Ocean & Coastal Management 103 (2015) 14–24

Contents lists available at ScienceDirect

Ocean & Coastal Management

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

Geographically weighted regression to measure spatial variations in correlations between water pollution versus land use in a coastal watershed

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ARTICLE INFO

Article history:
Received 14 January 2014
Received in revised form
16 July 2014
Accepted 14 October 2014
Available online 6 November 2014

Keywords:
Geographically weighted regression
Water pollution
Land use
Linkages
Spatial variation

ABSTRACT

Land use can influence river pollution and such relationships might or might not vary spatially. Conventional global statistics assume one relationship for the entire study extent, and are not designed to consider whether a relationship varies across space. We used geographically weighted regression to consider whether relationships between land use and water pollution vary spatially across a subtropical coastal watershed of Southeast China. Surface water samples of baseflow for seven pollutants were collected twelve times during 2010–2013 from headwater sub-watersheds. We computed 21 univariate regressions, which consisted of three regressions for each of the seven pollutants. Each of the three regressions considered one of three independent variables, i.e. the percent of the sub-watershed that was cropland, built-up, or forest. Cropland had a local R^2 less than 0.2 for most pollutants, while it had a positive association with water pollution in the agricultural sub-watersheds and a negative association with water pollution in the non-agricultural sub-watersheds. Built-up had a positive association with all pollutants consistently across space, while the increase in pollution per increase in built-up density was largest in the sub-watersheds with low built-up density. The local R^2 values were stronger with built-up than with cropland and forest. The local R^2 values for built-up varied spatially, and the pattern of the spatial variation was not consistent among the seven pollutants. Forest had a negative association with most pollutants across space. Forest had a stronger negative association with water pollution in the urban sub-watersheds than in the agricultural sub-watersheds. This research provides an insight into land-water linkages, which we discuss with respect to other watersheds in the literature.

1. Introduction

River water pollution in watersheds is strongly related to increasing anthropological influences, such as urbanization, agriculture, industry and sewage (Li et al., 2009; Xu et al., 2009; Ye et al., 2009). These anthropological influences are part of the larger process of watershed land use and land cover change that can affect the water pollution of rivers, lakes, and downstream estuarine and coastal waters (Baker, 2003; Roberts and Prince, 2010). Watershed land use impacts water pollution through non-point sources, which are major contributors of contaminants to the catchment-coast continuum (Swaney et al., 2012; Huang et al., 2013b). Therefore, exploring the linkages between land use and water pollution is commonly recognized as an imperative step to forecast river water pollution in watersheds and to control land-based pollution in coastal bays.

Many studies address the general relationships between land use and water pollution. Generally, built-up land and agricultural land have significant positive correlations with water pollution, which are associated with point or non-point source pollution (Johnson et al., 1997; Sliva and Williams, 2001; Fedorko et al., 2005; Mehaffey et al., 2005; Stutter et al., 2007; Tu et al., 2007; Bahar et al., 2008; Tran et al., 2010; Pratt and Chang, 2012; Yang, 2012). Woodland is significantly negatively correlated with nutrients, due to the general understanding that forests can absorb nutrients (Osborne and Kovacic, 1993; Novotny, 2002; Galbraith and Burns, 2007; Bahar et al., 2008; Lopez et al., 2008).

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http://dx.doi.org/10.1016/j.ocecoaman.2014.10.007
0964-5691/

However, the relationships between land use and water pollution can be inconsistent across time and space. Inconsistency is well documented in terms of seasonal or inter-annual variations (Sliva and Williams, 2001; Kaushal et al., 2008; Lee et al., 2009; Huang et al., 2013a), spatial scale effects (e.g. buffer versus entire watersheds) (Sliva and Williams, 2001; Uuemaa et al., 2005; Guo et al., 2010; Tran et al., 2010; Pratt and Chang, 2012) and watershed characteristics represented by various dominant land uses such as woodland, built-up, and mining (Mehaffey et al., 2005; Xiao and Ji, 2007; Bahar et al., 2008). The methods used in most of the above-mentioned studies are conventional global statistical methods, such as Pearson correlation analysis (Tong and Chen, 2002; Galbraith and Burns, 2007; Bahar et al., 2008; Lee et al., 2009; Sun et al., 2011b) and multiple regression (Sliva and Williams, 2001; Fedorko et al., 2005; Huang et al., 2013a; Yang, 2012). These global statistics are commonly used to analyze the overall association for the entire study area, and may hide some local relationships, especially among watersheds that are dominated by different uses, such as urban, forest or agriculture (Tu and Xia, 2008; Tu, 2011). Global statistics are not designed to explore spatial variations in relationships between land use and water pollution.

Some researchers have applied a statistical method named geographically weighted regression (GWR) to examine the spatially varying relationships between land use and water pollution (Brunsdon et al., 1998; Tu, 2011; Pratt and Chang, 2012). However, few studies have examined spatial variations in relationships between land use and water pollution in the watersheds of China. Such examinations are critical for China's watershed management, due to the fact that freshwater pollution is a prime concern, especially in the relatively developed regions such as the Eastern coastal areas of China (Huang et al., 2013a). More attempts need to be made to investigate relationships in these areas of China between land use and water pollution in the coastal watersheds with intensive human activities, great spatial variability of land use, and subsequent water pollution.

Our previous study used global multiple linear regression to show that land use, especially the percentage of built-up land, can be one of the most important predictors of water pollution in the Jiulong River Watershed (JRW), which is a typical medium-sized subtropical coastal watershed in China (Huang et al., 2013a). However, a better understanding concerning how land use impacts water pollution is critical for developing watershed management practices in such a coastal watershed. The objectives of this study

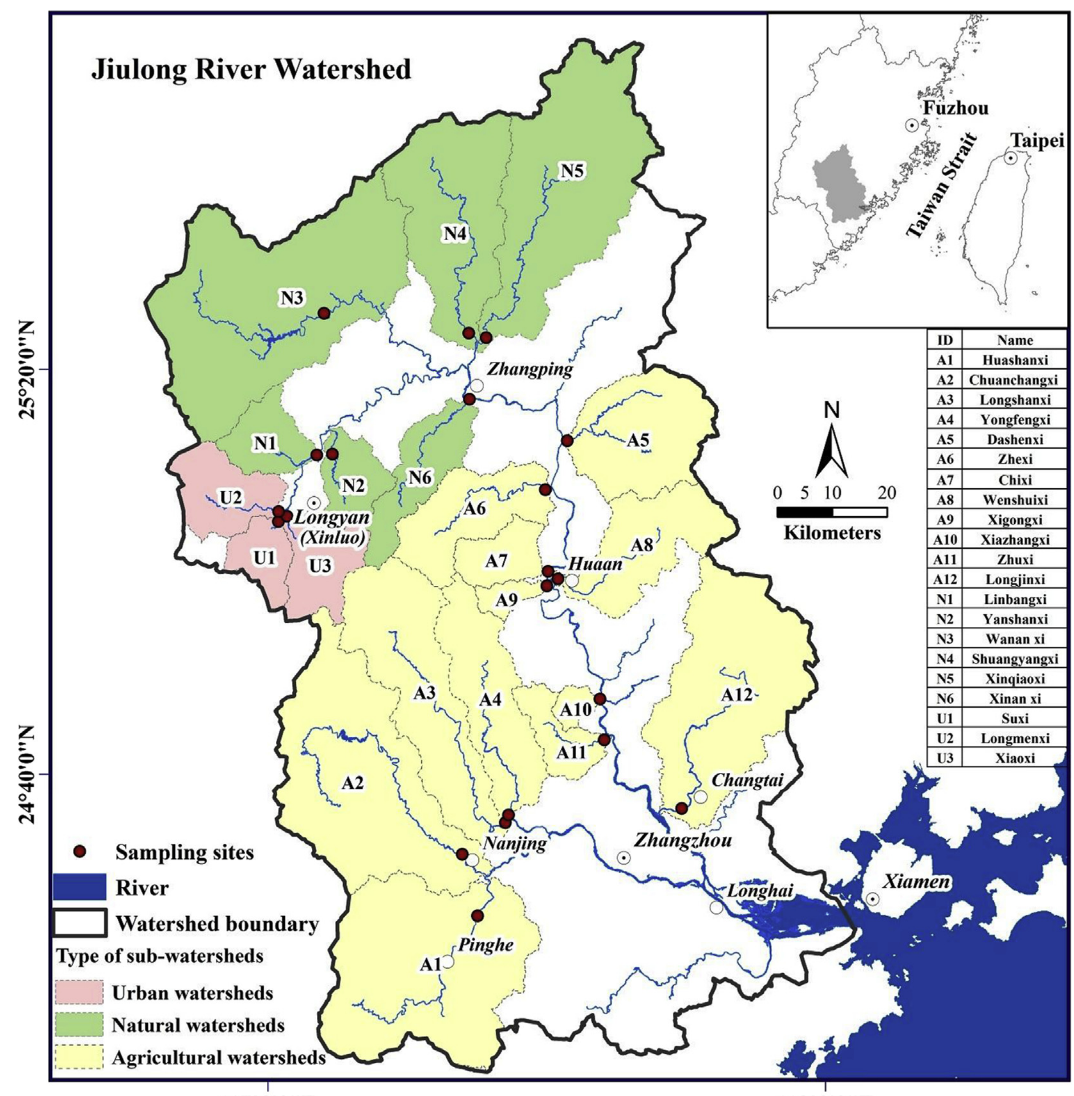

Fig. 1. Twenty-one sampling sites and three types of sub-watersheds.