Journal of Cleaner Production 177 (2018) 124–133

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Responses of urban ecosystem health to precipitation extreme: A case study in Beijing and Tianjin

Pei Wang [a, b, c], Xiangzheng Deng [a, b, c, *], Huimin Zhou [d], Wei Qi [a, c]

[a] Institute of Geographic Science and Natural Resources Research, Chinese Academy of Sciences, Beijing, 100101, China
[b] University of Chinese Academy of Sciences, Beijing, 100049, China
[c] Center for Chinese Agricultural Policy, Chinese Academy of Sciences, Beijing, 100101, China
[d] College of Geography and Environment, Shandong Normal University, Shandong, 250358, China

A R T I C L E I N F O

Article history:
Received 30 April 2017
Received in revised form
5 December 2017
Accepted 14 December 2017
Available online 28 December 2017

Keywords:
Climate change
Precipitation extreme
Urban ecosystem health
Emergy analysis
Difference-in-Difference

A B S T R A C T

Our research explores the relationship between precipitation extreme and urban ecosystem health by using emergy analysis based on urban ecosystem health assessment and Difference-in-Difference approach. In the case study area of Beijing and Tianjin, their urban ecosystem are getting healthier with the average growth rate of the key index, urban ecosystem health, are 0.23 and 0.12 respectively, simultaneously the overall index of Beijing is a little higher than that of Tianjin. Meanwhile, urban ecosystem seemingly has nothing to do with precipitation extreme, and the health of its urban sub-ecosystem performs significantly to the precipitation extreme except the sub-ecosystems, resilience, public services and human health. Vigor, one of the urban sub-ecosystems, its ecosystem health negatively associated with precipitation extreme. And urban sub-ecosystem health of vigor will reduce 14.42 if a precipitation extreme happens. The precipitation extreme has a positive effect on organization and emergies. And urban sub-ecosystem health of organization and emergies will increase 44.11, 12.02 respectively if a precipitation extreme happens. In addition, it is apparently nonsignificant to the sub-ecosystems, resilience, public services and human health. Moreover, the extreme precipitation consumes more emergies for the city, it seems beneficial for emergy flow for that precipitation extreme negatively affects emergy/dollar ratio, environmental loading rate and positively affects total emergy. But the extreme precipitation also negatively influences emergy yield ratio. Thus, urban ecosystem health associates with precipitation extreme in a complex way, both positively and negatively. Government measures for recovering urban ecosystem health should emphasize the sub-ecosystem vigor of the city, like constructing more public facilities. And policy makers may pay more attention on environmental loading rate, like advocating improving energy use efficiency.

1. Introduction

There is a broad recognition that global climate is changing over history, not only generally referring to global warming, but also extremes, such as rainstorm, which are projected to increase in intensity and magnitude (Kunkel et al., 2013). The 5th assessment report from Intergovernmental Panel on Climate Change (IPCC) has found that global land surface temperature was increased by 0.85 from 1880 to 2012, and it also has indicated that the past three decades is the hottest period during the last 14 centuries. Meanwhile, mounting studies have indicated that global warming affects precipitation characteristics, containing its amount, frequency, intensity and distribution patterns. Meteorologists have also stated that the water holding capacity of air increased by about 7% with per 1 °C warming, and the rising air moisture can produce more intense precipitation extremes (Trenberth, 2011). Particularly, China is dominated by monsoonal climate and accompanied by a continental arid climate in the northwest and a cold highland climate on the Qinghai-Tibet Plateau in the southwest (Ge et al., 2016). It is frequently affected by a variety of extreme precipitation and drought events due to its strong influence of monsoonal climate. Ma et al. (2015) concluded that the frequencies of dry days, trace days and all precipitation events over China were 56%, 12% and 31% respectively.

* Corresponding author. Institute of Geographic Science and Natural Resources Research, Chinese Academy of Sciences, Beijing, 100101, China.
E-mail addresses: wangpei@igsnrr.ac.cn (P. Wang), dengxz.ccap@igsnrr.ac.cn (X. Deng), zhouhm_simlab@163.com (H. Zhou), qiw@igsnrr.ac.cn (W. Qi).

https://doi.org/10.1016/j.jclepro.2017.12.125
0959-6526/

However, as agriculture intensified and urbanization spreads, immeasurable social assets and expensive infrastructure are exposed to climatic disasters. Report from the National Centers for Environmental Information (NCEI) has estimated that U.S. experienced 203 extremes with 5.5 billion-dollar events happening annually during 1980–2016, where overall damages exceeded 1.1 trillion dollar. The records have also denoted that each of the 15 billion dollar damages caused by weather disasters including three rainstorms in 2016 in U.S. (https://www.ncdc.noaa.gov/billions/). In China, Chen and Sun (2015) and Song et al. (2007) described that precipitation extremes were also frequently happened during the past 50 years and caused immeasurable damages. National Development and Reform Commission (NDRC) reported in 2013 that extremes gave rise to over 2000 people's death and approximately 0.2 trillion yuan direct damages annually since 1990s. Thus, precipitation extreme is one of the most destructive events for human society and it has attracted more attention due to the large-scale losses. And these trends impose heavy burdens on risk mitigation (Revi, 2008).

Moreover, ecosystem is vulnerable to climatic disasters, especially precipitation extremes. A high proportion of these vulnerabilities are in urban areas for a number of human's lives killed and public properties devastated in storms and floods (Olorunfemi and Raheem, 2013). Although the public throws the spotlight on direct monetary losses and deaths, indirect damages such as epidemics, environmental degradations grossly are underemphasized and less assessed. NDRC (2013) has announced that ecosystem, providing goods and services for sustainable development, is declining because of intensive precipitation extremes. But how did precipitation extreme affect ecosystem?

Regarding to climatic disasters, people had little choice but to resistance or move. With increasing climatic disasters like precipitation extremes happened in China, urgent measures are needed to enhance ecosystem health for risk mitigation in the context of climate change. Here, our research is concentrated on urban areas, and what we should do first is to clarify whether precipitation extremes affect urban ecosystem health, and if it do then how it works.

However, what is urban ecosystem health? There seems no unequivocal concept on it. Similar to ecosystem health, Su et al. (2010) summarized that a healthy urban ecosystem possessed three characteristics:

(i) Urban ecosystem services maintain a productive capacity;
(ii) System integrity is key component of urban ecosystem health;
(iii) Assessing urban ecosystem health requires a systems perspective.

Rapport in 1989 stated clearly that a healthy ecosystem was defined as being ‘stable and sustainable’, maintaining its organization and autonomy over time and its resilience to stress (Appendix). However, urban ecosystem is a complex system, it is affected by a broad suite of state factors, and its healthy assessment should consider both human wellbeing and the integrity of natural system, incorporating social-economic-ecological factors (Pickett et al., 2011; Shi and Yang, 2014). Olorunfemi and Raheem (2013) indicated that the complexity of urban ecosystem multiplied risk from climatic disasters. High population density, growing poverty, inequality and inadequate infrastructure in crowed urban is against risk mitigation when precipitation extreme occurs.

Our research has empirically analyzed the relationship between precipitation extreme and urban ecosystem health in Beijing via three steps. Firstly, we have assessed urban ecosystem health based on a measurable index system composed by 50 key indicators. Meanwhile, these indicators are selected to depict urban ecosystem in terms of six aspects, the vigor, organization, resilience, public services, human health and emerge in Beijing. Secondly, Tianjin, a comparative city is selected to answer whether precipitation extreme affect urban ecosystem health via comparatively analyzing the results of assessment of the two cities. Thirdly, we design a difference in difference (DID) experiment to detect that to what extent precipitation extreme has influenced urban ecosystem health for Beijing and Tianjin.

2. Study area

Our study area is Beijing (39.4°–41.6°N, 115.7°–117.4°E), situated in the north of North China Plain and bounded by Hebei province and Tianjin. Beijing is the capital of China, as well as the economic, political and cultural centre of modern China, with a total area of 16410.54 square kilometers. It is characterized by monsoon variability where an annual average precipitation is approximate 488 mm. In 2012, the mean precipitation was 733.2 mm and reached its peak during the past 50 years. In line with the records from Weather China (2012), the extraordinary rainfall in 2012 gave rise to urban waterlogging and numerable economic damages. Extensive forestry, many tourist attractions, agricultural crops and green belt in Beijing were partially destroyed in this disaster, which had a compound impact on urban ecosystem health.

Tianjin (38°34′—40°15′N, 116°43′—118°04′E) is selected as a comparative city to detect whether precipitation extreme affects urban ecosystem health. It is located at the eastern edge of China and close to the Bohai sea. Tianjin occupies 11916.85 square kilometers and creates 1.65 trillion yuan in 2015. As Tianjin is so close to Beijing, a large part of climatic conditions are similar.

3. Materials and analytic frameworks

An adequate index system is established in this section based on literature review to assess urban ecosystem health of Beijing and Tianjin. Hence urban ecosystem health is taken as a vital dependent variable here in the Difference-in-Difference (DID) model to clarify how precipitation extreme affects urban ecosystem health.

3.1. Emergy-based assessment of urban ecosystem health

3.1.1. Materials and index system

Combining with a broad literature review, indices framework is developed based on the principles of its quantifiable, data availability, regionality, objective and representative. All these indicators are divided into six categories and related references are listed in Table 1. Respectively, vigor is measured the urban ecosystem from the perspective of its activity, metabolism or primary productivity (Rapport, 1989). The organization sub-ecosystem describes the diversity and number of interactions between system components. Resilience could be assessed in terms of a system's capacity to maintain structure and function in the presence of stress (Appendix). Human health is measured by a series of indicators represent human's physical and mental health. Emergy flow of the city can be assessed based on emergy analysis, and key emergy indices are introduced into the complex system. Indicators highlighted in Table 1 implies that the higher the value, the worse the sub-ecosystem. In order to alleviate the deviation caused by the data itself, our study got the logarithm of each value at first, and distribute minus sign for those who still opposite to the other indicators.