Journal of Hazardous Materials 280 (2014) 244–251

Contents lists available at ScienceDirect

Journal of Hazardous Materials

journal homepage: www.elsevier.com/locate/jhazmat

Targeting priority management areas for multiple pollutants from non-point sources

Lei Chen, Guoyuan Wei, Yucen Zhong, Guobo Wang, Zhenyao Shen*

State Key Laboratory of Water Environment Simulation, School of Environment, Beijing Normal University, Beijing 100875, PR China

HIGHLIGHTS

- This paper provides a new approach for the control of multiple pollutants.
- The spatial distributions of each specific pollutant are explored and compared.
- Moderate-sensitive areas of each pollutant may be the multiple-pollutants PMAs.
- This paper provides cost-effective PMAs, especially for the headwater areas.
- This paper further illustrates the placement and removal requirement for BMPs.

ARTICLE INFO

Article history:
Received 7 January 2014
Received in revised form 17 July 2014
Accepted 4 August 2014
Available online 17 August 2014

Keywords:
Priority management area
Multiple pollutants
Multi-criteria evaluation
Watershed model
Non-point sources pollution

ABSTRACT

The control of multiple pollutants from non-point sources is very difficult because their loss potentials are not consistent on the same spatial distributions. In this research, an innovative approach was established for multiple-pollutant priority management areas (MP-PMAs). In the new framework, the MP-PMA approach focused on the sensitive areas that contributed a variety of pollutants instead of a specific targeted pollutant by integrating a watershed model and a Pareto-based multi-criteria evaluation approach. Based on the results, multiple levels of MP-PMAs were established with respect to the corresponding requirements of clean water statutes. Compared to traditional separate strategies, the MP-PMA approach would lead to more cost-effective watershed management because those moderate-level PMAs for specific targeted pollutant might be the high-level MP-PMAs. With respect to spatial distribution, the MP-PMA approach provided more accurate target results for the high-level PMAs, especially among the headwater areas. From a scientific view, the MP-PMA approach provides an integrated suggestion for the placement and removal potentials of best management practices at the watershed scale.

1. Introduction

Pollutant discharges to rivers, lakes, and other water bodies can be classified as either point source or non-point source (NPS) [1]. Comparatively, point source pollution is relatively simple to evaluate and control through periodic monitoring at specific river location, while NPS exports are intermittent because of irregular climatic forces and human activities [2]. Generally, NPS pollutants are transported from extensive areas of a watershed but almost 90% of NPS exports are from relatively small areas [3]. In this respect, a watershed manager needs to gain insights into the spatial dynamics of priority management areas (PMAs) or critical source areas (CSAs) as an inherent part of all watershed programs [4,5].

Previous studies have demonstrated that the impact of certain NPS pollutants depends on not only source factors, such as soil characteristics and plant biology, but also transport processes [2]. Therefore, the control of multiple pollutants is especially difficult at the watershed scale because their loss potentials are not evenly distributed on the same spatial and temporal scales [3]. Additionally, the changing climatic, topographic and anthropogenic factors exacerbate the spatial dynamics of multiple pollutants, making the control of multiple pollutants even more difficult [6,7]. Currently, separate strategies are developed for each targeted pollutant, whereas other pollutants are ignored. However, these narrowly targeted strategies may lead to confusing results. For example, the control of nitrogen (N) fertilizer may exacerbate soil phosphorus (P) enrichment, whereas conservation tillage that

* Corresponding author. Tel.: +86 10 58800398; fax: +86 10 58800398.
E-mail addresses: chenlei1982bnu@bnu.edu.cn (L. Chen), zyshen@bnu.edu.cn, zyshen@tsinghua.org.cn (Z. Shen).

http://dx.doi.org/10.1016/j.jhazmat.2014.08.012
0304-3894/

decreases the loss potential of P would increases the loss potential of N [8]. Despite the awareness of potential difficulties, the complete picture of multiple-pollutants PMAs is not yet clear at the watershed level [9].

An integrated approach is needed here to target watershed PMAs that contribute larger amounts of multiple pollutants. Water quality monitoring and plot sampling have been conducted at small-scale catchments [10,11] or for a specific land use, including paddy fields [12], forests [13], or rural areas [14]. Then the river pollutant fluxes are decomposed among their origin sources to identify the watershed-scale PMAs through the source apportionment approach [15]. However, monitoring approaches are generally expensive and time consuming, especially for large-scale watersheds [11,16]. Considering the complexity of watershed processes, watershed models, such as the Soil Water Assessment Tool (SWAT) and the Hydrological Simulation Program FORTRAN (HSPF), have been used as indispensable tools to deal with the dynamics processes over broad temporal and spatial scales [17,18]. However, the traditional model-based PMAs are typically designed for one specific pollutant, thus these specific-pollutant PMAs are often conflicting in the case of multiple pollutants because of their natural characteristics. Comparatively, the multi-criteria evaluation (MCE) approach [19], which has been applied widely in the field of water resources management [20,21], provides a valuable perspective to deal with this problem. In general, the application of the MCE is to combine the conflicting objectives into a single index form for multi-criteria evaluation [22]. Weighting factors are attributed to all GIS-based criteria and thus, a total score is quantified for each spatial unit. This concept is undeniably sound, but it leaves doubt about the extent of weight value. For these reasons, the control of comprehensive multiple-pollutants PMAs at the watershed scale is developing very slowly.

The aim of this paper is to establish comprehensive PMAs for multiple pollutants (MP-PMAs) for large-scale watersheds. In the new framework, the MP-PMAs approach focuses on the sensitive spatial units that contribute greater amounts of multiple pollutants instead of a specific targeted pollutant. An innovative approach is presented by integrating a watershed model and a Pareto-based MCE approach. Detailed information regarding the MP-PMAs approach and the study area is presented below.

2. Materials and methods

2.1. Study watershed description

The Daning River is located in eastern Chongqing municipality, South China, and forms a watershed (108°44′–110°11′ E, 31°04′–31°44′ N) that lies in the central part of the Three Gorges Reservoir area. The basin has a drainage area of approximately 2027 km^2. The region is dominated by a subtropical monsoonal climate, with an average annual rainfall, temperature, and relative humidity of 1124.5 mm (from 652 to 1964 mm), 18.4 °C (17.8 °C to 19 °C) and 73%, respectively. Approximately 80% of the annual rainfall occurs during the wet seasons (predominantly May–July). Forest vegetation coverage comprises over 65.8% of the total watershed, and other primary land uses are 22.2% cropland and 11.4% grassland. The main crops consist of corn, wheat, rice, and potatoes, whereas zonal yellow soil is the dominant soil in the watershed.

In this watershed, the loss potentials of N and P have increased sharply over recent years for the following reasons: the increased use of fertilizers on agricultural lands to feed the growing population; the increased tendency to raise livestock to meet the local preference for meat diets; and the filling stage of the Three Gorges Reservoir in 2003, which had considerably changed the river environments. For the purpose of comparison, both N and P were selected as the targeted pollutants in this research, and the target results of the watershed PMAs were based on the load contribution of each spatial unit to the rive fluxes of N and P.

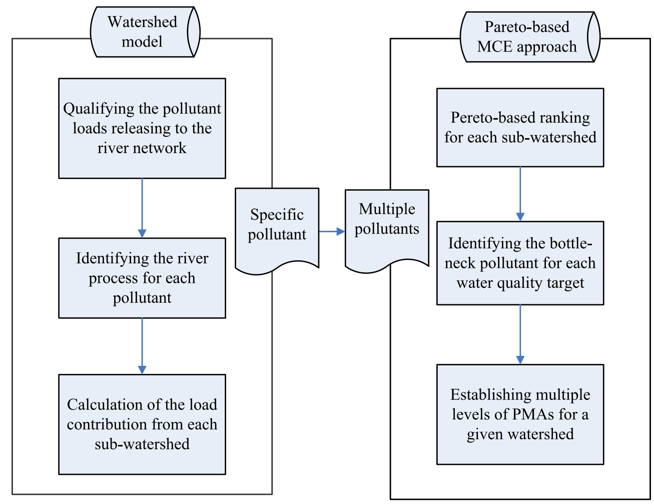

Fig. 1. The framework of the MP-PMA.

2.2. The MP-PMA approach

The MP-PMA approach was shown in Fig. 1, which integrated the assessments of a single specific pollutant and multiple pollutants in addressing watershed PMAs. First, the watershed model was used to quantify the amount of each pollutant that is exported from each spatial unit to the nearby water body. Second, a Pareto-based MCE approach was undertaken for ranking each spatial unit. Finally, the bottle-neck pollutants were identified and the multiple-levels PMAs were established based on the upgrading requirements of the water quality targets.

2.2.1. Watershed model description

Many studies have demonstrated the successful applications of the SWAT model to provide quantitative assessments of watershed PMAs [18,23,24]. Considering the spatial scales of the study and data availability, the SWAT model, developed by the USDA-ARS [25], was used to quantify the watershed processes of NPS-N and NPS-P. The SWAT model is physically based and semi-distributed, composed of a weather generator, hydrology, soil erosion, nutrient cycling and human management [26]. The hydrology of the SWAT model can be split into a land phase, which controls the amount of runoff, eroded soil and nutrients from each sub-watershed, and also a channel phase, which determines the pollutant routing through the river network [27]. In this research, the curve number (CN) method [28] and the Modified Universal Soil Loss Equation (MUSLE) [29] was used to estimate the runoff amounts and sediment yields from cropland farming, rural living and livestock breeding at the Hydrologic Research Unit (HRUs) level. In this stage, the respective loads of N and P that were released from each sub-watershed were achieved. Then these nutrients were routed through the river network to a specific river assessment point using the enhanced stream water quality model QUAL2E [30]. In this research, each stream reach was treated as a well-mixed channel and the transport mechanisms of dispersion and advection, as well as an updated kinetic transform, were considered for N and P. Essentially, the application of the SWAT model provided the linkages between the N and P exports from each sub-watershed and their final fluxes at a specific river assessment point. More information about the SWAT model could be found in the supplementary information (S1). The ArcGIS interface of the SWAT 2009 version was used for establishing