Marine Pollution Bulletin 87 (2014) 88–97

Contents lists available at ScienceDirect

Marine Pollution Bulletin

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

Study of landscape patterns of variation and optimization based on non-point source pollution control in an estuary

Mengzhen Jiang *, Haiying Chen, Qinghui Chen, Haiyan Wu

Third Institute of Oceanography, State Oceanic Administration, Xiamen 361005, China

ARTICLE INFO

Article history:
Available online 22 August 2014

Keywords:
High-resolution remote sensing image data
"Sink" landscape
Non-point source pollution control

ABSTRACT

Appropriate increases in the "sink" of a landscape can reduce the risk of non-point source pollution (NPSP) to the sea at relatively lower costs and at a higher efficiency. Based on high-resolution remote sensing image data taken between 2003 and 2008, we analyzed the "source" and "sink" landscape pattern variations of nitrogen and phosphorus pollutants in the Jiulongjiang estuary region. The contribution to the sea and distribution of each pollutant in the region was calculated using the LCI and mGLCI models. The results indicated that an increased amount of pollutants was contributed to the sea, and the "source" area of the nitrogen NPSP in the study area increased by 32.75 km^2. We also propose a landscape pattern optimization to reduce pollution in the Jiulongjiang estuary in 2008 through the conversion of cultivated land with slopes greater than 15° and paddy fields near rivers, and an increase in mangrove areas.

1. Introduction

Non-point source pollution (NPSP) is an environmental problem caused by factors such as population growth and land use change. Coastal waters are susceptible to the NPSP resulting from urbanization and economic development in coastal zones and estuary regions. The discharged pollution may increase the risk of eutrophication and pose a threat to the health of coastal marine ecosystems.

The main methods for studying NPSP are field investigations and the NPSP model. After the 1970s, the developing trend in NPSP study changed from qualification to quantification, from statistics and investigation to mechanism, and from simulation to control and management. Computer models, such as STORM and SWMM for urban storm runoff pollution, ARM for agriculture pollution, and HSPF for watersheds are gradually becoming an important means for quantitatively assessing and simulating agricultural NPSP. After the development of "3S" technology (RS, Remote Sensing; GIS, Geographic Information System; GPS, Global Position System) in the 1990s, integrating GIS and the NPSP model became an important means for studying NPSP. Concurrently, by modulating and improving the model parameters, the efficiency of the NPSP models increased. Several powerful, large-scale watershed models were developed that integrated spatial information processing, database technology, mathematical calculations, and visual expression. The performance and precision of NPSP simulation and forecasting were improved. Examples include AGNPS developed by the USARS (United States Agricultural Research Service) and the SWAT and BASINS models developed by the USEPA (USA Environmental Protection Agency). However, these models were seldom applied in estuary regions with long shorelines.

NPSP is associated with landscape distributions (Basnyat et al., 1999; Hood et al., 2003; Buck et al., 2004; Derek, 2010). Nevertheless, NPSP models gave little consideration to the "source" and "sink" of landscape patterns, especially the pollutant removal of the "sink" landscape and a landscape optimization based on NPSP control. Yue (2007a,b) suggested that the variations in landscape patterns had a significant impact on the water quality in watersheds by considering the type, pattern, spatial distribution and key location of the landscape patches and decreasing the NPSP as much as possible. Chen et al. (2006) proposed the theory of "source" and "sink" landscapes based on the "source-sink" theory of atmospheric pollution as a way to study the influence of the dynamic balance of landscape types on ecological processes that results in a suitable landscape pattern. Chen et al. applied the "source-sink" theory to the study of NPSP and discovered a method to quantitatively analyze the NPSP of the "source-sink" landscapes that contributed to the export of NPSP in the watershed. Based on the method of Chen et al. Jiang et al. (2013) proposed a method based on remote sensing technology to study the spatial distribution of an estuarine region that receives contributions from NPSP. These two methods can meet different study demands and provide

* Corresponding author. Permanent address: Third Institute of Oceanography, (SOA), No. 178, Daxue Road, Xiamen 361005, China. Tel.: +86 15259261969; fax: +86 592 2195982.

E-mail addresses: mengzhenj@gmail.com (M. Jiang), rainman00.work@gmail.com (H. Chen).

http://dx.doi.org/10.1016/j.marpolbul.2014.08.008
0025-326X/

a basis for landscape pattern optimization to control NPSP exported to the sea.

Landscape pattern variations may be determined through remotely sensed observations and surveys of multiple temporal scales and bandwidths (Hartter and Southworth, 2009). The remote sensing of landscapes and their classification primarily includes conventional supervised classification, manual neutral networks, knowledge mining and a decision tree model (MacAlister and Mahaxay, 2009; Davranche et al., 2010). High-resolution remote sensing images are advantageous for their high spatial resolution, sharpness and information content, which enables landscape information to be fully and precisely extracted. In this study, we used a high resolution SPOT 5 fused image, ALOS fused image and other aerial images to study the variations of "source" and "sink" landscape patterns in the Jiulongjiang estuary region during the time period 2003–2008. We also calculated the location-weighted Landscape Contrast Index (LCI) and the Modified Grid source-sink Landscape Contrast Index (mGLCI) to analyze the contribution and distribution of the "source" and "sink" structure of the NPSP in the estuary region to the sea. Finally, we researched the landscape optimization based on the NPSP control for the Jiulongjiang estuary in 2008.

2. Methods

In this study, we introduce the LCI index, GLCI index and the theory of landscape optimization based on non-point source pollution control. The LCI index is used to quantitatively calculate the contribution of the landscape to the non-point source pollution in an estuary using the "source" and "sink" landscape accumulated area ratio to contrast to the estuary boundary. The GLCI index is used to reflect the contribution of spatial variation in the landscape pattern to non-point source pollution in an estuary through each grid in the study region.

2.1. Data and process

2.1.1. Data

The Jiulongjiang estuary is located along the southeast coast of the Fujian province in China. The estuary has a subtropical monsoon climate. The terrain of the region is flat; the shallow sea areas and mudflats are large. The estuary has many islands with diverse biological resources and wetland landscapes. Since the mid-1980s, certain areas of coastal water in the Jiulong River region have been deteriorated by eutrophication and the excessive growth of aquatic algae (Cao and Wong, 2007).

Fig. 1 shows the location of the study area in China, and Fig. 2 shows the boundary of the 854 km^2 region that covers the administrative divisions of Xiamen City and Zhangzhou City (Jiang et al., 2013).

A high resolution SPOT 5 fused image, an ALOS fused image and other aerial images along with their acquisition times and spatial resolution and cover range are presented in Table 1.

The DEM with a resolution of 5 m $\times$ 5 m was also applied to calculate the LCI and GLCI.

2.1.2. Data processing

2.1.2.1. Preprocessing of remote sensing data. The images used for analysis precede the pre-treatment (including geometric precision correction, image registration and image fusion) to produce the SPOT 5 and ALOS natural color integrated satellite images of Jiulongjiang estuary in 2003 and 2008. The correction accuracy is fewer than 2 pixels, and the error of image registration was controlled at 0.5 pixels. Three-degree-wide zones of a Gauss-Kruger projection and a WGS-84 (World Geodetic System-1984) coordinate system were applied (Jiang et al., 2013).

2.1.2.2. "Source" and "sink" identification. Different land uses have different influences on the ecological environment (Li et al., 2008). We use total nitrogen (N) and total phosphorus (P) in this study. The "source" and "sink" landscape identification is performed at the annual scale. We identified the "source" and "sink" landscapes through "source-sink" theory, the high resolution remote sensing images, land uses' pollution discharge coefficients, regional investigation data, and other references (Jiang, 2012).

2.2. The contribution of "source" and "sink" landscapes to non-point source pollution

2.2.1. Location-weighted Landscape Contrast Index

Landscape plays the role of the "source," the "sink" or the transmission when producing NPSP (Chen et al., 2003). If the "source"

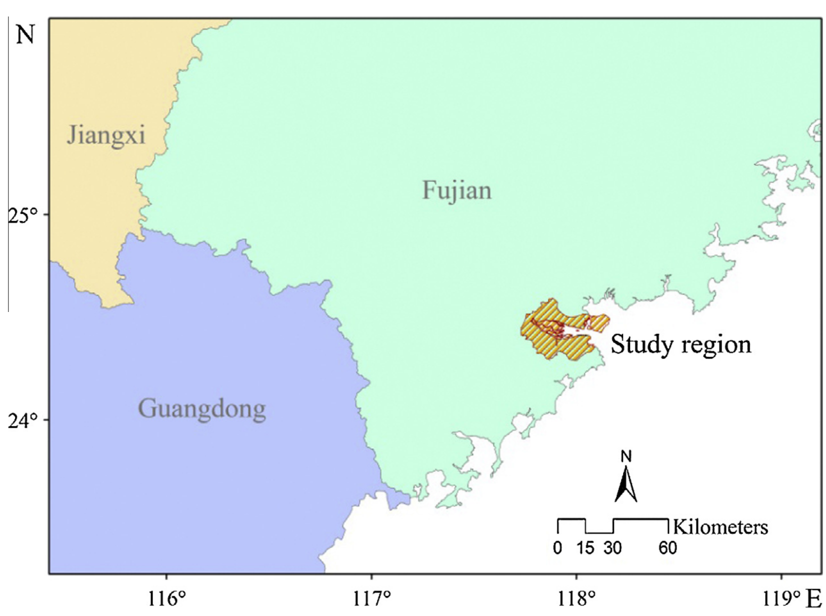

Fig. 1. Location of the study area in China.