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Assessment of pollutant mean concentrations in the Yangtze estuary based on MSN theory

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ABSTRACT

Reliable assessment of water quality is a critical issue for estuaries. Nutrient concentrations show significant spatial distinctions between areas under the influence of fresh-sea water interaction and anthropogenic effects. For this situation, given the limitations of general mean estimation approaches, a new method for surfaces with non-homogeneity (MSN) was applied to obtain optimized linear unbiased estimations of the mean nutrient concentrations in the study area in the Yangtze estuary from 2011 to 2013. Other mean estimation methods, including block Kriging (BK), simple random sampling (SS) and stratified sampling (ST) inference, were applied simultaneously for comparison. Their performance was evaluated by estimation error. The results show that MSN had the highest accuracy, while SS had the highest estimation error. ST and BK were intermediate in terms of their performance. Thus, MSN is an appropriate method that can be adopted to reduce the uncertainty of mean pollutant estimation in estuaries.

1. Introduction

The water quality of the Yangtze estuary has been a substantial concern in recent years due to the aggravated pollution caused by increases in regular human activities, industrial discharge, and oil leakage events. According to the China Marine Environment Quality Bulletin, the water quality of the Yangtze estuary and Hangzhou bay has been listed as extremely unqualified among the nine major tidal estuaries in China. Because marine resources have been emphasized as a strategic resource for the national interest, the observation, assessment, and management of marine pollution has become critical (Floehr et al., 2015; Smith, 2003; Su et al., 2015).

Estuary water pollution involves eutrophication with various excessive nutrient components distributed by biochemical and physical processes (D. and D., 2004; Huang et al., 2006; Li et al., 2014; Zhang et al., 2007). Increasing numbers of studies have focused on the physical, biochemical, and coupled mechanisms involved in the distribution and transfer of pollutants (Shen et al., 2001; Sun et al., 2013; Wang et al., 2006; Chen et al., 2009). The spatial and temporal distributions of nutrients are related directly to the evolution of the contamination area and thus merit considerable attention from both academia and industry (Edmond et al., 1985; Gui lin et al., 2012; Pan and Shen, 2010; Zhang et al., 2011). However, statistical approaches adopted for the assessment of nutrient concentrations are rarely discussed, although accuracy in such estimates is highly desired. The most commonly adopted general-mean-value theory, which still remains useful, is partially violated under conditions of non-homogeneity. Furthermore, potential interdependence of the observed data of a variable in the same block area is rarely considered. Few efforts have been made to improve the statistical method itself for the estimation of the nutrient pollutant concentration, especially for the two major components, nitrate and phosphate.

Regional mean nutrient pollutant concentrations are important indicators in spatial and temporal variation analysis that decision-makers use most; these concentration estimations are usually generated by typical interpolation and statistical methods. However, estimation uncertainty remains an issue that cannot be avoided or neglected (Cambule et al., 2014; Liu et al., 2014; Murphy et al., 2010). In most cases, the field data of the surface seawater layer are collected at sampling gauge locations at certain depths. Thus, the estimation of average pollutant concentration is actually a process that uses limited or finite datasets to estimate the continuous area. Classical statistical methods and model-based inference are each able to handle this circumstance (Haining, 1988; J. and V., 2002; Matheron, 1963; Shimada and Taro, 2015; Wang et al., 2009). Classical statistical methods can achieve an

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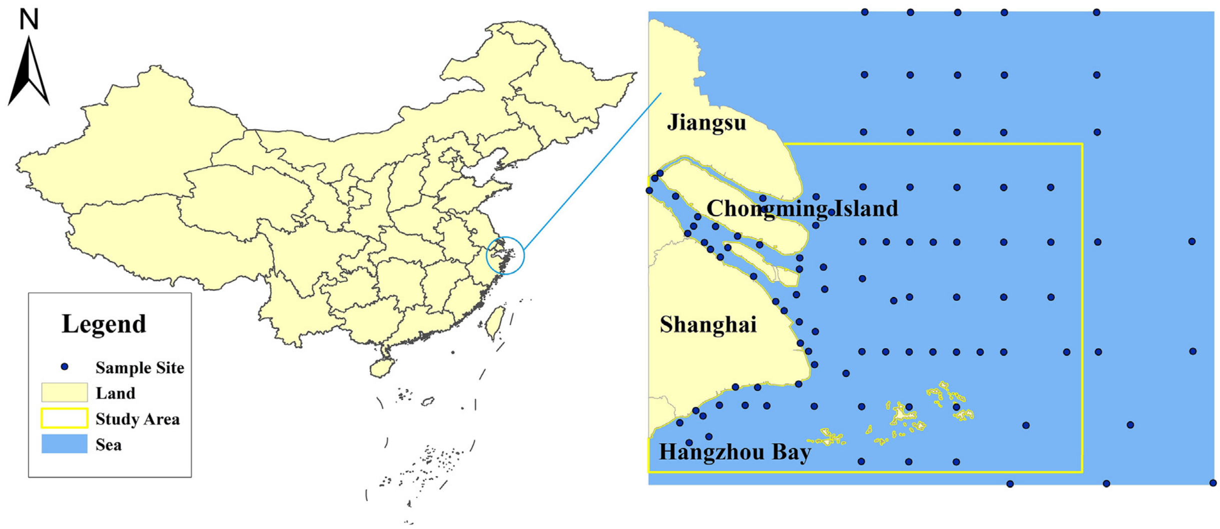

Fig. 1. Approximate position of the study area (circle of the left plot) and distribution map of monitoring sites.

unbiased estimation if the study area of interest approximately follows the independent identical distribution. Model-based inference methods provide more efficient estimation because they can guarantee an unbiased and optimal estimation, as both the spatial autocorrelation of target variables and minimum estimation variance are taken into account (Mishra et al., 2010; Thompson and Kolka, 2005). However, the homogeneous assumption for the survey region using this type of method strongly violates the stratified distribution in the real world and therefore hinders accurate assessment.

Non-homogeneity exists in a variety of natural phenomena and geophysical environments (e.g., moisture of soil, forest community) and is also inherent in estuary pollution because of complex physical and biochemical processes. Coastal water is affected by the impact from the land and sea, and because of hydrological and hydrodynamic conditions, changes within a small spatial scale can be substantial. In other words, it is a heterogeneous region (Hu, 1995). Wang et al. proposed the mean of surface with heterogeneity (MSN) method, which could provide preferable solutions to the non-homogeneous area and yield an optimized linear unbiased mean estimation (Wang et al., 2010a). Partition would be a reasonable way to divide a nonhomogeneous region into sub-areas that could be treated approximately as homogenous pieces. For the partition methods, different empirical or mathematical statistical approaches are applied according to various study targets (e.g., evolution stage, biological environment, nutrient salt, sediment-based and cluster-analysis-based estuary stratification) (Liu et al., 2011; Zhu et al., 2008). In this paper, a new assessment system is introduced and applied to reduce uncertainty regarding the nutrient pollutant's mean concentration. A hybrid-distance-based SOFM cluster method was adopted to stratify the Yangtze estuary. Then, the MSN method was used to calculate the mean pollutant concentration for each element for the whole study area. The results from the commonly used methods, block Kriging (BK) mean estimation (Kern and Coyle,

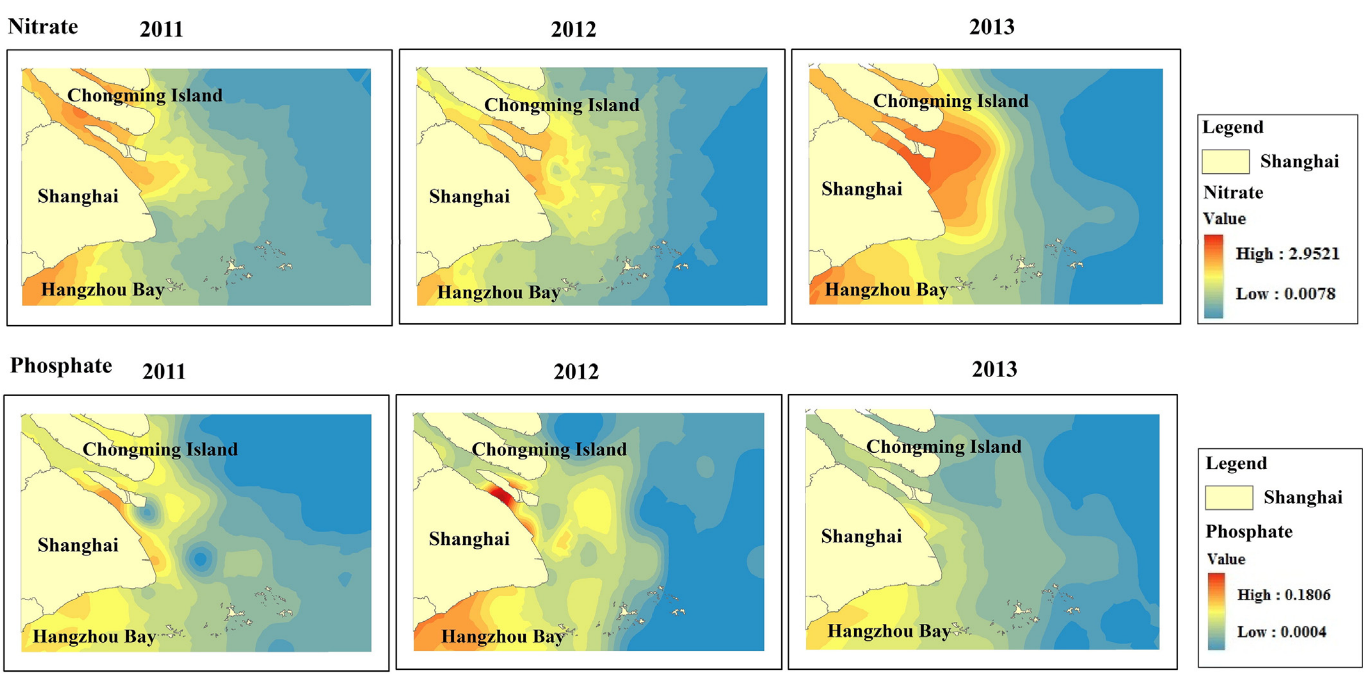

Fig. 2. Concentration (mg/L) map of nitrate (above) and phosphate (below) from 2011 to 2013. Red color represents high concentration; light blue color represents low concentration. The maximum and minimum concentrations are given in the legend. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

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