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Effects of disturbed landforms on the soil water retention function during urbanization process in the Three Gorges Reservoir Region, China

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ABSTRACT

Decreases in the water retention function of various artificial disturbed landform units (DLUs) caused by urbanization activities, compared to original landform units (OLUs), are the main factor that causes urban water and soil loss and the aggravation of urban floods under certain rainfall conditions and specially designed drainage network capabilities. Field investigations, laboratorial analyses of soil physical properties and analytic hierarchy process (AHP) composite methods were performed to comprehensively analyse the effects of various DLUs on the water retention function of OLUs. The results indicated as the following: (i) The >5 mm particle content (>54%) for various DLUs was higher than that for OLUs (lower than 3%); the natural repose angles of soil-rock mixtures (32–37°) and soil bulk density (1.41–1.74 g/cm^3) in the DLUs were all higher than those in the OLUs (30–31°, 1.18–1.14 g/cm^3); and the uniformity coefficients and curvature coefficients were 10.00–80.00 and 3.24–5.70 in the DLUs and 6.00–75.00 and 0.17–2.50 in the OLUs, respectively. (ii) The soil steady state infiltration rate in the DLUs decreased from disturbed soil accumulation with 2 months (DSA_{2m}, 15.00 mm/min) to disturbed soil accumulation with 2 years (DSA_{2a}, 5.63 mm/min), disturbed soil accumulation with 4 years (DSA_{4a}, 3.82 mm/min), the slope greening belt (SGB, 1.24 mm/min), and construction roads (CR, 0.51 mm/min). The conversion from forests to DSA_{2m} had the greatest impact on the soil infiltration capacity and soil storage capacity, while the conversion to CR had the lowest impact. (iii) The total reservoir storage in the DLUs' soil was ordered as follows: DSA_{4a} > SGB > DSA_{2a} > DSA_{2m} > CR. The conversion process from grass to CR exerted the greatest impact on storing water and regulating the overland flow. (iv) The water retention functions in the DLUs were all weaker than those in the OLUs: DSA_{2m} was the weakest (0.287), while paddy fields were the strongest (0.668). Thus, the occupied areas of urban water surfaces (e.g., lakes, rivers and ponds), forests and grassland and their spatial distribution during urbanization must be carefully considered. These results could help to understand the ecological service functions of urban soil and water conservation, provide relevant knowledge to landscape rehabilitation, alleviate urban floods during urban development and recover the functions of soil and water conservation ecological services in project areas during the urbanization construction process.

1. Introduction

With increasing urbanization, human disturbances to the environment, such as large scale land-excavating, disturbed soil accumulations and micro topography changes, may cause original landforms with important ecological and hydrological functions to disappear. These original landforms include paddy fields, forests, grassland and sloped farmland. Furthermore, some disturbed landforms with completely different material compositions may be produced, which would cause significant changes in regional underlying surface conditions and rainfall-runoff processes. Reservoir resettlement and the construction of new houses, buildings and roads in the Three Gorges Reservoir Region, which is one of the most serious soil erosion areas in China, have not only damaged various surface vegetation and land resources but also produced such special artificial landform units as disturbed soil accumulations of different ages, urban green spaces, construction roads and impervious surfaces (Biemelt et al., 2005; Li et al., 1996; Shi, 2006; Wang and Cheng, 2002). Urbanization has increased peak flows in river hydrographs because of an increase in surface runoff during rainstorms (Quan et al., 2013), thus causing significant urban soil loss and aggravated urban floods. Urbanization impacts the ecological environment quality at the global, regional and local scales (Gao et al., 2003). Forest land is usually associated with water conservation: the soil not only provides the necessary

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water conditions for plant growth but also plays important roles in rainfall infiltration, controlling floods and reducing disasters (urban floods and droughts) (Wu et al., 2008; Neris et al., 2013). Some land use patterns have changed greatly after urbanization in Beijing: many green lands were replaced by impervious buildings, cement and asphalt pavement and artificial landform units (Wang et al., 2013). Meanwhile, the soil structures of large original landforms have been entirely destroyed, which would decrease the infiltration capacity and significantly increase the surface runoff coefficient, causing urban floods under certain conditions. In recent years, many specialists have focused on soil and water losses during urbanization. Gan et al. (1999) divided the soil erosion environment during the urban construction process into three system elements, namely, exogenic agency systems (erosion forces such as water, gravity, wind and human forces), material source systems (including original surface materials, external materials, disturbed soil accumulation and pile soils) and interface systems (interfaces such as geomorphology, vegetation and ground infiltration), and systematically analysed their interacting characteristics during soil erosion. Sun and Gan (1998) studied the erosion and sediment production processes in landform units such as steep slopes that are formed by dumped soil and natural steep slopes in an urbanized construction area with simulated rainfall experiments. Ng and Marsalek (1989) and Brun and Band (2000) assessed the effects of land-use change on the runoff in urbanized watersheds with the Hydrologic Simulation Program—Fortran (HSPF) and a commonly used GIS. Ge et al. (2003) and Shi et al. (2001) studied changes in the surface runoff, peak flow and runoff coefficient that are caused by urbanization through the Soil Conservation Service (SCS). Qin et al. (2005) quantitatively analysed the long-term effect of urbanization on runoff with Long-term Hydrological Impact Analysis (L-THIA). However, few studies have addressed the effects of artificial disturbed landform on the water retention function of original landforms in urban development areas. Therefore, this study considered original landform units and various disturbed landform units that are caused by urban construction in the Three Gorges Reservoir Region to investigate: (1) differences in the soil physical properties between original landform units and various disturbed landform units; (2) the influence of urban construction projects on the soil infiltration capability of original landforms; and (3) the effect of urban construction projects on the soil water storage capacity. These results could provide the scientific basis for understanding the ecological service functions of urban soil and water conservation, which also help to provide relevant knowledge to landscape rehabilitation and alleviate urban floods during urbanization in urbanizing areas.

2. Materials and methods

2.1. Experimental site

The experimental site is a typical urban construction project for commercial buildings (latitude 29°43′36″N, longitude 29°43′36″N, altitude 400 m) that is located in Caijiagang, Beibei District, Chongqing, China (Fig. 1). The total area of the study site is 45.7 km^2. This area is characterized by a subtropical monsoon climate with an average annual rainfall of 1133.5 mm, which is mainly concentrated from April to October, with July being the rainiest month and January the driest month. The maximum rainfall intensity was approximately 8.0 mm/min. Precipitation with daily rainfall of ≥50 mm occurred several times every year in this area (Liu et al., 2012). Approximately 60% of the years (about 50 years) experienced heavy storms with daily rainfall of ≥100 mm. The soil type at this site includes paddy soil (classified as Hydragric Anthrosol in the FAO Taxonomy), alluvial soil (Dystric Fiuvisol), purple soil (Regosols), lime soil (Haplic Phaeozem) and yellow soil (Haplic Acrisol), in which the paddy soil and purple soil accounted for 81.7% of the total area in this district. The main land use types before urbanization were forest land (45%), grassland (12%), sloped farmland (35%) and paddy field (8%). The vegetation type was dominated by subtropical evergreen broadleaf forests, mixed conifer-broadleaf forests, bamboo forests and evergreen broad-leaved shrubs. The period of the construction project lasted from January 2013 to December 2016. Because of its special characteristics of the construction technology, the disturbed landform units that were created by the urbanization construction included disturbed soil accumulations with different accumulation periods (comprehensive mixtures of soil and rock fragments from artificial disturbances such as surface soil stripping, slope excavation,

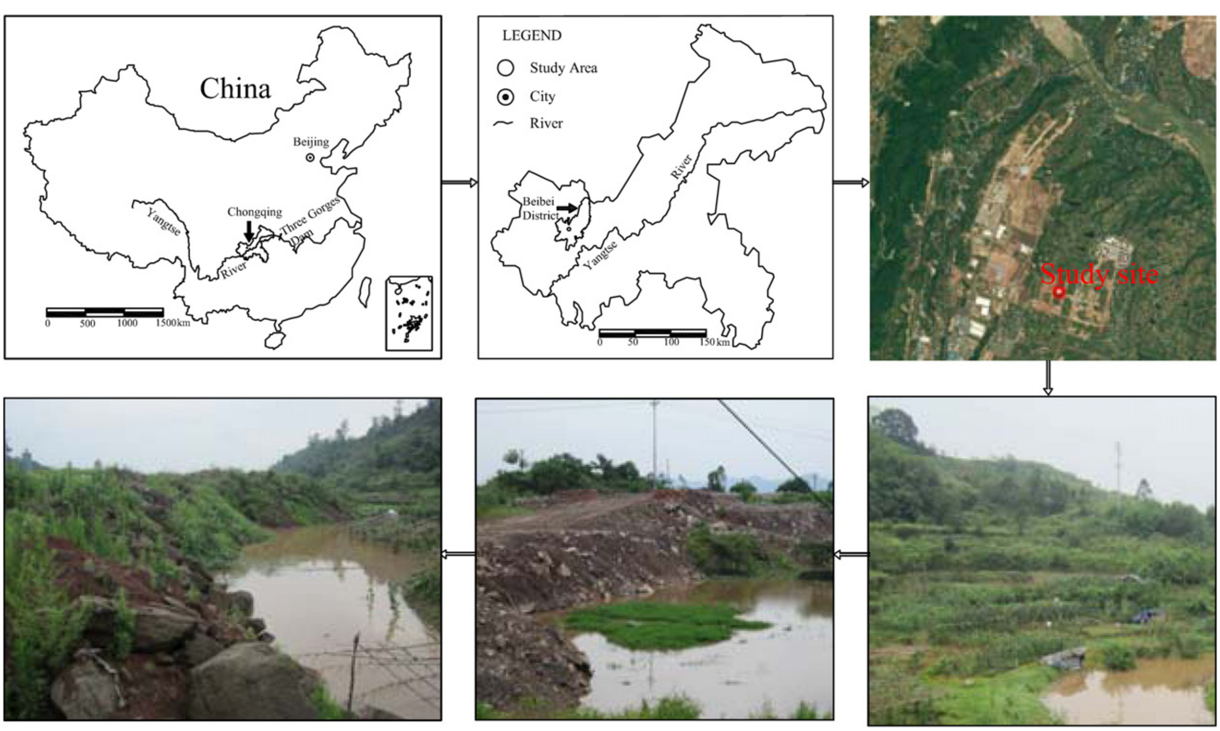

Fig. 1. Maps showing the location and overview of the urban construction project.