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Impacts of urbanization on land use /cover changes and its probable implications on local climate and groundwater level

Suman Patra[a,*], Satiprasad Sahoo[b], Pulak Mishra[a], Subhash Chandra Mahapatra[c]

[a] Department of Humanities and Social Sciences, Indian Institute of Technology Kharagpur, India
[b] School of Water Resources, Indian Institute of Technology Kharagpur, India
[c] Rural Development Centre, Indian Institute of Technology Kharagpur, India

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ABSTRACT

Given that urbanization is considered as one of the most significant anthropogenic alterations of the environmental framework, the present study attempts to understand spatiotemporal characteristics of urban growth and its implications for the hydro-meteorological parameters in the Howrah Municipal Corporation (HMC) of the Indian state of West Bengal. The empirical approach of the paper is based on land use/land cover (LULC) changes and normalized difference built-up index (NDBI) computed using remote sensing and GIS techniques. Spatiotemporal satellite images and conventional data are used to characterize the urban growth process, whereas K-Means based unsupervised classification technique is used for LULC changes. Inverse distance weighting (IDW) interpolation method is applied for the spatial distribution of rainfall, temperature and groundwater level analysis. In order to examine whether hydro-meteorological (e.g., rainfall, temperature) parameters have any relationship with hydrological components (e.g., groundwater level) the Kendalls Tau test was performed. It is found that the maximum urban built-up area has increased during the last two decades with fluctuations in depth to groundwater level in northern, north-western and south-western side of the city. Notably, built-up expansions have taken place from the north-eastern to the south-eastern part. There are evidences of urban sprawl or shrinkage indicating expansion of built-up area and thus causing environmental degradation in the city area. While the methodology used in the paper has the potential for understanding the urbanization process, the findings have important implications for designing necessary policies and regulations.

1. Introduction

While the process of urbanization has important implications for changes in demographic characteristics and transformation of the physical landscape, unplanned, unsystematic and rapid urbanization can cause profound impacts on various environmental components, especially on land and water. A detailed understanding of the dynamics of urbanization induced land-cover change is, therefore, necessary for coping with environmental changes and facilitating sustainability. This is so particularly because most of the urban areas in the world has experienced considerable land-cover changes over the years. Further, these urban areas consume most of the global energy and cause serious environmental problems and degradation of ecosystems through pollution of air, water and land (Battista & Vollaro, 2017; Yan, Wang, Xia, & Feng, 2016).

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* Corresponding author.
E-mail addresses: suman.geo1989@gmail.com, sumanpatrabhu@gmail.com (S. Patra).

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The problem is more critical in India that contributes nearly 16 percent of world's total human population with only 2.5 percent of the total geographical area (UNEP, 2001).[1] The degree of urbanization in the country has also increased significantly over the years (Elmqvist et al. 2013; Nagendra, Sudhira, Katti, & Schewenius, 2013).[2] It has increased from 27.7 percent to 31.1 percent with a growth of 3.3 percent points during 2001–2011 as compared to an increase of 2.1 percent during 1991–2001(Bhagat, 2011). It is projected that urban population of India will nearly double reaching 600 million by 2031 (Heilig 2012). Such rapid urbanization in the country seems to have transformed the urban landscape leading to changes in land-use and land-cover considerably and causing severe pressure on various natural resources. It is expected that with degree of urbanization, Indian cities will suffer from local environmental problems and unhealthy living conditions (Kantakumar, Kumar, & Schneider, 2016; Mohan, Pathan, Narendrareddy, Kandya, & Pandey, 2011).

Rapid urbanization and changing environment in the developing countries like India raise three important research questions:

(1) How does urbanization cause spatiotemporal changes in LULC?
(2) How does urbanization affect temperature, rainfall, and groundwater level?
(3) What are the interrelationships amongst temperature, rainfall, and groundwater level under rapid urbanizations?

There are a large number of studies that have attempted to examine land use and land cover changes using remote sensing and GIS techniques. It is found that anthropogenic activities influence urban environment considerably (Alberti et al., 2003; Andersson, 2006; Lundholm et al., 2010), and hence greater attention is required towards monitoring the changes in land use and land cover in urban areas (Stow & Chen, 2002). Further, a number of climatic parameters also change following replacement of vegetation by urban settlement (Cui & Shi, 2012; Kometa & Akoh 2012; Voogt & Oke, 2003; Zhao et al., 2006). According to Kalnay and Cai (2003), both the minimum and the maximum temperature increased due to changes in land cover in the USA. Urbanization also impacts groundwater status (both quality and quantity) and its recharge adversely (Graniel, Morris, & Carrillo-Rivera, 1999; Karamouz, Ahmadi, & Akhbari, 2011). It is observed that conversion of natural, agricultural and other low-population density lands into urban settlements has changed the hydrology of the area (Blanco, McCarney, Parnell, Schmidt, & Seto, 2011). Evidences suggest that, with extreme urbanization, more than one-half of rainwater runs off and only a fraction of it goes for deep infiltration (Arnold & Gibbons 1996).

From the above review of literature, it is clear that urbanization and subsequent changes in land use and land cover has severe adverse implications for the local ecology (Fig. 1). However, the existing studies have, in general, focused on examining bivariate relationships between urbanization and LULC changes (Alqurashi & Kumar, 2017; Sajjad & Iqbal, 2012), urbanization and changes in temperature (Chapman, Watson, Salazar, Thatcher, & McAlpine, 2017; Wang, Yan, Li, Liu, & Wang, 2013), urbanization and changes in rainfall (Chen, Li, Du, Mao, & Zhang, 2015; Kug & Ahn, 2013), or urbanization and changes in groundwater level (Khazaei, Mackay, & Warner, 2004; Wakode, Baier, Jha, & Azzam, 2018). Hence, multivariate relationships amongst urbanization, LULC changes, changes in temperature, rainfall, groundwater level have remained largely unexplored in the literature. The present paper is an attempt to fill in this gap. In other words, the present paper is to examine urbanization and temperature, rainfall and groundwater controlling for their interdependence.

Thus, the rationale of the present paper lies in understanding spatiotemporal urban dynamics through LULC analysis, changes in local climate, and their probable impacts on groundwater level. This is very important in the context of rapid urban growth with serious social and environmental challenges, such as urban poverty, various forms of pollution, vulnerabilities to natural events and climate change impacts. It is expected that findings of the paper would help in designing sustainable urban development policies and comprehensive framework for its planning and management. In addition, the findings are also likely to pave the way for further research on sustainable utilization of urban land and its necessary eco-friendly modifications and distribution given the local ecology and socio-economic dimensions.

2. Study area

The present study has been carried out in Howrah Municipal Corporation (HMC) area. It is one of the oldest urban settlements in the eastern part of the country. The Howrah municipality was first established in 1862 and it became a municipal corporation in 1984. Earlier, Howrah used to be known as the "Manchester of India" for its industrial activities. Location of a number of jute mills and dockyards were other important sources of economic activities in the area. The HMC, located between 22° 33′ 00″ North to 22° 37′ 4.8″ North Latitude and 88° 14′ 38.40″ East to 88° 21′ 39.60″ East Longitude is a riparian city stretching over 14 km along the west bank of the river Hooghly (Ganges) with an average width of about 6 km. Howrah is the second largest town within the Kolkata Metropolitan Area (KMA) and also in the state of West Bengal. Since long, it has been conceived as a twin city of Kolkata, with the river Hooghly acting as a physical barrier between these two cities. Today, the HMC has an area of 51.74 square km and is subdivided into 50 wards. As Bally Municipality very recently merged with HMC since 1st August 2015 now the total Wards no. is increased from 50 to 66 as well. Fig. 2 depicts administrative boundary of the HMC. Climate of Howrah is hot moist and sub-humid. The population of the study area (Fig. 3) grew 17.36 percent from 1991 to 2001 and only 1.96 percent from 2001 to 2011 (Census of India, 2011).

[1] Currently, urban population in India is around 377 million comprising 30 percent of the country's total population (JNNURM Directorate, Ministry of Urban Development, Government of India, and National Institute of Urban Affairs, 2011).

[2] The Indian cities are expanding fast in respect of both the size and density of population.