future.

Modeling migration and transformation of trace diffuse pollutants has just begun and needs further modification of traditional distributed models. The fate of pesticides and heavy metals is an important factor in safeguarding water quality and human health. The study of trace pollutants also broadens the application of diffuse modeling and can integrate previous field-scale monitoring and lab results. Studies of diffuse nutrient pollution modeling in China still mainly depend on experiences from other countries, but there are plenty of data to develop effective tools for trace pollutants in China.

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