Energy Proceedings
Vol 29, 2022
ISSN 2004-2965

An urban waterlogging footprint accounting based on emergy

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ABSTRACT

The waterlogging disaster has become a major threat to the sustainable and resilient development of cities. However, there is still a lack of unified accounting for waterlogging damage, particularly ignoring its environmental loss. In this paper, we developed an emergy-based footprint to assess the synthetic economic and environmental impact of urban waterlogging. The results show that the average waterlogging footprint under different return periods is 4.43E +19sej. The waterlogging footprint of each sector sorted from largest to smallest is transportation (35.47%), commerce (27.48%), environment (17.79%), industry (13.02%), residential (3.97%), infrastructure (2.26%), indicating that the impact of waterlogging on the environment is noticeable. The emergy-based waterlogging footprint can provide a useful metric for quantifying the potential and indirect losses embodied in the waterlogging processes. This paper may provide a useful tool for urban waterlogging disaster risk and loss assessment.

Keywords: Urban waterlogging; Depth-damage curve; Emergy; Disaster loss

1. INTRODUCTION

With climate change, urban waterlogging is becoming more frequent, and the economic loss and social impact of that is increasing. The massive rainstorm that hit Beijing on July 12, 2012, led to serious urban waterlogging, caused economic losses of more than 1 billion dollars, and forced the evacuation of more than 50,000 people [1]. The urban waterlogging disaster caused direct economic losses of 40.9 billion yuan in Zhengzhou on July 20, 2021 [2]. Waterlogging loss assessment is not only fundamental for disaster prevention and mitigation but also crucial for urban emergency management and post-disaster recovery.

Waterlogging loss assessment depends on both the disaster bearing body and the exposure degree [3]. Large-scale flood loss assessment at the national and regional levels has been extensively analyzed by scholars to determine the relationship between flood loss and submerge depth through historical flood events and disaster loss data provided by flood insurance, with using land use or infrastructure as disaster bearing bodies. Flood-prone countries have established flood loss assessment models using different disaster-bearing body classification systems, such as HIS-SSM [4], HAZUS [5], NRC framework [6], and the Joint Research Centre also published the global flood depth-damage functions in 2017 [7]. However, the currency value cannot consider loss [8] , which ignores the role of nature and separates the real value (or the real energy contained) of natural system and human social and economic system as well as the relationship between resources and environment.

Emergy analysis is a system analysis method based on system ecology and environmental economics, which is a powerful theory of environmental economics [9]. Natural and social systems are involved in a general energy hierarchy at different dimensions, forming an energy network. In recent years, some scholars have introduced emergy analysis into vulnerability assessment of natural disasters [10]. Chang et al. have unified social economy, structural measures and energy implied in rainfall process, and assessed flood vulnerability in Taiwan Province by embedding emergy theory into the framework of exposure, sensitivity and adaptability [11]. Combining emergy with GIS, Wu et al. built an urban flood vulnerability assessment model toreveal the impact mechanism of flood potential impact and regional adaptation on vulnerability, and providing a comparable basis for disaster vulnerability in different regions [12]. It has been proved that emergy analysis can connect land use with social and economic factors, and reflect the real value of the interaction between natural system and social and economic system.

In this paper, we established an emergy-based waterlogging footprint assessment model to evaluate the ability of a city to cope with waterlogging risk under different rainfall return periods. It measures the direct and indirect impacts of flooding on infrastructure, industry and commerce, residential capital, transportation, and the environment. The paper is

This is a paper for the 14th International Conference on Applied Energy - ICAE2022, Aug. 8-11, 2022, Bochum, Germany.

structured as follows. The next section introduces the framework and methods of waterlogging footprint accounting. Section 3 presents the main results of waterlogging footprint assessment. Finally, conclusions are presented in section 4.

2. METHODOLOGY

2.1 Urban Waterlogging Simulation and modelling

This paper takes the second Ring Road as a case study, a range of typical urban old communities in Beijing where the disaster risk is more prominent, and builds a urban waterlogging simulation model based on InfoWorks ICM model.

2.2 Framework of waterlogging footprint based on emergy

From a systems perspective, the cause-effect relationship between waterlogging losses and rainstorm events is linked through energy and material flows between natural and social systems. This paper defines the losses caused by waterlogging and the bearing capacity that can provide resistance to the loss caused by rainfall events in the region from the view of ecological energy, and puts forward the evaluation method of emergy and the evaluation index of resilience.

2.2.1 The waterlogging footprint based on emergy

This paper introduces a new concept of waterlogging footprint to measure the directly and indirectly economic impacts that are caused to productive factors, infrastructure and residential assets. Besides, we also consider the impact of environmental pollution.

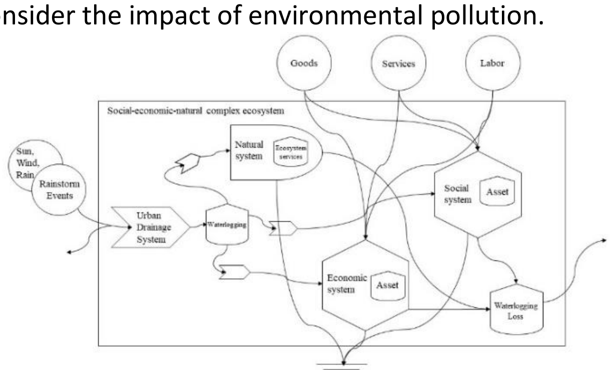

Fig.1 The emergy flow diagrams of Urban waterlogging footprint

1) The emergy of economic loss

We used the Asian depth-damage curve from the Global flood depth-damage functions database to determine loss rates at different waterlogging depths [5,9]. The direct economic losses are obtained by multiplying the rate of loss by the value of each unit of land [3, 7].

The products consumed in the production process will change when the output of one sector changes, which will spread to other sectors through inter-industry linkages, resulting in indirect economic losses. We used the input-output model to calculate the indirect economic losses caused by waterlogging [13].

The ratio of emergy value to money (EMR) can connect the natural environment and economic society. EMR represents the amount of economic activity that can be supported by a given emergy flow or reserve [14].

2) The emrgey of environment loss

We considered total nitrogen (TN), total phosphorus (TP), ammonia nitrogen (NH_3-N) and chemical oxygen demand (COD), and EMC was used to obtain the non-point source pollution load of each land use type under rainfall events.

3. RESULTS

The waterlogging footprint under each return period is 1.88E+19sej (1-year), 2.84e +19sej (2-year), 3.39e +19sej (3-year), 4.13e +19sej (5-year), 5.30e +19sej (10-year)， 6.21E +19sej (20-year), 7.23E +19sej (50-year), respectively, and the average value is 4.43E +19sej. The waterlogging footprint increases along with the rainfall return period. The waterlogging footprint of the transportation is the largest, accounting for 35.47% of the total, followed by commerce (27.48%), environment (17.79%), industry (13.02%), residence (3.97%), and infrastructure (2.26%).

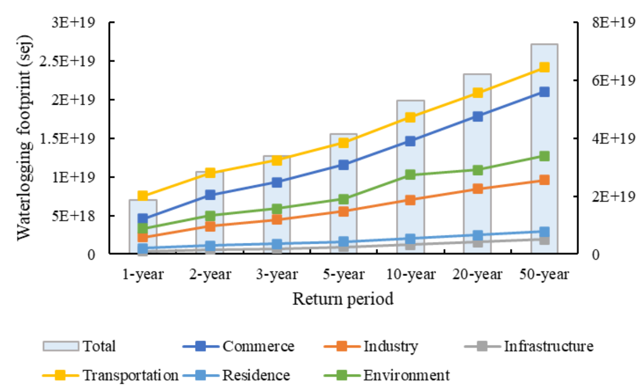

Fig.2 The waterlogging footprint changes of each sector with return period

4. CONCLUSIONS

This paper aims to establish a set of water-logging loss accounting framework based on emergy theory and provide reference for water-logging risk management and related decision making. The use of energy units to unify weights and measures can take into account economic and environmental impacts. The results show that the average waterlogging footprint under different return periods is 4.43E +19sej. The waterlogging footprints of various sectors from large to small are transportation (35.47%), commerce (27.48%), environment (17.79%), industry (13.02%), residential (3.97%) and infrastructure (2.26%), which also indicates that the impact of waterlogging on the environment cannot be ignored. Environmental impact should be taken into account in future disaster loss accounting. However, the application of emergy theory of ecological economics in disaster loss accounting is still in the exploratory stage and needs further optimization in practical application.

ACKNOWLEDGEMENT

This work was supported by the Strategic Priority Research Program of Chinese Academy of Sciences (No. XDA20100104), Beijing Outstanding Scientist Program (BJJWZYJH01201910027031), National Natural Science Foundation of China (Nos.72091511, 71725005) and Beijing Natural Science Foundation (9222017).

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