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Spatial identification of conservation priority areas for urban ecological land: An approach based on water ecosystem services

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Abstract: How to effectively prevent land degradation and ecosystem deterioration in the pro- cess of urbanization has been the focus of land degradation researches in urban areas. Urban ecological land can be defined as the natural base on which a city relies to eco- logically survive. It closely links the social economy with the natural eco-environment, providing an important integrated approach to resolve the contradiction between urban expansion and natural ecosystems conservation in the process of urbanization. The research question addressed in this study is how to accurately identify the conservation priority areas for urban ecological land. Taking Zhuhai City, located in China, as an example, an approach based on seven kinds of water ecosystem services was put forward, combining social demand and natural supply for the services to determine service targets and conservation priority areas. The results showed that the conservation priority areas in Zhuhai City covered 868 km2, accounting for 51.03% of the total land area, which were mainly covered by woodlands or paddy fields and fish ponds. In addition, by synthesizing ecological importance and ecological sensitivity, management zones for urban ecological land were delineated, including

510 km2 of primary control areas and 358 km2 of secondary control areas. In the

supply and demand view of water ecosystem services, this study put forward an integrated ecosystem- based approach for conservation priority area identification of urban ecological land, aiming to prevent land degradation and achieve urban ecological sustainability.

Keywords: conservation priority areas, spatial identification, urban ecological land, water ecosystem services, Zhuhai City, China

1 Introduction

Since the beginning of this century, rapidly increased population and intensified utilization of land resource have caused continuous degra- dation of land as well as ecosystem deterioration at the global scale, threatening food and ecological security on the mid to long term (Capps, Bentsen, & Ramírez, 2016; Ng, Leung, Cheung, & Fang, 2017). Hence, combating land degradation is vital to sustainable development. Land degradation research should not only measure or predict the drivers of land degradation but, more importantly, also focus on the prevention of land degradation, especially in developing regions. As a significant trend of human development, urbanization has become the most prominent feature of social development since the 20th century (H. Li, Peng, Liu, & Hu, 2017; Y. Li, Sun, Zhu, &Cao, 2010; Qiu, Song, & Li, 2017). Urban expansion would often trans- form the original natural ecosystem into impervious surface with fun- damental change of material and energy flows (Alberti, 1999) and thus bringing significant degradation of habitat quality (Bajocco, Angelis, Perini, Ferrara, & Salvati, 2012; W. Li, Wang, Li, & Liu, 2017; Oliveira, Tobias, & Hersperger, 2018). The quantity and quality changes of eco- system services have led to urban eco-environmental problems such as urban heat islands, air pollution, and flood disasters (Cheng, Chen, Sun, & Kong, 2018; H. Fu & Chen, 2017; J. Li et al., 2011).

As the most fundamental material basis for the survival and devel- opment of human society, land provides the basic spatial carrier for human activities (Felipe- Lucia, Comín, & Bennett, 2014; Ólafsdóttir & Júlíusson, 2015). Because land use is the most predominant carrier for human's influence on natural ecosystems, human society is closely linked with natural ecosystems through the inherent connection between land use and land cover (B. B. Lin et al., 2018; Runfola & Pontius, 2013; Thomas, Sporton, & Perkins, 2015). Urban ecological land, as one functional type of land use, can be defined as the natural base on which a city relies to ecologically survive (Peng, Zhao, Guo, Pan, & Liu, 2017). It not only maintains the ecological cycle and biodiversity but also provides the ecosystem services to satisfy human demands (Bergsten, Galafassi, & Bodin, 2014; McPhearson, Kremer, & Hamstead, 2013). Thus, urban ecological land is fundamental to urban ecological sustainability, and effectively protecting urban ecological land has been considered as one of the key issues in combating land degradation in urbanizing areas.

With increasing global awareness about ecological security and sustainability (Q. Lin, Mao, Wu, Li, & Yang, 2016; Peng, Yang, et al., 2018; Runfola et al., 2017; Zhang, Peng, Liu, & Wu, 2017), research on identification and protection of important urban ecological land has flourished over recent years. For example, the method of ordered weighted averaging was used to identify priority areas for forest resto- ration with the objective to improve water resource conservation (Vettorazzi & Valente, 2016); optimal conservation planning of multiple hydrological ecosystem services was conducted considering land use and climate change (M. Fan, Shibata, & Wang, 2016); the conservation and management of urban green space were reviewed considering the biodiversity of terrestrial fauna species (opucki & Kiersztyn, 2015); green infrastructure was designed on the premise of spatial conservation prioritization (Snäll, Lehtomäki, Arponen, Elith, & Moilanen, 2016); and urban green infrastructure planning was explored combining the conservation of biodiversity and the delivery of ecosystem services (Capotorti, Vico, Anzellotti, & Celesti- Grapow, 2016). Among the abovementioned studies, whether the restoration and protection of urban ecological land, the identification and management of urban green space, or the planning and design of urbangreen infrastructure were all based on prioritizing the protection of ecologically important areas. Given the huge human pressure on natu- ral ecosystems in the process of rapid urbanization, the protection of most important ecological land units with a limited investment should be considered as a basic principle of urban ecological management. This is crucial for securing the welfare of future generations through long- term ecosystem management.

Inherently linking natural ecosystem process with human well-being (Kong et al., 2016; C. Li et al., 2015; Zheng et al., 2016), ecosystem services provide an effective approach for assessing con- servation needs and spatially identifying the priority areas for urban ecological land. Water- related ecosystem services, referred to as the "water ecosystem services" (Yang, Zhang, Li, & Wu, 2015), are considered as the core services to meet urban residents' demands. Water ecosystem services can strongly influence a wide range of other (nonwater) ecosystem services and thus dominate the most important feedback mechanisms between man and nature. As water ecosystem services can also be quantitatively measured and monitored (Farooqui, Renouf, & Kenway, 2016; Martin- Ortega, Ojea, & Roux, 2013; Moore & Hunt, 2012; Mulatu, Veen, & Oel, 2014), they meet the representa- tive, comprehensive, and threshold requirements for identifying con- servation priority areas for urban ecological land. Consequently, water ecosystem services can be considered as an effective tool to identify the conservation priority areas for urban ecological land.

Zhuhai City is located in the lower reaches of the Pearl River Basin, the third largest drainage basin in China. The city is built near the river, covering natural habitat for water- related flora and fauna. As a result, natural ecosystems as well as the daily activity of local res- idents are closely linked with water. Thus, Zhuhai City is the ideal study area for identifying conservation priority areas in view of water ecosystem services. Furthermore, as one of the earliest special eco- nomic zones established in China, Zhuhai City is ushering in a new round of urban construction against the background of new phase of intensified urbanization. Consequently, it is most urgent that the city identifies the conservation priority areas for urban ecological land based on water ecosystem services. The objectives of this study are (a) to establish a framework for measuring and mapping water ecosystem services; (b) to identify conservation priority areas for urban ecological land based on water ecosystem services; and (c) to delineate management zones for urban ecological land considering both ecological importance and sensitivity.

2 Materials and methods

2.1 Study area and data sources

Zhuhai City is located south of Pearl River Delta and along the west side of the Pearl River estuary (Figure 1), covering the estuary of the Modaomen, Jitimen, Hutiaomen, and Yamen water systems in the Pearl River Basin (113°03′–114°19′E, 21°48′–22°27′N). The city is characterized by wet climate condition, with an average annual rainfall amount of 2,042 mm. However, the rainfall is unevenly distributed during the year with remarkably less over the winter and spring and more over the summer and autumn. More precisely, the precipitation tends to be concentrated in the flood season from May to June, which accounts for more than 30% of the total annual rainfall. Xijiang River, the main stream of the Pearl River, is divided into a plurality of tributaries as it enters Zhuhai City in the northern part of Doumen District. The tributaries then merge into three main streams and discharge into the South China Sea from north to south, where disasters such as extensive flooding are occurring frequently.

As a result, soil retention, runoff reduction, and flood regulation are selected as key regulating services in this study. In addition, water pollution is a serious issue in this city, as drinking water sources often contain chemical pollutants, and most groundwater is also contaminated by heavy metal ions. Thus, water protection and water conservation are selected as key provisioning services in the view of water quality and quantity, respectively. Moreover, as a coastal city, there are various kinds of water landscapes, including a large amount of waterfront parks. Accordingly, close- to- water recreation and distant- water appreciation are selected as key cultural services.

The whole city occupies an area of 7,836 km2, with 1,701 km2 of land area and 6,135 km2 of sea area. Land use types in Zhuhai City mainly include woodland, paddy field and fish pond, and construction land, accounting for 28.24%, 26.44%, and 23.67% of the total land area, respectively. Woodland and construction land are interdependently distributed, with a large amount of woodland distributed within or around the built- up areas. Paddy field and fish pond are mainly dis- tributed along the water system and the reservoirs. Furthermore, there are also almost 200 km2 of unused land and a small amount of water bodies, dry croplands, and grasslands.

The data of this study mainly included two categories:

Spatial data. Land cover data for the year 2010 from the Globeland30- 2010 dataset were provided by the Chinese Basic Geographic Information Center (www.globallandcover.com/ GLC30Download/ index.aspx). Digital elevation model data SRTM90m (CGIAR- CSI) were provided by the Computer Network Information Center of the Chinese Academy of Sciences (http://www.cnic.cas.cn/ zcfw/ sjfw/ gjkxsjjx/). Normalized difference vegetation index data were obtained from the MODIS MOD13Q1 product with spatial resolution of 250 m, provided by the U.S. Geological Survey (https:/ / lpdaac.usgs.gov/ dataset_ discovery/ modis/

modis_products_table/ mod13q1). Soil type data were the 1:1,000,000 soil dataset of Western Environmental and Ecological Science Data Center of the Chinese Academy of Sciences. Meteorological data, including precipitation, temperature, and sunshine, were from the Chinese Meteorological Data Service Platform (http:/ / data.cma.cn/).

Urban and regional planning reports, which were collected from the official websites of the governmental departments of Zhuhai City, include the following documents: urban master planning, overall planning for land utilization, geological disaster protection planning, water supply engineering scheme, water resources comprehensive planning, green space system planning, and the major function- oriented zoning.

2.2 Research framework

aking ecological land as the spatial carrier of ecosystem services and integrating the supply and demand of ecosystem services, a concep- tual framework of spatially identifying conservation priority areas for urban ecological land was developed (Figure 2). First, seven kinds of water ecosystem services covering the three categories of regulating, provisioning, and cultural services were selected in the study area, together with mapping the supply of these services. Second, for each kind of water ecosystem services, service targets were determined according to societal demand and natural supply capacity. Third, based on the supply capacity of ecological land in terms of ecosystem services, ecological land fulfilling the service target was identified. Finally, all the identified ecological lands were overlapped using ArcGIS in order to spatially identify conservation priority areas for urban ecological land in Zhuhai City. In addition, by synthesizing ecological importance and sensitivity, management zones for urban ecological land were delineated.

2.3 Spatial identification of ecosystem service land

(1) Regulating service land

Regulating services refer to the services and benefits derived from the regulatory effect on ecosystem processes. Water regulation services achieve their regulatory effect by controlling hydro-ecological processes, including the services of soil retention, runoff reduction, and flood regulation.

Soil erosion reflects the degree of soil loss, which is related to rainfall erosivity, soil erodibility, slope length, slope steepness, crop management and support practices (Guo et al., 2018; Liu et al., 2010). Ecological land with high soil retention service was identified by calculating the difference of soil erosion amounts from areas that included and excluded ecological land. According to the degree of soil erosion in Zhuhai City and its hazard level, the mild soil erosion rate (2500 tons$\cdot$km$^{-2}\cdot$a^{-1} or more) was selected as the service target of soil retention. Ecological land with soil retention service exceeding the target amount was identified as the service land of soil retention.

The revised version of the Universal Soil Loss Equation, i.e. RUSLE (Galdino et al., 2016), was used to calculate the total amount of soil retention (B):

$$B = R \cdot K \cdot L \cdot S \cdot (1 - C) \cdot P \tag{1}$$

Where *R* is the rainfall erosivity factor, calculated using Wischmeier's empirical formula (Fu et al., 2005); *K* is the soil erodibility factor, calculated by the K-value estimation method proposed in the EPIC model (Polyakov et al., 2007); *L* is the slope length factor, calculated by an empirical formula that combines horizontal slope length and slope length index (Kinnell, 2010); *S* is the slope steepness factor, calculated according to McCool's classic slope formula based on the gradient (Nakil & Khire, 2016); *C* is the crop management factor, obtained by the vegetation coverage, which can be calculated from the average annual NDVI; and *P* is the support practice factor. Referring to previous studies, the *P* value of various types of land cover was determined (Panagos et al., 2015; Taye et al., 2017).

To identify service land of runoff reduction, the Sponge City Construction Technology Guide promulgated by the Ministry of Housing and Urban-Rural Development of China was followed. According to the technology guide which was based on a statistical analysis of the daily rainfall in 200 Chinese cities during 1983-2009, the runoff reduction target in Zhuhai City was set as 70%, and the corresponding design rainfall was 25.2 mm hr^{-1}. In details, the main steps were as follows. Firstly, the runoff collection point in a catchment area was identified as the regulation control point after dividing catchment areas. Secondly, the demanding size of service land of runoff reduction was determined according to the runoff load in the catchment area and the regulating capacity of ecological land. Finally, based on the spatial location of the regulation control point and the demanding size of service land, the service land of runoff reduction was spatially identified.

The United States Soil Conservation Service (SCS) hydrological model was used to calculate the runoff load (Ajmal et al., 2015). The model can reflect a wide range of underlying factors, such as land use, soil type and pre-soil wetting conditions, as well as the impact of human activities on rainfall runoff. Relatively few parameters are required in the model.

$$Q = \begin{cases} \frac{(P-0.2S)^2}{S+P-0.2S}, & P > 0.2\,S \\ 0, & P \leq 0.2\,S \end{cases} \tag{2}$$

Where *Q* is the runoff (mm), *P* is the total rainfall (mm), and *S* is a parameter reflecting the effects of soil and water conservation. As a mean of measuring the value of *S*, the SCS model was used, which has a dimensionless parameter called the curve number (CN) based on physical features and soil types. It also defined the relationship between S and CN as follows:

$$S=254\times\frac{100}{CN-1} \tag{3}$$

In this study, the original CN values for hydrological groups of soils were amended based on previous studies in Pearl River Delta (Fan et al., 2013; Lin et al., 2014; Xu et al., 2016). The runoff pattern under rainfall events was simulated using the SCS model, and thus the runoff of each catchment area was calculated to obtain the runoff load.

In flood regulation, what downstream cities such as Zhuhai can do is mainly manifested in two aspects, i.e. maintaining the smooth flow of the flood discharge channel and ensuring the rivers to access the floodplains. In this study, Laolao Creek, Helao Creek, Hengkeng Waterway, Chifen Waterway, Luozhou Creek, Huangyang River, Jintimen Waterway, Modaomen Waterway, and Tiansheng River, all of which connected Xijiang River and Pearl River estuary, were identified from more than 170 rivers in Zhuhai City as the main protected flood discharge channels. According to the green space system planning of Zhuhai City, a 100-m buffer zone on both sides of the flood discharge channels was set as the flood avoidance area. Important flood discharge channels and the 100-m buffer zone were integrated as the service land of flood regulation.

(2) Provisioning service land

Water provisioning services are the services that human obtains directly from natural water resources, including the provision of drinking, industrial and agricultural water. Ecological land plays a significant role in water provisioning services through protecting and conserving water resources. The main water supply channels, water intake points and water storage areas are the most vulnerable areas in the view of the safety of urban water source. Thus, they were designated as water protection areas.

Meanwhile, according to the relationship among rainfall, runoff and evaporation, urban ecological land characterized by high water conservation capacity was set as water conservation areas.

In order to specify the water protection areas more precisely, the water supply engineering scheme of Zhuhai City was considered. It identified (i) the Modaomen Waterway and Huangyang River as main sources of drinking water, (ii) the Hutiaomen Waterway as the main source of industrial water, and (iii) the reservoirs in the middle and western part of the city as auxiliary water sources. Furthermore, in the water resources comprehensive planning of Zhuhai City, two levels of water protection area were designated. The first level was set as the target of water protection, according to the effect and cost of ecological land for protecting water sources. Subsequently, based on the set service targets, the following riparian areas were classified as water protection areas (Kingsford et al., 2011): (i) the rivers with main function of water supply, (ii) the water areas within 1500m upstream and downstream of the five water intake points, and (iii) the land within 100 meters distance from the water intake points. In fact, although ultimately aiming at the provisioning of water resource, criteria (ii) and (iii) also refer to the highest service of water purification. In addition, all the 26 reservoirs in the city, as well as their corresponding catchment areas with the first-level protection were also classified as water protection areas.

For water conservation service, the conservation degree of rainfall by ecological land was calculated through the relationship among water conservation and water demanding. The relationship between regional annual water conservation H and water demanding X is as follows:

$$k \cdot H = X \tag{4}$$

$$H = \alpha \cdot P \tag{5}$$

where k is the local water use efficiency, and P is the average annual rainfall. According to the water resources comprehensive planning of Zhuhai City, k was set as 56% with 2042 mm for P, and X was 440 million m^3 including domestic, ecological and agricultural demanding. As a result, the degree of conservation (α) should reach 22.7%, compared with the total rainfall.

To remain consistent with runoff reduction, assuming 25.2 mm of rainfall in 1 hour as the representative rainfall event, the degree of conservation in this rainfall event should also be 22.7%. Considering the area of Zhuhai City, such a representative rainfall event would produce a rainfall amount of 42.56×10^6 m^3, and the amount of water conservation should reach 9.67×10^6 m^3. In a single rainfall event, for ecah spatial unit, assuming that the amount of water conservation is x, the rainfall is p, the runoff is q, and the evaporation is z, the following water balance equation will exist:

$$x = p - q - z \tag{6}$$

Furthermore, water conservation capacity for ecological land was calculated using SCS model as mentioned above. The ecological lands with the highest conservation capacity were selected as water conservation area, meeting the demanding amount of water conservation.

(3) Cultural service land

Cultural ecosystem services refer to the non-material benefits people obtain from natural ecosystem. As a kind of ecological land, water body can also fulfill important cultural services. In this study, water-based recreation was regarded as the representative of water-related cultural services, including both close-to-water recreation and distant-water appreciation. Water-based recreation relies on areas that have recreation attraction. The important recreation areas in Zhuhai City were extracted as the basic evaluation units, including recreational rivers, natural and cultural heritage areas, nature reserves, scenic locations, urban parks, and greenways.

In terms of service land of close-to-water recreation, it should include not only water bodies with recreation attraction, but also ecological land with high accessibility to the water bodies. According to the water resources comprehensive planning of Zhuhai City, water bodies with recreation attraction were extracted. Based on the extracted water bodies, the usual distance that connects scenic spots, i.e. a five-minute walking distance of 360 m (Bassett et al., 2000), was used to determine the buffer zone. These water bodies and recreation areas within the buffer zone were identified as water recreation areas.

To identify distant-water appreciation areas, recreation areas from which water bodies could be watched with high frequency were considered. Taking the main water bodies as watching objects, spatial pattern of watching frequency of these main water bodies across the entire city was obtained using the sight analysis tool of GIS software. More precisely, recreation areas with water-watching frequency above the average were included in the cultural service land.

2.4 Partition control of urban ecological land

A city is a coupled human and nature system, with great spatial heterogeneity in its component and functioning. Ecological land is the spatial basis for provisioning ecosystem services. However, for different kinds of ecological land, and even the same kind of ecological land at different locations, their importance and sensitivity to ecosystem services maybe be quite different. Partition control has become an effective way in urban ecological land management. Ecological importance of urban ecological land refers to the intrinsic ecological functions and services it undertakes, whereas ecological sensitivity of urban ecological land can be defined as the sensitivity of the land to maintain ecosystem services under the impact of strong external disturbance (Peng et al., 2015). Hence, through grading the ecological land according to ecological importance and ecological sensitivity, and overlaying the two kinds of grading, a partition management for urban ecological land could be conducted.

To quantify the ecological importance, the three maps of regulating service land, provisioning service land, and cultural service land were overlaid in ArcGIS. And subsequently, the ecological importance of ecological land was graded into three levels, i.e. high importance, medium importance, and low importance, corresponding to the appearance in three, two, and one kind of service land maps, respectively.

When investigating the ecological sensitivity, urban areas, towns, villages, roads and railways were considered to quantify human threats on biodiversity using habitat quality module of InVEST, which helped to grade the sensitivity of ecological land. InVEST model has been widely used to analyze the impact of human-induced ecological threating on land cover, and further to evaluate habitat quality and its degradation (Posner et al., 2016). The principle of ecological sensitivity evaluation is as follows:

$$D_{xj} = \sum_{r=1}^{R} \sum_{y=1}^{Y_r} \left(\frac{w_r}{\sum_{r=1}^{R} w_r} \right) r_y i_{rxy} \beta_x S_{jr} \tag{7}$$

$$i_{rxy} = 1 - \left(\frac{d_{xy}}{d_{r\max}} \right) \tag{8}$$

where D_{xj} is the ecological sensitivity, R is the number of sensitive source, w_r is the sensitivity weight, Y_r is the pixel number of sensitive source, r_y is the number of sensitive source on each pixel, i_{rxy} is the threating of sensitive source, β_x is degree of legal protection, S_{jr} is the sensitivity coefficient, d_{xy} is the sensitive distance, and d_{rmax} is the maximum sensitive distance of sensitive source. Specifically, urban areas, towns and roads were considered to exert higher threating on ecological land, whereas it was relatively small for villages and railways. In addition, dry croplands, paddy fields and fish ponds as well as unused land were considered to be most sensitive to these threating, followed by grassland, woodland and water body. (Table 1).

[Table 1 is here]

As the result of management zoning, primary and secondary control areas were spatially identified through overlaying the maps of ecological importance and ecological sensitivity. Using the method of natural break, ecological sensitivity of ecological land could be divided into three levels, i.e. high sensitivity, medium sensitivity, and low sensitivity. Then the management zones for urban ecological land in Zhuhai City were delineated according to the combination of ecological importance level and ecological sensitivity level. In detail, ecological land with high ecological importance or high ecological sensitivity was identified as primary control area, whereas the other part of conservation priority areas were identified as secondary control areas.

3 Results

3.1 Key areas supplying ecosystem services

Through integrating the supply and demanding of ecosystem services, spatial distribution of key areas supplying the demanded seven ecosystem services were obtained (Figure 3). I This result showed that the soil retention service was mainly distributed in mountainous areas characterized by abundant vegetation that could effectively retain soil (Figure 3a). The runoff reduction service was concentrated in the low-lying areas around the main water systems (Figure 3b), covering a total area of 128 km^2 with the minimum and maximum patch area of 1 ha and 249 ha, respectively. The flood regulation service was chiefly distributed in riparian zone around major rivers with the potential to ameliorate or prevent flood disaster (Figure 3c). The water protection service covered a total area of 120 km^2, locating around such water sources as rivers and reservoirs (Figure 3d). The water conservation service had an area of 444 km^2, accounting for 26.10% of the total land area, and was mostly provided by woodlands and paddy fields (Figure 3e). The water recreation service was located in areas adjacent to water body and contained all the offshore islands and the banks of the rivers (Figure 3f). The water appreciation service was concentrated in the high-lying areas, which had the topographical induced advantage of having a great sight potential for attractive waterscape (Figure 3g).

[figure 3 is here]

3.2 Conservation priority areas for urban ecological land

Spatial distributions of the three categories of ecosystem service land were obtained through overlaying key areas of ecosystem services in the same category (Figure 4). As shown in Figure 4a, regulating service land was 547 km^2, accounting for 32.16% of the total land area. Comprised of soil retention area, runoff reduction area, and flood regulation area, the regulating service land included the main mountain areas with high vegetation coverage, the major flood channels and floodplains, as well as the low-lying green areas distributed at the outlets of various sub-catchments. The area of provisioning service land was 509 km^2, accounting for 29.92% of the total land area. It contained 120 km^2 of water protection area and 444 km^2 of water conservation area, and was mainly distributed in water supply channels and water bodies, woodland in mountain areas, and paddy fields in the plain (Figure 4b). The area of cultural service land was 498 km^2, accounting for 29.28% of the total land area. It was mainly located in the surrounding areas of inland rivers, reservoirs and ponds (Figure 4c). Being close to the main water bodies, the cultural service land had the advantages of providing water-related recreation and appreciation services.

[figure 4 is here]

Based on the relationship between ecological land and its ecological functions and services, which was embodied in ecological processes, ecological land that met the demanding targets of key ecosystem services was defined as conservation priority areas. More specifically, through overlaying the regulating service land, provisioning service land and cultural service land, the conservation priority areas of water ecosystem services in the study area could be mapped (Figure 5). After removing the overlapped ones among the three kinds of service land, the conservation priority areas for urban ecological land in Zhuhai City were determined to be 868 km^2, accounting for 51.03% of the total land area. They were mainly composed of woodlands in mountain areas, water bodies and cropland in the plains.

[figure 5 is here]

3.3 Management zoning for urban ecological land

As shown in Figure 6a, there was distinct spatial agglomeration for ecological importance grades of conservation priority areas in Zhuhai City. In total an area of 243 km^2 (accounting for 28% of the conservation priority areas) was contained in the maps of three kinds of service land, and hence, it was classified as area of high ecological importance. These areas included two parts: one was found in the mountainous areas with dense vegetation coverage, referring to the ecosystem services of soil retention, water conservation, and water appreciation. The other one was mainly located across the main rivers, representing the ecosystem services of water recreation, water protection, runoff reduction and flood regulation. Furthermore, the medium and low ecologically important areas, i.e. contained in two and one kind of service land map, counted to be 241km^2 and 384 km^2, respectively. Low ecological importance area was mainly composed of woodlands in the plains providing water conservation service, paddy fields, fish ponds and beaches for runoff reduction service.

Ecological sensitivity of conservation priority areas was also quantified (Figure 6b). In total an area of 245 km^2 was identified as areas of high ecological sensitivity, accounting for 28.23% of the conservation priority areas. These areas mainly covered the runoff reduction land and water conservation land close to the urban areas in the plain, as well as the locations along the periphery of Fenghuang Mountain, Huangyang Mountain and Jiangjun Mountain. The areas of medium and low ecological sensitivity counted to be 249 km^2 and 374 km^2 respectively, both concentrated in the central part of mountain areas as well as islands far away from human activities.

By synthesizing ecological importance and sensitivity, 510 km^2 of primary control areas were identified, accounting for 58.76% of the conservation priority areas for ecological land. These primary control areas were mainly concentrated in mountains and islands, or runoff reduction land, with high ecological importance or severe human disturbance. The secondary control areas covered an area of 358 km^2, accounting for 41.24% of the conservation priority areas for ecological land. It was mainly distributed in the plains with lower ecological importance or sensitivity. Generally speaking, the primary control areas should implement the strictest ecosystem protection. For example, any construction activities, unrelated to a specific ecological protection, scientific research or educational purpose, should be prohibited. Population growth should be strictly controlled through the gradual relocation of permanent residents out of the areas (Gong et al., 2017). Besides strictly controlling human interference with original landform, vegetation and water system, ecological protection, restoration and construction should also be implemented by means of biological engineering measures (Bai et al., 2018). On the contrary, human activities such as infrastructure construction could be permitted in the secondary control areas, under the premise of non-increasing the risk of environmental pollution or ecological degradation.

[figure 6 is here]

4 Discussion

4.1 Spatial differentiation of conservation priority areas

The spatial differentiation of conservation priority areas in Zhuhai City was analyzed in the view of land use type and elevation, which were highly correlated with area proportion of conservation priority areas. Seven land use types in the study area were considered, i.e. construction land, woodland, water body, dry cropland, paddy field and fish pond, grassland and unused land. Through comparing the area proportion of land use types in conservation priority areas, and that of land use types identified as conservation priority areas, land use differentiation of conservation priority areas could be analyzed (Figure 7). The results showed that the main land use types in the conservation priority areas were woodland (430.2 km^2), and paddy field and fish pond (175.1 km^2), accounting for 49.56% and 20.17% of the total conservation priority areas, respectively. As an efficient kind of ecological land with multiple ecosystem services, woodland had been mostly identified as conservation priority areas, with an area proportion of 88.98%. Because of the focus on water ecosystem services in this study, more than 95% water bodies were identified as conservation priority areas. Although having a high area proportion in total land area of 38.69%, paddy fields and fish ponds only covered 20.17% of the conservation priority areas. In addition, including beach and bare land with high water ecosystem services, 38.92% unused land was also identified as conservation priority areas. That was to say, water body, wood land, unused land, and paddy field and fish pond had the top priority for ecological conservation in Zhuhai City, due to their importance in supplying water ecosystem services.

[figure 7 is here]

According to the topographical features of Zhuhai City, the areas with the elevation less than 25 m, 25–60 m, 60–200 m, and 200–600 m were classified as plains, hills, low mountains and high mountains, respectively. Through comparing the area proportion of topographical types in conservation priority areas, and that of topographical types identified as conservation priority areas, elevation differentiation of conservation priority areas was investigated (Figure 8). As the most common terrain in Zhuhai City, the plains occupied 57.65% of the conservation priority areas. However, as low as 37.87% of all the plains were covered in conservation priority areas, which might be due to the high importance of woodland in supplying ecosystem services and its low distribution in the plains. Considering the high suitability for construction, conservation priority areas in the plains were in face with severe human disturbance, and the trade-offs between economic development and ecological conservation usually occurred in land use policy. On the contrary, hills, low mountains and high mountains occupied only a small proportion of the conservation priority areas, accounting for 13.18%, 23.70% and 5.47% respectively. However, almost all were included in the conservation priority areas with the ascending order of their conservation proportion. This was mainly because of the increasing woodland coverage and intensified vegetation activity, along with the elevation rising.

[figure 8 is here]

4.2 Limitations and future research directions

Although quantification is an obvious advantage compared to studies focusing on the identification of spatial pattern of ecosystem services (Peng et al., 2018a, Peng et al., 2018b), there are still some limitations needing further improvement in this study. Firstly, spatial distributions of three kinds of service land were obtained based on the simple overlaying of various key areas supplying ecosystem services, with equally weighting of each kind of ecosystem services. In fact, the weights of the specific ecosystem service might be different, slightly or obviously, especially considering potential difference in human preference and thus ecosystem services trade-offs in policy making. Accordingly, weighting issue also lied in the overlying of different service land maps to obtain the map of conservation priority areas.

In addition, this study was conducted based on human demanding for ecosystem services. Although it considered the dynamic process of human development, the proposed identification approach was a kind of prediction based on static data in temporal dimension. More dynamic data should be introduced as regards ecological processes. Moreover, the timeliness and uncertainty of multivariate data should be focused on in future studies.

5 Conclusions

Although demand quantification is an obvious advantage compared with studies focusing on the identification of spatial pattern of ecosys- tem services (Peng, Yang, et al., 2018; Peng, Pan, Liu, Zhao, & Wang, 2018), there are still some limitations needing further improvement in this study. First, spatial distributions of three kinds of service land were obtained based on the simple overlaying of various key areas supplying ecosystem services, with equal weighting of each kind of ecosystem services. In fact, the weights of the specific ecosystem service might be different, slightly or obviously, especially considering potential difference in human preference and thus ecosystem services trade- offs in policy making. Accordingly, weighting issue also lied in the overlying of different service land maps to obtain the map of conservation priority areas.

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Figures and tables

Figure 1 The geographical location of Zhuhai City

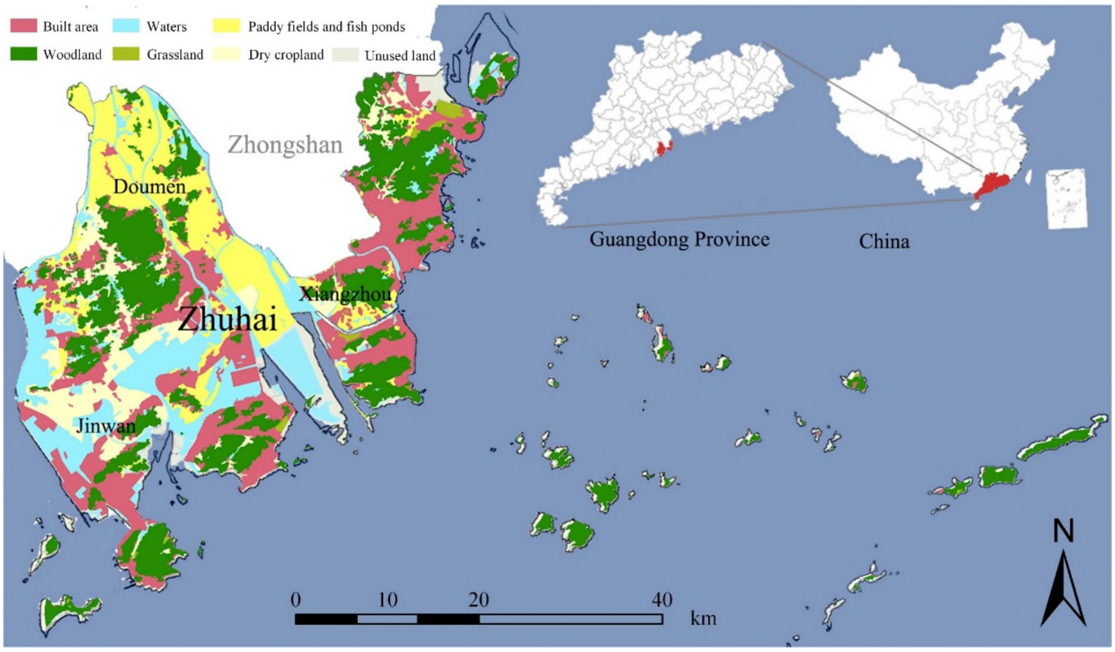

Figure 2 Research framework for identifying the conservation priority area and management zoning for urban ecological land

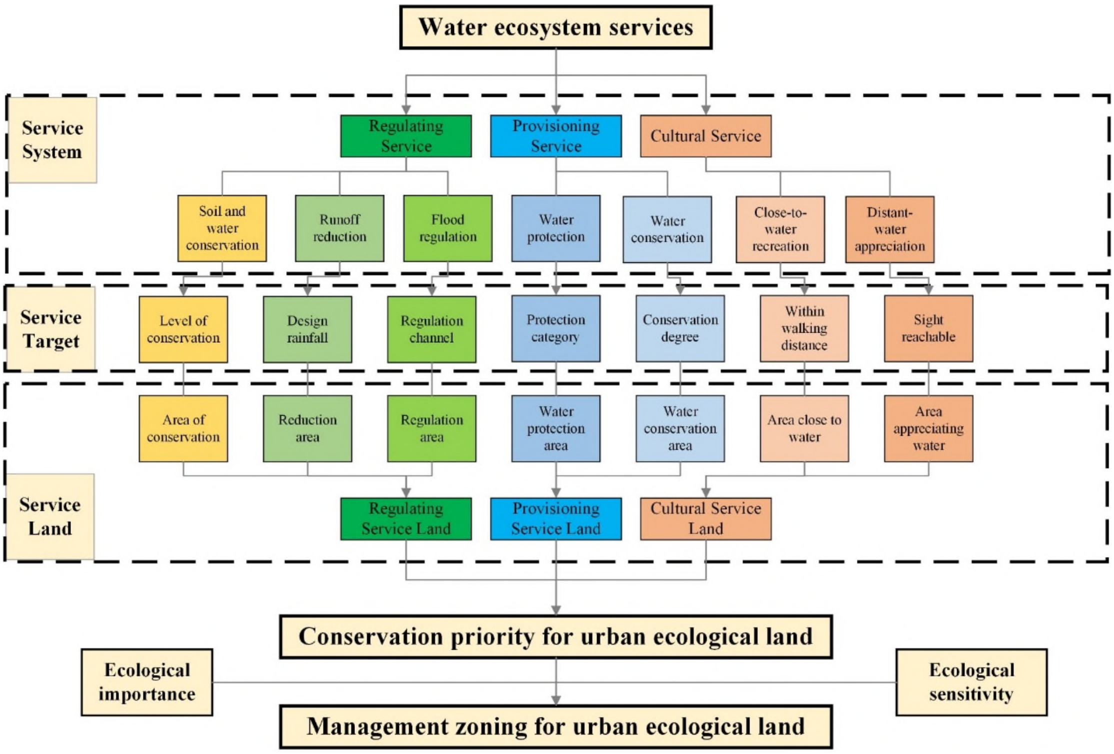

Figure 3 Spatial distribution of key areas for water ecosystem services in Zhuhai City. a) Soil retention area; b) Runoff reduction area; c) Flood regulation area; d) Water protection area; e) Water conservation area; f) Water recreation area; g) Water appreciation area.

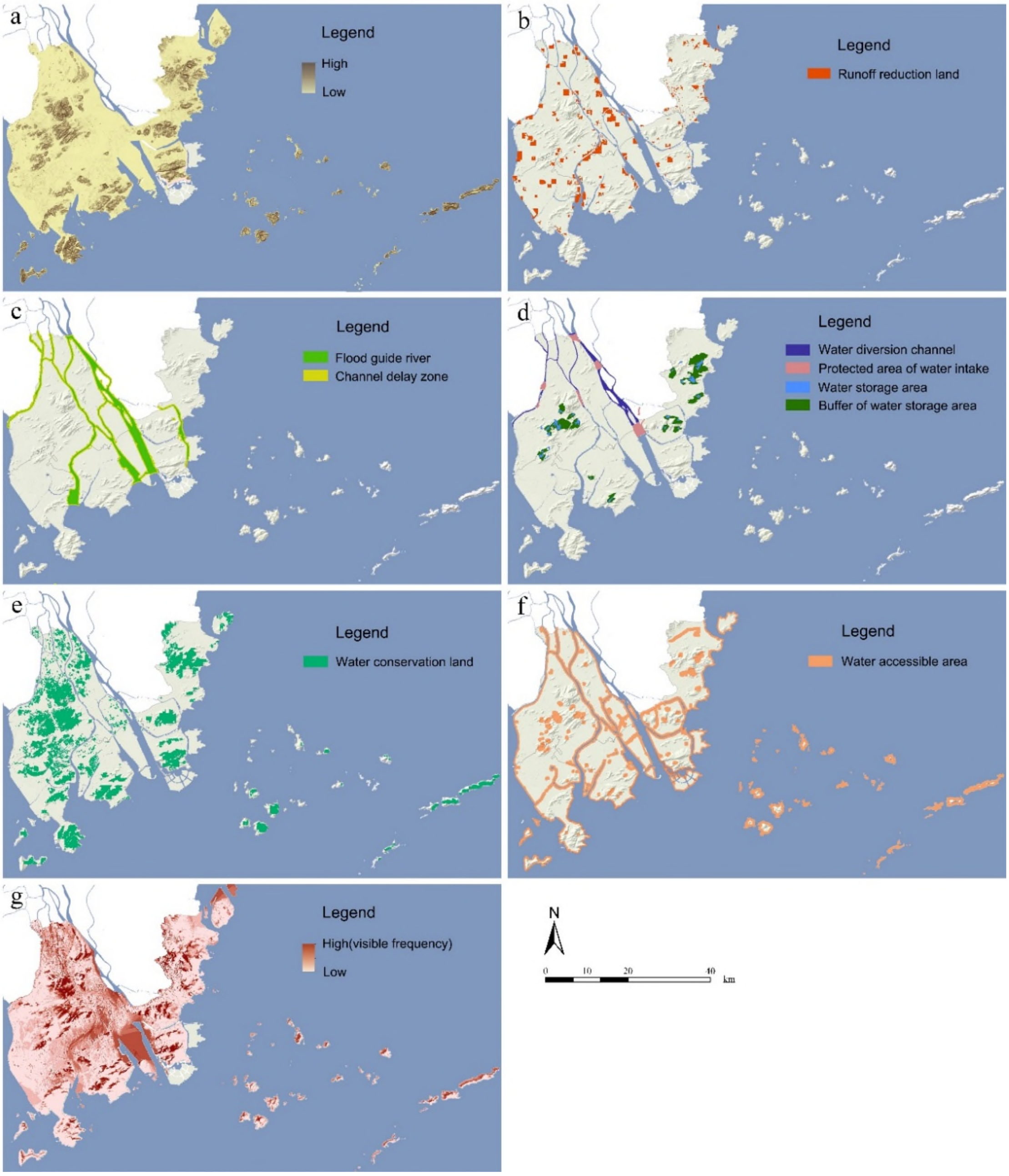

Figure 4 Spatial distribution of water ecosystem service land in Zhuhai City.

a) Regulating service land; b) Provisioning service land; c) Cultural service land

Figure 5 Conservation priority areas for urban ecological land in Zhuhai City

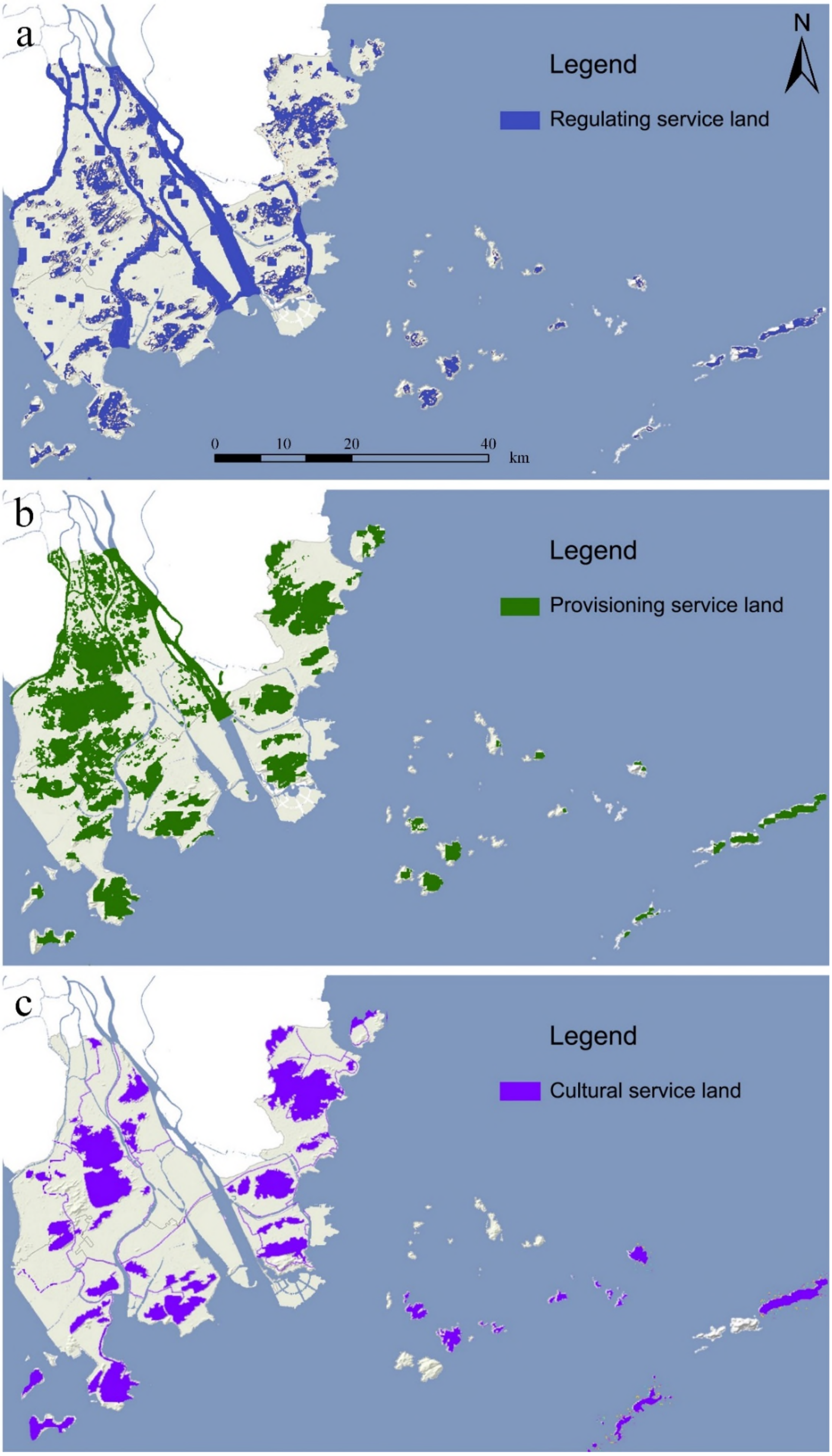

Figure 6 Management zoning for urban ecological land in Zhuhai City. a) Ecological importance; b) Ecological sensitivity; c) Management zoning

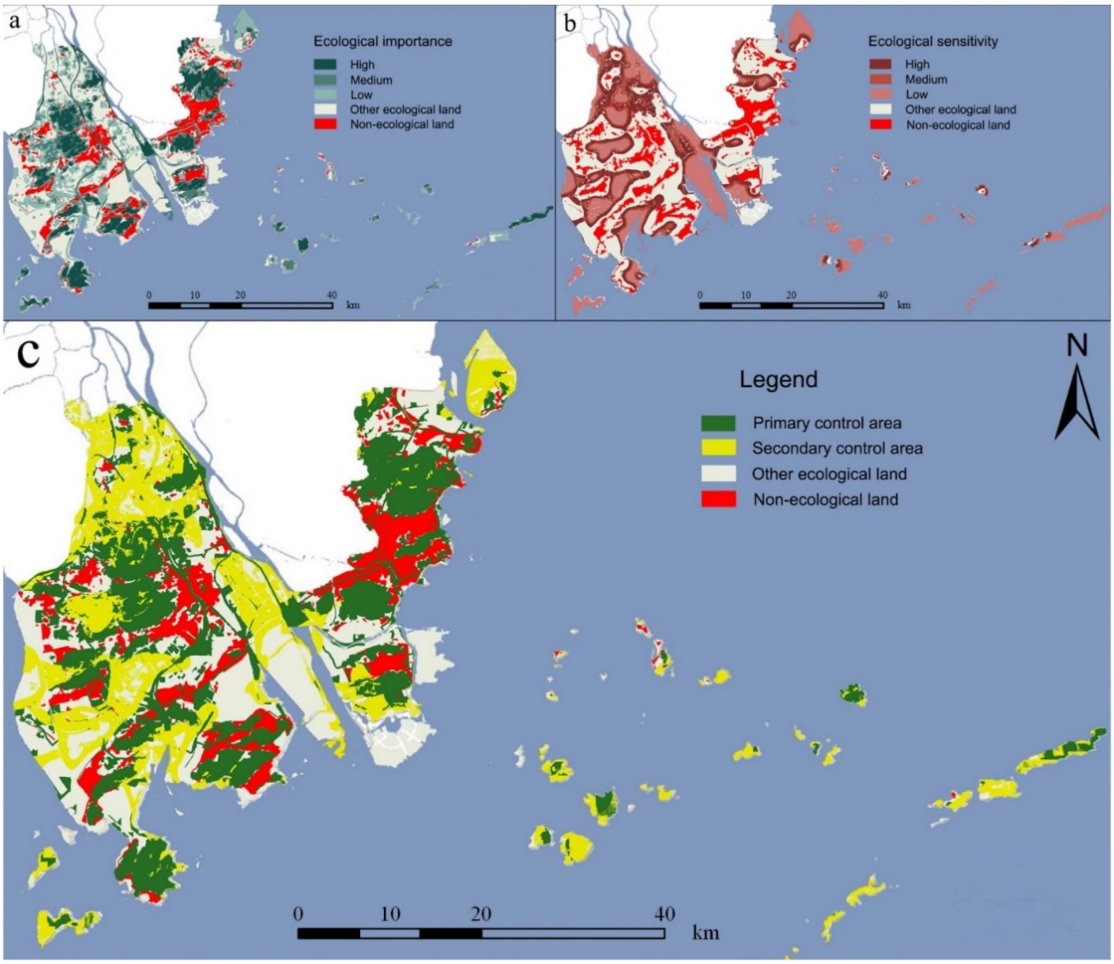

Figure 7 Area proportion contrast of land use types in the conservation priority area

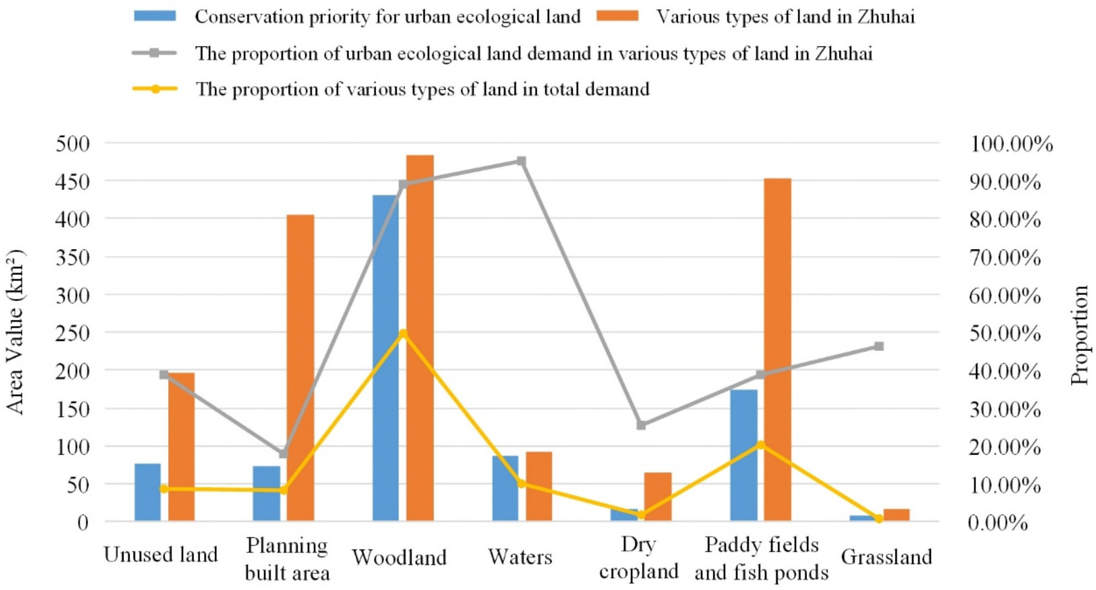

Figure 8 Area proportion contrast of topographical types in the conservation priority area

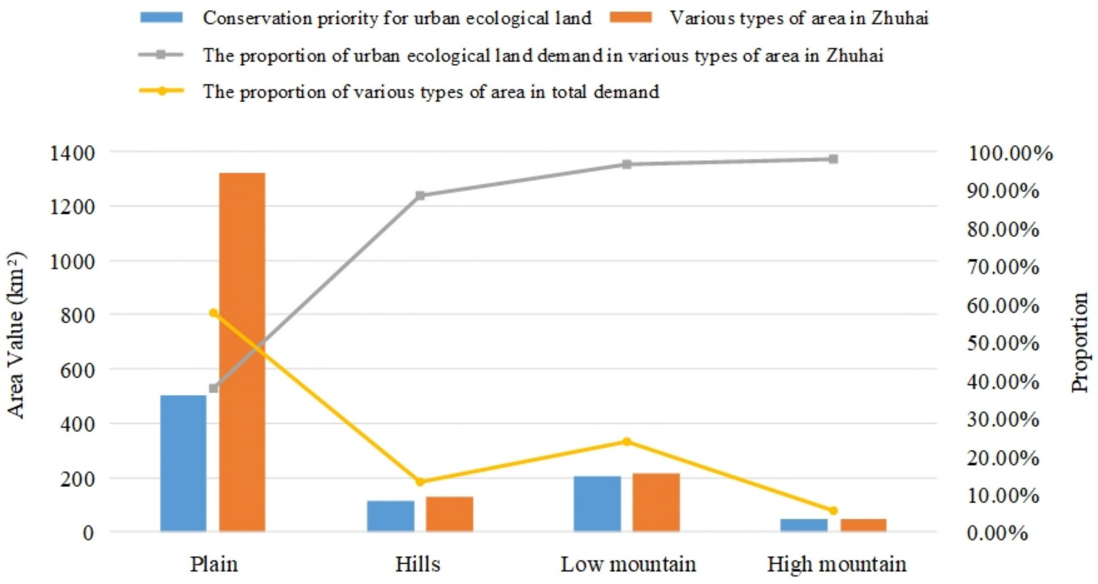

Table 1 Sensitivity coefficient of ecological land

Table

Table 1. Sensitivity coefficient of ecological land.

Sensitive source	Sensitive distance (km)	Sensitivity weight	Sensitivity coefficient					
			Woodland	Water body	Dry cropland	Paddy field and fish pond	Grassland	Unused land
Urban area	6	1	0.8	0.8	1	1	0.8	1
Town	4	0.8	0.7	0.7	0.8	0.8	0.7	1
Village	3	0.5	0.5	0.5	0.3	0.3	0.5	0.5
Road	4	0.6	0.7	0.7	0.9	0.9	0.8	0.9
Railway	2	0.3	0.3	0.3	0.5	0.5	0.5	0.5

Spatial identification of conservation priority areas for urban ecological land: An approach based on water ecosystem services

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