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Non-Algorithmically Integrating Land Use Type with Spatial Interpolation of Surface Soil Nutrients in an Urbanizing Watershed

WU Qian[1], LI Qingliang[1,2], GAO Jinbo[1,3], LIN Qiaoying[1,3], XU Qiufang[2], Peter M. GROFFMAN[4] and YU Shen[1,*]

[1] *Key Laboratory of Urban Environment and Health, Institute of Urban Environment, Chinese Academy of Sciences, Xiamen 361021 (China)*
[2] *Zhejiang A&F University, Lin'an 311300 (China)*
[3] *University of Chinese Academy of Sciences, Beijing 100049 (China)*
[4] *Cary Institute of Ecosystem Studies, Millbrook NY 12545 (USA)*

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ABSTRACT

Integrating land use type and other geographic information within spatial interpolation has been proposed as a solution to improve the performance and accuracy of soil nutrient mapping at the regional scale. This study developed a non-algorithm approach, *i.e.*, applying inverse distance weighting (IDW) and ordinary kriging (OK), to individual land use types rather than to the whole watershed, to determine if this improved the performance in mapping soil total C (TC), total N (TN), and total P (TP) in a 200-km^2 urbanizing watershed in Southeast China. Four land use types were identified by visual interpretation as forest land, agricultural land, green land, and urban land. One hundred and fifty soil samples (0–10 cm) were taken according to land use type and patch size. Results showed that the non-algorithm approach, interpolation based on individual land use types, substantially improved the performance of IDW and OK for mapping TC, TN, and TP in the watershed. Root mean square errors were reduced by 3.9% for TC, 10.7% for TN, and 25.9% for TP by the application of IDW, while the improvements by OK were slightly lower as 0.9% for TC, 7.7% for TN, and 18.1% for TP. Interpolations based on individual land use types visually improved depiction of spatial patterns for TC, TN, and TP in the watershed relative to interpolations by the whole watershed. Substantial improvements might be expected with denser sampling points. We suggest that this non-algorithm approach might provide an alternative to algorithm-based approaches to depict watershed-scale nutrient patterns.

Key Words: geographic information system, inverse distance weighting, non-algorithm approach, ordinary kriging, spatial pattern

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INTRODUCTION

Spatial interpolation using geographic information system (GIS) is a powerful tool for interpreting spatial patterns and impacts of anthropic activities at varying scales. Multiple methods of spatial interpolation have been developed to estimate spatially continuous data across regions of interest from point observations of environmental attributes (Li and Heap, 2008). Ordinary kriging (OK) and inverse distance weighting (IDW) are two of the most frequently applied spatial interpolation methods and have been compared with other methods (Li and Heap, 2011). The kriging approach successfully mapped the contents of organic matter, total N, P, and K, and available P and K in black soil (1 400 samples with a 5-km interval each) in Northeast China (Zhang *et al.*, 2007). Accuracy is the most vital standard for assessing the performance of spatial interpolation methods (Chaplot *et al.*, 2006). Factors influencing the performance of spatial interpolation methods were summarized as sampling density, sample spatial distribution, sample clustering, surface type, data variance, data normality, quality of secondary information, stratification, grid size or resolution, and their interactions (Li and Heap, 2011). These factors create non-linear heterogeneity in attributes of interest across a region and no single best method has emerged.

Watersheds, regarded as terrestrial "landscape-level units" with "identifiable natural boundaries" (Odum and Barrett, 2004), have been widely used to study water quality problems and as a basis for management plans to protect receiving waters (USEPA,

*Corresponding author. E-mail: syu@iue.ac.cn.

2008; Kaushal *et al.*, 2011; Lutz, 2011). The spatial distribution of nutrients, contaminants, and matrix properties are critical for predicting the dynamics of nutrients and contaminants in watersheds (Yang and Jin, 2010; Makhamreh, 2011; Fu *et al.*, 2013; Xu *et al.*, 2013a). Watersheds are comprised of diverse landscape units, including natural features and human-impacted units with various intensities. Non-linear anthropogenic impacts on landscape units result in considerable uncertainty in spatial interpolations of attributes in watersheds. Karydas *et al.* (2009) found that topography, crop alteration, and farming practices significantly affected the performance of spatial interpolation methods (*i.e.*, OK, IDW, and radial basis functions) in mapping soil organic matter, electric conductivity, Fe content, clay content, and total $CaCO_3$ in a 25-ha area of grape vines and olive trees. Land use type was identified as one of the most important factors affecting the heterogeneity and spatial interpolation accuracy of soil attributes (Wang *et al.*, 2009; Wang and Shao, 2013). Incorporating land use information would improve prediction accuracy and reduce uncertainty in spatial interpolation of soil properties, such as total N (Qu *et al.*, 2013a, b).

There are few algorithm-based approaches integrating land use information with the spatial interpolation methods, such as geographically weighted regression (GWR) (Zhang *et al.*, 2011; Wang *et al.*, 2013), high accuracy surface modeling (HASM) (Shi *et al.*, 2012), and area-and-point kriging (AAPK) (Qu *et al.*, 2012). The GWR model includes geographic factors, such as land cover/land use type, soil type, and elevation, as independent attributes. GWR applications in mapping soil organic C in Ireland (Zhang *et al.*, 2011) and soil total N in Longyan, Fujian Province, China (Wang *et al.*, 2013) produced clear spatial patterns and reduced smoothing effects of spatial interpolation in comparison with other spatial interpolation methods, including OK, IDW, multiple linear regression, and ordinary cokriging. The HASM approach was developed from the fundamental theorem of surface theory and was recently applied to spatially interpolate soil properties (Shi *et al.*, 2011), while the AAPK approach was originally developed for real estate pricing and was more effective in spatially interpolating soil total N at a county scale than OK and residual kriging (Qu *et al.*, 2012).

Land use is a product of natural landscape settings, natural attribute variation, and human practices (Pan *et al.*, 1999; Sanderson *et al.*, 2002; Jia *et al.*, 2011; de Baan *et al.*, 2013). In China, a rapid urbanization in the past decades resulted in dramatic changes of land use/land cover nationwide (Xu *et al.*, 2013a). However, most past studies of spatial interpolation of soil attributes have neglected land use type because the algorithm-based spatial interpolation approaches were not available for various land use conditions. We hypothesized that applying spatial interpolation to individual land use types in a region of interest instead of to the whole region might reduce non-linear heterogeneity of attributes among land use types and improve the performance of spatial interpolation instead of algorithm simulation for land use types. To test this hypothesis, we applied classical spatial interpolation methods to each land use type individually and merged them to produce a depiction of the whole region. We then compared this depiction with a traditional interpolation for the whole region that does not account for land use type. We tested our hypothesis in a small watershed (approximately 200 km^2) in Southeast China. The IDW is widely used for soil property mapping and the OK was tested better than the regression kriging when spatial structure could be well captured by point-based observations (Zhu and Lin, 2010). The two frequently used spatial interpolation methods (OK and IDW) were employed to map soil nutrients (total C, N, and P) in the watershed in this study. The performance of the two spatial interpolation methods (by land use type individually *versus* the whole region) was assessed through evaluating the differences in root mean square error (RMSE) (Li and Heap, 2011) and the differences between the predicted and measured data for the two applications.

MATERIALS AND METHODS

Study area

The Bantou Reservoir watershed covers approximately 200 km^2 in northwestern Xiamen, Fujian Province, China (24°39′12″ N, 118°0′58″ E). The climate belongs to subtropical monsoon with a mean annual precipitation of 1 144 mm and a mean annual temperature of 20.8 °C. Lateritic soil dominates this watershed. Land use was classified into forest land, agricultural land, green land, and urban land, derived from Landsat ETM+ images in August 2010, and few changes were confirmed using Landsat ETM+ images in August 2013 and field investigation. Agricultural land consists of cultivated land, orchard, and nursery gardens; urban land consists of impervious surfaces and building sites; green land consists of parks and natural covered spaces excluding trees; forest land refers to mature, full canopy forest. The watershed has 5 subwatersheds: forested headwater (FH) subwatershed, mixed