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Research paper

Water-related ecosystem services provided by urban green space: A case study in Yixing City (China)

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HIGHLIGHTS

- Green space in urban areas play a positive role in water regulation and purification.
- More rainfall was intercepted per unit area by artificial woodland than lawn.
- Water-related service function within and outside the built-up areas were different.

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ABSTRACT

With the development of urbanization, green space in urban areas has received widespread attention and become an important symbol of urban ecosystem health. Urban green space plays a positive role in water regulation and purification, but this function is often ignored by municipal authorities. Based on remote-sensing image interpretation and practical investigations in Yixing (China), this study evaluated the water regulation and purification functions performed by urban green space, using the modified Soil Conservation Service model, in conjunction with relevant experimental data. The results show that during the period 2007 to 2009, the average volume of rainfall stored by the urban green space in Yixing was 5.3×10^7 m^3 yr^{-1}, which represented more than 88% of the rainfall received. The average figures for chemical oxygen demand (COD_{Cr}), total nitrogen (TN), ammoniacal nitrogen (NH_4–N), and total phosphorus (TP) in rainfall that were removed by green space during 2007 to 2009 were 233.6×10^3 kg yr^{-1}, 70.9×10^3 kg yr^{-1}, 12.6×10^3 kg yr^{-1}, and 1.7×10^3 kg yr^{-1}, respectively. Differences were found between the water regulation and purification performed by urban green space inside built-up areas and those performed outside built-up areas, which relate to the importance attached to green space in the two types of area. This research will contribute to an understanding of the role that green space plays in water regulation and purification, and in the scientific management of urban green space.

1. Introduction

Green space in the urban environment has attracted widespread interest because its ecosystems can improve the urban environment by providing ecosystem services. Many studies have demonstrated the importance of the ecosystem service functions of urban green space. Tratalos, Fuller, Warren, Davies, and Gaston (2007) determined a value for reasonable residential density in five British cities, based on the green space ecosystem service function (Tratalos et al., 2007), and Bolund and Hunhammar (1999) considered that the ecosystem functions of green space could influence human settlements and therefore needed serious consideration when urban developments were being planned (Bolund & Hunhammar, 1999). Green space can improve living conditions for residents by purifying the air, lowering levels of airborne dust, and reducing noise (Li & Wang, 2003; Ouyang, Li, Juergen, Wang, & Li, 2004). The ecosystem services provided by urban green space in relation to water are generally afforded less attention, however, because the growth of vegetation is normally sustained by rainfall. Nevertheless, urban green space can reduce surface runoff efficiently (Bernatzky, 1983; Cheng, Yang, & Xu, 2008; Douglas, 2011; Shepherd, 2006), and also reduce pollutant concentrations in surface runoff (Barrett, Walsh, Malina, & Charbeneau, 1998; Stagge, Davis, Jamil, & Kim, 2012; Yang, Dick, McCoy, Phelan, & Grewal, 2013).

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Although ecosystem services provided to the urban water cycle by green space are sometimes neglected, they have recently received increased attention in areas suffering from water shortages or from serious water pollution. Yang, Li, Peng, and Li, (2011) have described the important role of urban green space in the water environment of the Taihu Basin, which has experienced relatively serious water pollution(Yang et al., 2011), whilst Zhang, Xie, Zhang, and Zhang (2012) have calculated the economic value of green space in reducing surface runoff in Beijing (Zhang et al., 2012). Nevertheless, studies of the ecosystem services that are provided by urban green space affecting water supplies and water quality are still at an early stage, and they have not been comprehensively described.

According to the Millennium Ecosystem Assessment (MA), ecosystem services may be divided into 'provisioning services', 'regulating services', and 'cultural services', all of which have direct effects on human well-being, together with the support services that are necessary to maintain the services within these three overall categories (MA, 2005). The ecosystem services provided by green space in relation to water are mainly water regulation and purification functions lying within the 'regulating services' category, together with support services that are associated with maintenance of the hydrological cycle. Because the scale and scope of the hydrological cycle are so broad, even global (MA, 2005) assessment of the cycle is very difficult; furthermore, its relationship to human well-being is indirect (MA, 2005). For the purposes of this study, therefore, the hydrological cycle has been excluded from consideration; instead, the focus is on water regulation and purification, each of which has a direct effect on human welfare.

Green space delivers a water regulation function mainly through interception of rainfall by leaf canopy, water storage by soil capillaries, and the downward infiltration of rainfall. Several indirect studies have demonstrated the effectiveness the water-regulation function of green space. Compared the surface runoff in five English cities is lower in areas with a high proportion of green space (Tratalos et al., 2007). The runoff coefficient and runoff modulus for various different land patterns lowest in green space areas in Xian City, China (Qi, Li, Li, & Qin, 2010). Studied the influence of changes in land use upon surface runoff in Pudong, Shanghai (China), leading to an increase or decrease in the area of green space directly affect the amount of surface runoff (Quan et al., 2009). These studies have therefore indicated that green space in an urban ecosystem can efficiently reduce surface runoff and thus that it has a water regulation function.

In addition to its water regulation function, green space in an urban ecosystem can effectively reduce the levels of pollutants in rainfall and surface runoff, and thus also has a water purification function. The removal of pollutants that occurs in a green space depends initially upon the interception, adsorption, and absorption of pollutants by soil and plant roots. After rainfall, it then depends upon the activities of soil-dwelling microbes to degrade these pollutants and to effect soil purification and regeneration. The water purification function of green space has been recognized and studied in a number of experimental simulations and field measurements.

By simulating the urban green space and rainfall system, the chemical oxygen demand (COD_{Cr}), ammoniacal nitrogen (NH_4–N), nitrate nitrogen, total nitrogen (TN), and total phosphorus (TP) were reduced, on average, 41.3%, 44.1%, 38.5%, 38.2%, and 39.0%, respectively, after 2 h of rainfall (Yang, Lu, Li, Huang, & Yang, 2008). Based on the experimental sunken green space in Shanghai, the removal rates of pollutants in surface runoff for organic compounds, nitrogen, and phosphorus were between 30% and 50%, and those for COD_{Cr} and NH_4–N between 20% and 30% (Mi & Xie, 2007). According to field sampling measurement, grass swale roadsides removed total suspended solids and heavy metals including lead, copper, zinc, and cadmium (Stagge et al., 2012).

To summarize, green space in an urban ecosystem performs both water-regulation and water-purification functions; however, these functions are frequently ignored in calculations of ecosystem services, with the result that they are not taken into account in the planning and construction of green space. Nevertheless, these functions of green space have a direct impact upon water resources and the water environment of a city, especially where there are water shortages or serious water pollution. Therefore, it is very important to understand how green space affects water availability and quality so that these functions are always included in the calculations of ecosystem services that are used to make decisions.

In the work reported here, Yixing City has been used as a case study with which to evaluate the water-regulation and water-purification functions of green space. Yixing is located on the western side of Taihu Lake, and water quality in Yixing has received increased attention in recent years because of water pollution in the lake. In particular, the objectives were: (1) to evaluate the functionality of water regulation and purification by the green space in Yixing; and (2) to analyze the spatial variation of water regulation and purification between different areas. This work will contribute to an understanding of the role that urban green space plays in water regulation and purification, as well as to the creation and scientific management of urban green space.

2. Methods

2.1. Study area

The total area of Yixing City, Jiangshu Province, China (31°07′–31°37′N, 119°31′–120°03′E) is 1996.6 km^2 (including the water area of Taihu Lake, 242.29 km^2). The south of the city is higher than the north; there are substantial hills in the southwest and the highest peak, Huang Tading, is 611.5 m above sea level. Taihu Lake is located to the east of the city and average elevation is 3 m, whereas in the north and west of the city there are plain and lowland polder areas, respectively. Yixing has a subtropical climate with an average annual temperature of 16.0 °C. The soils in this area are classified as gleysols (FAO-UNESCO, 1998) and the soil texture is predominantly clay loam (Jiangshu Soil Survey, 1995).

Daily rainfall data (provided by the Yixing Meteorological Bureau in Jiangsu Province) show that the annual rainfall in Yixing was 1342.0 mm, 1360.2 mm and 1434.0 mm in 2007, 2008, and 2009, respectively (Fig. 1).

2.2. Green space in Yixing City

The areas and types of green space in Yixing were determined from land use data interpreted from a remote sensing image using the integration of the 2009 ALOS 2.5 m panchromatic and multispectral bands, followed up by a practical investigation in Yixing. The spatial distribution of green space patches was generated using ArcGis 9.2 software (Fig. 2). The main types of green space in Yixing were identified as artificial woodland and artificial lawn, with the area of artificial woodland larger than that of artificial lawn (Table 1). Artificial woodland is defined as green space, in which the canopy density is ≥20%, and which satisfies the forest criteria (Regulations on the Implementation of the Forest of the People's Republic of China, 2000, artificial woodland picture, see Fig. 3); artificial lawn is green space in which grass is the main vegetation type.