Land Use Policy 54 (2016) 366–377

Contents lists available at ScienceDirect

Land Use Policy

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

Land use policy and spatiotemporal changes in the water area of an arid region

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ARTICLE INFO

Article history:
Received 11 April 2015
Received in revised form 17 February 2016
Accepted 22 February 2016

Keywords:
Land use policy
Arid region
Water area
Kernel density surface
Spatial autocorrelation

ABSTRACT

In this study, we developed a framework to analyze the impact of land use policies on water area changes. We used quantitative and qualitative approaches in our model, including Delphi method, *Moran's I*, 3D kernel density surface (3D-KDS) technique, and orthogonalized regression. The model facilitates visual examination of spatiotemporal patterns in water area changes and identification of the net effect of land use policies on water area changes. We consider three types of land use policy and four control variables which include water management policy and climate change factors to test the model by using data from Ejina, an oasis area from Inner Mongolia, China. The results of both 3D-KDS and *Moran's I* coefficient showed distinctive patterns in negative and positive water area changes. Standardized coefficients from the augmented orthogonalized ordinary least squares (OLS) models helped isolate the net effects of the three types of land use policy on negative and positive water area changes. Land use policies had greater impact on hydrological environment changes than water management policy and climate change factors. Our model can be utilized to assess the effectiveness of land use policies in an area and aid in helpful in monitoring the implementation of existing policies and design of new land use policies.

1. Introduction

The advancement of science and technology has greatly enhanced our ability to modify nature. Now more than ever, humans have more influence on water area changes (Mehta, 2014). The interactions between human activities and water area changes are an important international research topic that has attracted considerable attention from many research institutions and individuals worldwide (see, for example, Das et al., 2015; Gibbs, 2010; Yin et al., 2013). The International Association of Hydrological Sciences (IAHS) launched the first International Hydrological Decade (IHD) in 1965. This project aimed to promote international cooperation in research on hydrology and water resources from the perspective of rational utilization of water resources. Within a decade since its inception, the project had promoted research activities and government efforts on important issues, such as the relationship among urbanization, water resource planning, social environment, and hydrological environment changes (Nace, 1980). In 2013, IAHS launched IHD (2013–2022) at Gothenburg, Sweden. "Changes in the relationship between hydrological science and social system" was the theme of the latest IHD (Montanari et al., 2013). The impact of land use policy as an important component of social system (Li et al., 2015) has been selected as a sub-topic in IHD (2013–2022). More recently, the relationship between water resources and land uses has attracted considerable attention of the policy-makers, practitioners, and government organizations in the 2015 World Water Forum. The future development of water resource requires effective communication between scientists and policy-makers to ensure that expertise is translated into actions that address water challenges (Oki and Kanae, 2006). Sustainable land-use policies must involve management of landscape structure such as water areas (Eduful and Shively, 2015). Therefore, the interrelationship between land use policies and water area changes at a large spatiotemporal scale is one of the key research topics for future studies.

Efforts from researchers worldwide have resulted in considerable literature on the relationship between human activities and water resource change. Existing studies can be classified broadly into qualitative and quantitative studies. Qualitative research often

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http://dx.doi.org/10.1016/j.landusepol.2016.02.027
0264-8377/

develops conceptual models by classifying specific human activities to identify causes of changes in hydrological elements, such as deterioration in water environment or frequent occurrence of flood and drought (see, for example, Jothityangkoon et al., 2013; Le Maitre et al., 2014). Subsequently, various monitoring, prevention, and alleviating suggestions have been proposed based on the analysis. This stream of research aims to promote effective public policies to slow down or stop the deterioration of the water environment. Quantitative research focuses on the analysis, prediction, and simulation of the impact of human activities on the changes in the water environment based on numerical investigations (see, for example, Das et al., 2015; Ismaiylov and Fedorov, 2001; Williams, 1989) Econometric methods, including regression analysis (Ahmed et al., 2014), Monte Carlo simulation (Shindu and Govindaru, 2014), entropy evaluation method (Shindu and Govindaru, 2014), and spatial–temporal models (Yang and Liu, 2014), have been used to identify potential impact from natural and human factors on water changes. The scientific validity and comparability of empirical findings have been improved by adopting these quantitative approaches. Commonly, a combination of quantitative and qualitative methods is used in studies, providing a comprehensive analysis of available information and data (see, for example, Chou et al., 2014; Luo et al., 2013; Zhang et al., 2013).

Urbanization brings both economic prosperity and environmental challenges in most developing countries (Cohen, 2006). Government often rely on land use planning and conservation strategies to strike a balance between economic development and sustainable water resources management, (Cobbinah et al., 2015). Not surprisingly, poor compliance with urban land use regulations can results in threats to water resources preservation. This has become a systematic urban planning problem in many developing countries (Cobbinah et al., 2015). This problem often manifests itself in the form of water areas reduction and changes of the spatial distribution of water areas. Unfortunately, water resources management in developing countries is far from adequate, which can be attributed to a wide range of reasons besides low compliance with land use regulations (UN-Habitat, 2009). These include the lack of environmental policies and regulations, poor regulatory enforcement, lack of environmental awareness and skilled personnel, conflict of interests among sectors, and financial constraints (UN-Habitat, 2009). However, the majority of the literature has not considered the role of land use policies on water area changes sufficiently (Gyau-Boakye and Biney, 2002). It is necessary to conduct interdisciplinary research and quantitative assessment of the role of land use policies in order to improve water resources management in developing countries (Oki and Kanae, 2006). To bridge this gap in the literature, we investigate the relationship between land use polices and water area changes.

European Environment Agency's definition of water resource changes includes water quantity changes, water quality changes, and water area changes (EEA, 2012). In this paper we focus on the changes of water area because it is most relevant to water resources management in arid regions. Moreover, in the era of the 'Anthropocene', where human impacts on land use processes are large and widespread, researchers have started to consider the impact of human interventions on water area changes (Oki and Kanae, 2006). Monitoring and understanding the direction and speed of water area changes are helpful to understand the interaction between human activities and environmental changes (Lambin and Meyfroidt, 2010). Therefore this narrow definition of water resource changes serves our research purpose well.

Following the best practice in the literature, we adopt both qualitative and quantitative approaches to investigate the impact of land use policy on spatial–temporal changes in water areas. We develop an analytical framework by employing Delphi method, *Moran's I*, 3D kernel density surface (3D-KDS) technique, and orthogonalized regression. This combination of qualitative and quantitative approaches enables us explore available data fully and investigate all important aspects of the issues at hand. We test our model by using data from Ejina, China, an oasis area that is prone to water area changes. Empirical evidence suggests that our model can effectively illustrate water area changes over time through a combination of graphical evidence and numerical results. The net effect of land use policy on water area changes is identified directly based on coefficient estimates from orthogonalized regression. Therefore, the developed framework will be useful for policy makers and researchers in related fields.

The rest of this paper is organized as follows. Section 2 presents the methodology. Section 3 discusses the empirical implementation. Sections 4 and 5 provide the results of spatiotemporal variations in water area changes and the impact of land use policy on water area changes, respectively. Section 6 provides the conclusions.

2. Methodology

Land use policy can either encourage or discourage water area preservation. For example, if a "Green Belt" is designated by the local government, water areas within and surrounding the Green Belt will likely to be preserved, while other types of land may be converted to water land. Hence, the impact of such a land use policy is positive. Nevertheless, if industrial use land parcels are provided at a discounted price to encourage local economic growth, water areas in affected regions will likely to be converted for non-agricultural uses. The effect of such a land use policy on water area preservation is negative. We determine the impact of land use policy on hydrological environment accurately by classifying water area changes into negative changes (i.e., water areas converted to arable land, forest, grassland, desert, or construction land) and positive changes (i.e., arable land, forest, grassland, desert, or construction land converted to water areas). Without losing any generality, we define the relationship between land use policy and water area changes as

$$Y_i = f(\mathrm{L}, \mathrm{C}) \tag{1}$$

$$i \in \{P, N\}$$

where Y_i is the water area changes, with P denotes positive changes and N indicates negative changes; $\boldsymbol{L}$ is a matrix of land use policy indicators; and $\boldsymbol{C}$ is a matrix of control variables. Eq. (1) assumes that water area changes (positive or negative) are affected by land use policies, holding constant the effects from other factors, such as national and local water management policies, annual precipitation and temperature. The measurements of Y_i and $\boldsymbol{L}$ are essential to make Eq. (1) operable.

The changes in water areas are gradual, typically over years or even decades. Therefore, neither cross-sectional nor time-series observations of water area changes at specific locations are adequate and appropriate to support our analysis. Instead, we need a tool to measure the intensity or concentration of positive or negative water area changes over a sufficiently long period. This approach is efficient for measuring the impact of land use policy on water area changes considering that the effect of government policy tends to be long-lasting. Spatial autocorrelation methods can be used to achieve this goal. Spatial autocorrelation models measure how much closer objects are similar to one another when compared with distant objects within a region. The distribution tendency of objects in space is indicated (e.g., spatially clustered or dispersed). In this study, we use a popular spatial autocorrelation indicator, *Moran's I*, as the measure of spatial autocorrelation by following