sustainability
MDPI

Article

A Quantitative Study on the Identification of Ecosystem Services: Providing and Connecting Areas and Their Impact on Ecosystem Service Assessment

Qing Liu [1], Guoming Du [1,*] and Haijiao Liu [2]

1 School of Public Administration and Law, Northeast Agricultural University, Harbin 150030, China; hitlqmadam@gmail.com
2 School of Economics and Management, Harbin Engineering University, Harbin 150009, China; liuhaijiao911@gmail.com
* Correspondence: duguoming@neau.edu.cn

Abstract: The spatial location relations between service-providing areas and service-demand areas determine the effective provision level of ecosystem services. Some scholars use the term ecological service flow to conceptualize the transmission path, transmission characteristics, and service benefits of the provision-oriented service type between service-providing areas and service-demand areas. A few scholars have characterized the transmission range and spatial unit characteristics of single or several ecosystem service types, such as production services and regulation services between the providing area and demand area based on landscape, region and global scale. The current literature lacks quantitative studies on the spatial location relations between providing areas and demand areas of ecosystem services and the actual level of ecosystem service provision at the municipal scale based on the demand for ecosystem services faced by cities. This study takes Jinan, China, as the research area, quantifies the providing areas, connecting areas and demand areas of seven services—namely, the air purification service, climate regulation service, flood prevention service, water pollution prevention service, water supply service, soil erosion prevention service, and habitat supply service—and analyzes the spatial relation characteristics of each element. On this basis, the Hellwig model is used to quantitatively analyze the impact of service-providing area and service-connecting area on regional overall ecosystem service assessment. The results prove that service-providing areas and service-connecting areas are the key units that affect the level of regional ecosystem service provision. The evaluation of regional ecosystem service provision level is inseparable from the identification of service-providing areas and service-connecting areas and the study of their attributes, characteristics, and spatial relations. Service-providing areas and service-connecting areas should be differentiated when developing strategies to optimize and improve the level of regional ecosystem service provision. Different optimization measures should be formulated according to the differences in unit attributes and service barriers in different areas. The results provide guidance for the optimization of ecosystem services to ensure the efficient and sustainable provision of regional ecosystem services and improve the actual benefits of service-demand groups or service-demand areas.

Keywords: ecosystem service; service-providing areas; service-connecting areas; service-demand areas; spatial characteristics; spatial relations; benefits

check for updates

Citation: Liu, Q.; Du, G.; Liu, H. A Quantitative Study on the Identification of Ecosystem Services: Providing and Connecting Areas and Their Impact on Ecosystem Service Assessment. *Sustainability* **2022**, *14*, 7904. https://doi.org/10.3390/su14137904

Academic Editors: Erfu Dai and Chunsheng Wu

Received: 1 May 2022
Accepted: 26 June 2022
Published: 29 June 2022

1. Introduction

It is very important to consider the spatial relations between service-providing areas and service-demand areas in the process of ecosystem service assessment. The main reason is that there may be spatial differences between the providing areas and the demand areas of ecosystem services, and the role of space media may lead to the level of service provision being weakened or strengthened. Therefore, ecosystem service assessment not only involves service-providing areas, but also involves the exploration of connecting areas between the providing areas and demand areas. This issue has been paid attention to by many scholars in the assessment of ecosystem services. These scholars argue that these questions are crucial to measuring the actual provision of ecosystem services [1–4]. Action 2 of the European Union's 2020 Biodiversity Strategy and Convention on Biological Diversity 2020 is directed at enhancing ecosystem services and strengthening effective delivery to service-demand areas in order to enhance demand area benefits [5]. On the one hand, the spatial relations between service-providing areas and service-demand areas should be clarified, and on the other hand, the impact of such spatial relations on ecosystem service assessment should be verified quantitatively.

Some scholars tend to use the term "ecosystem service flow" to explore the spatial relations between service-providing areas and demand areas, which refers to the service transmission path or space–time connectivity between service-providing and -benefiting areas [6,7]. A conceptualized service delivery approach based on the concept of "ecosystem service flow" was proposed by Silvestri and Kershaw et al. and has been used to assess the actual provision of ecosystem services [8–10], for example, the correlation between providing and benefiting zones of commodity trade such as timber, fish and agricultural products [11–13]. Such studies assess the service benefits of provision-oriented types by analyzing the conceptual characteristics of ecosystem service flows. In addition, some scholars classify ecosystem service types based on the spatial transfer characteristics of ecosystem service flows. For example, Costanza proposed five delivery types of ecosystem services: global non-adjacent, local adjacent, flow direction, in situ and user migration [14]. On this basis, Fisher et al. separated the benefit area from the demand area and proposed three delivery types of ecosystem services: isotopic, omnidirectional, and specific direction [15].

At present, only a few studies have carried out the spatial characterization and quantitative analysis of ecosystem service flows at the landscape scale, regional scale, continental scale, global scale, and cross-scale. For example, Fisher and Burkhard et al. studied the relations between providing and demand regions [2,16]. Palomo et al. quantitatively analyzed the benefit of the demand area [17]. Inspired by the research of Turner et al. [3], H.M. Serna-Chavez et al. constructed an analytical framework for the spatial relations between providing and benefiting areas, and quantified the importance of ecosystem service flow zones to ecosystem service provision [7]. Based on the research results of Costanza and Fisher et al., Ralf-Uwe Syrbe et al. divided ecosystem service-providing areas, -connecting areas and -benefiting areas, and explained the potential regional characteristics of each component. At the same time, the possibility of measuring and assessing each regional unit based on the landscape index has been shown [10]. The above studies mainly focus on single or several types of production services and regulation services, but there are no studies on the spatial relations between the providing areas, connecting areas and demand areas of ecosystem services at a municipal scale. Moreover, there are a lack of quantitative studies on the impact of service-providing areas and service-connecting areas on regional ecosystem service assessment.

Inspired by the research of Ralf-Uwe Syrbe and H.M. Serna-Chavez, this study takes Jinan, China, as the research area, and quantifies the providing areas, connecting areas and demand areas for ecosystem services within the city range of Jinan in view of the current ecological and environmental problems faced by Jinan, and analyzes the spatial relation characteristics of each component. On this basis, the Hellwig model is used to quantitatively analyze the impact of service-providing areas and service-connecting areas on regional overall ecosystem service assessment so as to guide the optimization direction to ensure the efficient and sustainable supply of regional ecosystem services and improve the benefits of service-demand groups and service-demand areas.

2. Theoretical Basis

2.1. Definition of Service-Providing, -Connecting, and -Demand Areas

(1) Service-providing areas

Referring to the study of Fisher et al. [15], 'the region where landscape services are generated or derived is called the landscape service providing area, which is determined by the ecosystem, population and physical characteristics of its site'. On this basis, the service-providing areas of the ecosystem services defined in this study are those regional units that obviously carry out ecosystem services, such as biologic community units, water body units, soil units, vegetation units, or units that affect the service process of ecosystem services, such as flood plains, watersheds, natural/semi-natural land cover units or natural ecological units, etc.

(2) Service-connecting areas

Referring to the definition of service-connecting areas by Syrbe et al. [10], service-connecting areas are defined as 'the interval space between non-adjacent distributed service providing areas and service demand areas, which is a spatial structural variable affecting the service process'. When the service-demand areas and service-providing areas are not in the same spatial location, the study on service-connecting areas will be triggered, that is, how ecosystem services benefit the service-demand group or the demand areas through the effect of the spatial medium. Therefore, the connecting areas between service-providing areas and service-demand areas need to be considered in a complete ecosystem service assessment process. In order to improve the actual benefit of service-demand areas, it is necessary to repair and improve the attribute characteristics of service-connecting area by artificial or natural means when studying the improvement of the ecosystem service provision level.

(3) Service-demand areas

Fisher et al. proposed that ecosystem conditions and processes become services only after they are actually used or consumed, and the service-demand area is an indispensable part of ecosystem service process analysis [15]. Therefore, ecosystem services assessment involves an analysis of the benefits of service-demand areas. The service-demand areas may be far away from the corresponding service-providing areas, and under the effect of spatial media, ecosystem services may be strengthened or weakened, which leads to the key question of ecosystem service assessment, namely, how does the demand group or the demand area actually benefit? All of these analyses are closely related to the spatial location of the service-demand areas.

2.2. Identification Principles of Service-Providing, -Connecting, and -Demand Areas

According to the definition of service-providing, -connecting and -demand areas, different ecosystem service types involve different ecosystem service processes, and different ecosystem service processes need to be supported by areas with different attribute characteristics. The identification results of service-providing, -connecting and -demand areas under different ecosystem service types in relevant studies are summarized in Table 1. Meanwhile, according to the potential area characteristics of service-providing, -connecting, and -demand areas summarized in Ralf-Uwe Syrbe's study [10], the identification principles of service-providing, -connecting and -demand areas are formulated as follows:

Table 1. The area units of relevant studies on the different attribute characteristics selected for SPA, SCA or SDA identification.

Service Type	SPA	SCA	SDA	Relevant Literatures
Air purification	Land-use unit complexes	-	-	Marks et al. (1992) [18]
Climate regulation	Natural units	-	-	Röder (2002) [19]
	Open spaces uphill around a city	Depth contours and slopes around a city	The city downhill	Syrbe (2012) [10]
Flood prevention	Watersheds	-	-	Nelson et al. (2009) [20]
	Flood-originating area		Built area within the floodplain	Syrbe (2012) [10]
	Natural units	-	-	Röder (2002) [19]
Water pollution prevention	River sections	-	-	Horn (1999) [21]
	Natural units	-	-	Röder (2002) [19]
	Surface water bodies	Water catchment	Housing or recreation area	Syrbe (2012) [10]
Water supply	Watersheds	-	-	Cowling et al. (2003) [22]
	Groundwater recharge areas	-	-	Hoctor et al. (2000) [23]
	Arable and wetland in a groundwater basin	Pollution risk area in that catchment	Built area, irrigated land in the basin	Syrbe (2012) [10]
Erosion prevention	Natural units	-	Natural units	Syrbe (2002) [24]
	Wood, hedges, groves around and between acre fields	Field edges	Acre fields	Syrbe (2012) [10]
Habitat supply	Watersheds	-	Watersheds	EPA (2011) [25]
	Biotopes; natural units	-	-	Bastian (1991) [26]
	Sub-habitats for foraging, hunting, and hibernating	Ecological networks	Nesting habitats	Syrbe (2012) [10]

Note: SPA stands for service-providing area, SCA stands for service-connecting area, and SDA stands for service-demand area.

(1) General principle of service-providing area identification

When there is a natural unit or regional unit with a known boundary that meets the demand of the service-providing area, the relevant properties of the associated natural unit or regional unit will be preferred for direct supply as a service area: (1) if the service provision is produced by the specific ecological system or population, it is suitable to select the corresponding ecological unit as a service-providing area; (2) if the service provision is based on a certain resource, it is appropriate to select the natural unit containing the resource as the service-providing area; (3) if the service-providing area is also the service-demand area, the service-providing area can be identified according to the principles of service-demand area identification.

When there are no regional units with known boundaries or related landscape types that can be directly used as service-providing areas, certain technical means and quantitative methods are used to quantitatively identify them based on the physical geographical conditions or spatial structure characteristics of the regional units involved in the service-providing process.

(2) General principle of service-connecting area identification

Service-connecting area identification involves the ascertainment of the range of service association, such as the catchment area related to surface runoff, the air diffusion area related to air movement, and the activity path related to animal and human activities, etc. Compared with service-providing area identification, service-connecting area identification is more complex, and it is often difficult to directly extract regional units or related natural units with known boundaries as service-connecting areas. Correlation spatial analysis tools or models are combined to extract service-connecting areas: (1) if the service-connecting areas are regional units relying on certain structural features, it is appropriate to extract regional units as service-connecting areas according to the structural features, such as surface-runoff-gathering catchment areas; (2) if the service-connecting area is generated based on the related physical process, it is appropriate to extract the associated regional unit according to the physical process as the service-connecting area, such as the cold air transmission range; (3) if the service-connecting area is related to the function of land patches, it is appropriate to select relevant land patches as service-connecting areas according to the function, such as the laying range of irrigation ditches and water pipes, etc.

(3) General principles of service-demand area identification

The principle of directness (1): these areas are hot spots of natural ecological and environmental problems, such as high-temperature spaces and high-pollution spaces, so these areas have service demand for climate regulation and air purification. The potential principle (2): these areas are more likely to be hit by natural disasters or experience a high risk to their ecological security, such as high rainfall or low-lying surface-runoff-collection areas which are prone to flood disaster, so these areas have a service demand for flood prevention; ecologically fragile and ecologically sensitive areas often face problems of soil erosion, water pollution and biodiversity decline, and so these areas have potential service demand for soil erosion prevention, pollution prevention and biodiversity protection. The principle of demand (3): the area where the demand group is located, or the demand area, has a great demand for ecosystem services, such as the main living and production space of human beings, specifically urban centralized construction areas, rural residential areas and farmland irrigation areas, which have a huge demand for water supply.

3. Methods

3.1. Identification Methods of Service-Providing, -Connecting, and -Demand Areas

Based on the above literature research results and general principles for the identification of service-providing, -connecting and -demand areas, combined with the actual situation of the research area, the specific principles and key points for the identification of service-providing, -connecting and -demand areas under different service types in this study were determined by the logical deduction method, as shown in Table 2. Meanwhile, data management and spatial analysis tools, binary suitability assessment tools, weighted suitability assessment tools, and hydrological analysis tools supported by the Arcgis 10.8 software platform that is developed by ESRI (Environmental Systems Research Institute, Inc., Redlands, CA, USA) in the United State were used to determine the identification methods of service-providing, -connecting and -demand areas. The details are shown in Table 2, which also shows the applicability of the following methods, that is, when the ecosystem service process and key factors discussed in the list are considered, the following methods can be used to identify the service-providing, -connecting and -demand areas.

Table 2. Specific identification principles, key points and methods of service-providing, -connecting and -demand areas.

Serial No.	Service Type	Composition	Identification Principles	Identification Key Points	Identification Methods
1	Air purification	SPA	Services are generated by specific ecosystems that provide services primarily through biogeochemical processes, regulating CO_2/O_2, O_3 and SO_x levels.	SPA is mainly aimed at areas with high forest coverage and high ambient air quality standards.	Using Arcgis 10.8 software, 11 ambient air functional zones of class I were directly extracted from the Jinan ambient air functional zoning.
		SCA	Air diffusion is involved.	SCA is mainly aimed at the range of fresh air transmission affected by wind direction and topography.	The prevailing wind direction in the study area was north. From north to south, the higher the altitude was, the more difficult the air diffusion was. The spatial scope of SCA was determined by spatial analysis with Arcgis 10.8 software.
		SDA	The principle of directness.	SDA is mainly aimed at areas where air pollutants accumulate.	By using Arcgis 10.8 software, the spatial interpolation method was used to extract the distribution areas with high PM 2.5 concentration.
2	Climate regulation	SPA	Services are generated by specific ecosystems and can effectively regulate regional temperatures.	SPA is mainly aimed at areas with high carbon density or a high net carbon sequestration rate or areas where water bodies are located	Arcgis 10.8 software was used to directly extract ambient air functional zones of class I rivers, lakes, reservoirs, inland beaches and marshes with known boundaries in Jinan city.
		SCA	Regional or global atmospheric circulation processes is involved.	SCA is mainly aimed at the transfer range of moist and cool air affected by three physical factors: wind direction, gravity and temperature difference.	Based on the analysis of the influence of wind direction, slope direction and temperature difference on air flow, the reclassification tool and spatial weighting overlay tool in Arcgis 10.8 software were used to determine the SCA space range.
		SDA	The principle of directness.	SDA is mainly aimed at areas with obvious heat island effects.	By using Arcgis 10.8 software, the regions with high mean annual temperature were extracted by inverse distance weight interpolation (IDW).
3	Flood prevention	SPA	The service-providing area is also the service-demand area, and the vegetation inside participates in the flood storage and detention process.	SPA is mainly aimed at the rainfall areas and low-lying catchment areas.	By using Arcgis 10.8 software, the kriging interpolation method was used to extract areas with high average annual rainfall and flow direction, and flow accumulation and watershed tools were used to extract the highest-grade catchment area.

Table 2. *Cont.*

Serial No.	Service Type	Composition	Identification Principles	Identification Key Points	Identification Methods
		SCA	This relates to the process of the timely, rapid and massive absorption of rainfall within the spatial collection range of surface runoff.	SCA is mainly aimed at the surface runoff flowing through the catchment area.	By using Arcgis 10.8 software, flow direction and flow accumulation, watershed tools were used to generate surface runoff and the corresponding catchment, and the catchment except for the highest-grade catchment was extracted.
		SDA	The principle of directness and potential.	SDA is mainly aimed at areas with heavy rainfall or low-lying land.	By using Arcgis 10.8 software, the kriging interpolation method was used to extract areas with high average annual rainfall, and flow direction, flow accumulation and watershed tools were used to extract the highest-grade catchment area.
4	Water pollution prevention	SPA	Services are generated by specific ecosystems that participate in processes such as the storage and recycling of a certain amount of organic and inorganic waste through dilution, assimilation and chemical recombination.	SPA is mainly aimed at the spatial scope of rivers, lakes, reservoirs and their affiliated wetlands, and the catchment areas associated with various pollution sources.	On the one hand, rivers, lakes, reservoirs and their affiliated wetlands (such as marshes, tidal flats, etc.) were directly extracted by Arcgis 10.8 software. On the other hand, the above catchments and pollution sources were analyzed by overlay tools, and the catchments associated with various pollution sources were extracted.
		SCA	This relates to the processes of interception, adsorption and the microbial decomposition of heterogeneous nutrients and compounds by plant roots and soil within a catchment area.	SCA is mainly aimed at the surface runoff flows through the spatial extent.	Based on the above catchment identification results, the corresponding catchment area of surface runoff was extracted.
		SDA	The principle of directness.	SDA is mainly aimed at various water bodies.	The Arcgis 10.8 software was used to extract various water bodies from "Water Environmental Function Zoning" in the 13th Five-Year Plan for the Ecological and Environmental Protection of Jinan city.
5	Water supply	SPA	Agricultural irrigation water source and urban and rural domestic water source supply services through participating in the hydrological cycle of water resource filtration, retention and storage.	SPA is mainly aimed at agricultural water source area, drinking water source area and groundwater catchment area.	The agricultural water functional areas and surface drinking water sources were extracted from the 13th Five-Year Plan for the Ecological and Environmental Protection of Jinan by using Arcgis 10.8 software, and the above catchment areas were added.

Table 2. *Cont.*

Serial No.	Service Type	Composition	Identification Principles	Identification Key Points	Identification Methods
		SCA	This relates to the physical process of transporting water resources to areas of demand.	SCA is mainly aimed at the space laying range and accessibility of its internal ditches, water delivery or water intake pipelines.	By using Arcgis 10.8 software, firstly, the above catchment areas were extracted. Secondly, the spatial laying scope of water supply pipeline facilities was identified based on the relevant information of regional infrastructure status. Thirdly, based on remote sensing data, the ditches used for irrigation were extracted directly.
		SDA	The principle of demand.	SDA is mainly aimed at areas of various types of water use	Using Arcgis 10.8 software and based on remote sensing data, irrigated land, paddy field, urban land, and village land were interpreted.
6	Soil erosion prevention	SPA	This relates to the service provided by vegetation cover and root systems within natural units through participating in soil stabilization, stormwater erosion, and the prevention of compaction and erosion of bare soil	SPA is mainly aimed at the catchment area where the area sensitive to soil erosion is located.	Based on the Arcgis 10.8 software platform, four evaluation indexes including rainfall erosivity, soil erodibility, slope and vegetation coverage were selected and weighted. A suitability evaluation method was adopted to comprehensively evaluate the sensitivity to regional soil erosion. Based on the evaluation results, areas that were highly sensitive to soil erosion were extracted and spatially superimposed with the above catchments. Finally, the catchment area where the area sensitive to soil erosion was located was extracted.
		SCA	This relates to the process in which the vegetation cover and the vegetation root system in the catchment block the surface runoff carrying sediment into the drainage system	SCA is mainly aimed at the surface runoff flows through the space between the catchment where the area sensitive to soil erosion is located and the water system	The catchment space associated with surface runoff was extracted according to the screening principle of surface runoff flowing through the area sensitive to soil erosion, and finally into rivers, reservoirs and natural lakes.
		SDA	The principle of directness and potential	SDA is mainly aimed at areas with a high risk of soil erosion or areas prone to soil erosion disasters	Based on the Arcgis 10.8 software platform, on the one hand, the areas that were highly sensitive to soil erosion were extracted; on the other hand, based on the above surface runoff extraction results, rivers, reservoirs and natural lakes fed by surface runoff flowing through areas that were highly sensitive to soil erosion were extracted.

Table 2. *Cont.*

Serial No.	Service Type	Composition	Identification Principles	Identification Key Points	Identification Methods
7	Habitat supply	SPA	Services are generated by specific ecosystems that support the life activities, evolution and reproduction processes of flora and fauna.	SPA is mainly aimed at living areas of flora, fauna and microorganisms.	The region group tool in Arcgis 10.8 was used to merge the forest land, grassland, wetland and natural water body that were spatially related to each other, and extract the large patches with an area of more than 10 km^2 after merging.
		SCA	This relates to the functions of natural units such as breeding, nesting, foraging, reproduction or migration.	SDA is mainly aimed at the ecological corridor or ecological steppingstone and other related land that can connect various ecological sources.	Based on the spatial weighted distance tool in the spatial analysis module of the ArcGIS 10.8 software platform, the space of minimum passage cost between SPA was taken as the result of SCA recognition, representing the possible movement trends, directions and range of animals in the space.
		SDA	The service-providing area is also the service-demand area,	SDA is mainly aimed at the living area of flora, fauna and microorganisms.	The region group tool in Arcgis 10.8 was used to merge the forest land, grassland, wetland and natural water bodies that were spatially related to each other and extract the large patches with an area of more than 10 km^2 after merging.

Note: SPA stands for service-providing area, SCA stands for service-connecting area, and SDA stands for service-demand area.

3.2. A Quantitative Method on the Impact of Service-Providing, and -Connecting Areas on Ecosystem Service Assessments

In this research, the Hellwig model [27] was used to quantify the impact of service-providing areas and service-connecting areas on ecosystem service assessment, and to find which component had the greatest impact on ecosystem service assessment results, that is, the greatest correlation with the effective provision of regional ecosystem services.

The Hellwig model was introduced to calculate the information carrying capacity h_k index of service-providing area (SPA) and service-connecting area (SCA), representing the relationship between the service-providing area (SPA) and the service-connecting area (SCA) and the service supply level of the regional ecosystem. The value range of h_k is between $[0, 1]$. The higher the value of h_k, the greater the correlation between the component and the service provision level of the regional ecosystem, and the more important it is for influencing the assessment results of regional ecosystem services. The specific calculation process and formula are as follows:

Step 1: In this study, we assumed that service-providing area (SPA) and service-connecting area (SCA) both affect the evaluation results of ecosystem services, and the formula calculation includes the information carrying capacity of the two explanatory variables of service-providing area (SPA) and service-connecting area (SCA).

Step 2: We calculated the information carrying capacity h_k of each explanatory variable. Four indexes were selected to calculate the information carrying capacity of service-providing area (SPA) and service-connecting area (SCA), including the service diversity index, service diversity participation rate, benefit area rate of service-demand area, and service benefit contribution rate. The specific calculation formula is shown in Formula (1):

$$h_k = \frac{r_k^2}{I_k} \tag{1}$$

In the formula, k represents the serial number of the information carrying capacity of the two explanatory variables of SPA or SCA; r_k represents the correlation coefficient between one of the explanatory variables of SPA or SCA and the provision of regional ecosystem services; and I_k represents the correlation coefficient between explanatory variables.

(1) The service diversity index comprehensively reflects the diversity of service types provided by service-providing areas and the diversity of service types associated with service-connecting areas within the region, and are recorded as *ID (SPA)* and *ID (SCA)*, respectively.

(2) The service diversity participation rate comprehensively reflects the contribution rate of the number of types of services undertaken by each regional unit of the service-providing area or service-connecting area to the number of types of ecosystem services provided by the overall regional ecological space, which are recorded as *IP (SPA)* and *IP (SCA)*, respectively.

The calculation method for the service diversity index and the service diversity participation rate refers to the calculation method for the species diversity index and species abundance participation index in Łopucki R's research [28]. The calculation formulas are shown in Formulas (2)–(5):

$$ID(SPA) = -\sum_{i=1}^{m} p_i \ln p_i \tag{2}$$

$$ID(SCA) = -\sum_{j=1}^{n} p_j \ln p_j \tag{3}$$

$$IP(SPA) = \frac{\sum_{i=1}^{m} DP(i)}{m \cdot TDP} \times 100\% \tag{4}$$

$$IP(SCA) = \frac{\sum_{j=1}^{n} DP(j)}{n \cdot TDP} \times 100\% \tag{5}$$

In this formula, p_i represents the ratio of the service types provided by the *i*-th service-providing area unit to the sum of the service types provided by each area unit; p_j represents the ratio of the service types associated with the *j*-th service-connecting area unit to the sum of the service types associated with each area unit; *DP(i)* represents the number of service types provided by service-providing area unit *i*; *DP(j)* represents the number of service types associated with service-connecting area unit *j*; *TDP* represents the type of service provided by the overall regional ecological space; *i* represents the serial number of each unit in the service-providing area; *j* represents the serial number of each unit in the service-connecting area; *m* represents the total number of units in the service-providing area; and *n* represents the total number of units in the service-connecting area.

(3) The benefit area rate of the service-demand area represents the proportion of the actual benefit area benefited by the service-demand area from the service-providing area (SPA) and the service-connecting area (SCA), which are recorded as *%Ben.pro(i)* and *%Ben.con(i)*, respectively.

(4) The service benefit contribution rate represents the contribution of the service-providing area and the service-connecting area to the total benefit area of the service-demand area, and are recorded as *%IPSP(SPA)* and *%IPSP(SCA)*, respectively. The calculation formulas are shown in Formulas (6)–(9):

$$\%Ben.pro(i) = \left(\frac{\sum_{i=1}^{n} area(b_p(i))}{\sum_{i=1}^{n} Area(SDA(i))} \right) \times 100\% \tag{6}$$

$$\%Ben.con(i) = \left(\frac{\sum_{i=1}^{n} area(b_c(i))}{\sum_{i=1}^{n} Area(SDA(i))} \right) \times 100\% \tag{7}$$

$$\%IPSP(SPA) = \left(\frac{\sum_{i=1}^{n} area(b_p(i))}{\sum_{i=1}^{n} Area(SBA(i))} \right) \times 100\% \tag{8}$$

$$\%IPSP(SCA) = \left(\frac{\sum_{i=1}^{n} area(b_c(i))}{\sum_{i=1}^{n} Area(SBA(i))} \right) \times 100\% \tag{9}$$

In this formula, *%Ben.pro(i)* represents the area proportion of SDA benefiting from SPA under the *i*-th service type; *%Ben.con(i)* represents the area proportion of SDA benefiting from SCA under the *i*-th service type; *Area (SDA(i))* represents the total area of the service-demand area under the *i*-th service type; *Area(SBA(i))* represents the total area of the service-benefiting area under the *i*-th service type; $area(b_p(i))$ represents the area of the service-demand area benefiting from the service providing area under the *i* type of service; $area(b_c(i))$ represents the area of the service-demand area benefiting from the service-connecting area under the *i*-th service type; *i* represents the *i*-th service type; *n* represents the number of service types, and *n* = 8 in the study scope.

Step 3: We standardized the h_k index. In order to facilitate the comparison of the h_k index values of different explanatory variables, the following formula was used to solve the problem of inconsistent indicator units:

$$S_{h_k} = \frac{h_k - h_{k\min}}{h_{k\max} - h_{k\min}} \times 100 \tag{10}$$

In this formula, S_{hk} represents the standardized value of h_k; $h_{k\min}$ represents the lowest value of h_k in the explanatory variable; and $h_{k\max}$ represents the highest value of h_k in the explanatory variable.

The standardized value range of h_k is between [0, 100]. A value of 100 indicates that the explanatory variable has a high correlation with the explained variable, that is, this component highly influences the results of the regional overall ecosystem services assessment.

4. Case Study

4.1. Overview of the Study Area

Jinan, the capital of Shandong province in China, is located in a mid-latitude area. The location of Jinan city in China is shown in Figure 1. The terrain is high in the south and low in the north. From south to north, it is hilly and mountainous, then occupies a piedmont plain, and then the Yellow River floodplain. Jinan has typical warm, temperate continental climate characteristics, with a cold winter and hot summer; the annual average temperature in the northern region is higher than that in the southern region, and the annual average rainfall in the northern region is less than that in the southern region. There are countless rivers within the city limits of Jinan, with the Yellow River, Xiaoqing River and Haihe River as the main streams forming three drainage basins, and the southern mountainous area is an important water conservation area. The types of soil and vegetation vary from south to north. Forest and grassland are mainly distributed in the mountainous and hilly areas in the south, and the cultivated land is mainly distributed in the piedmont plain and the northern plain.

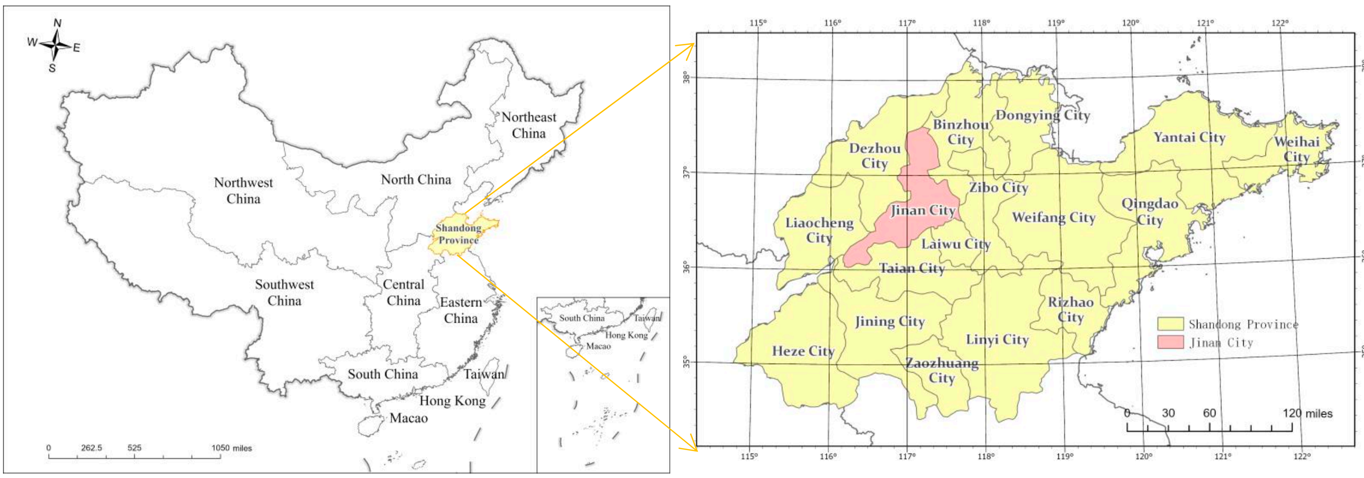


Figure 1. The location of Jinan city in China.

Affected by the conditions of topography, hydrology, climate, and human activity, Jinan is a typical city facing ecological and environmental problems such as haze pollution, urban heat island, water shortage, water pollution, urban water logging, soil erosion and biodiversity decline in the process of China's rapid urbanization, which leads to the demand for air purification and climate regulation services, hydrological regulation services (including water supply, water pollution prevention, and flood prevention), soil erosion prevention services, and habitat supply services.

4.2. Data Sources

According to the availability and accuracy of data, combined with the above theoretical basis and research methods, the data types used in the case study mainly include remote sensing data, atmospheric data, meteorological data and other maps and text data. Among them, the downloaded remote sensing data came from the Geospatial Data Cloud platform of the Computer Network Information Center of the Chinese Academy of Sciences, whose website is http://www.gscloud.cn (accessed on 15 June 2021). DEM data and land cover data from 2018 were mainly obtained from this platform. Atmospheric data were mainly collected in the form of PM 2.5 concentration data from www.pm25x.com (accessed on 1 August 2021). The website provides PM 2.5 concentration data from monitoring stations in major cities across the country. In this study, the annual average data of surface air quality monitoring stations from 30 major monitoring cities in Shandong province from the past five years were obtained, and the subsequent spatial interpolation method was used to intercept the spatial distribution data of air pollutant concentration in Jinan city. The meteorological data mainly included rainfall and temperature data, which were derived from the average daily precipitation and temperature datasets of 824 national reference and basic stations in China from the past five years. The accuracy and quality of these data are strictly controlled, and the accuracy is nearly 100% higher than others. The data of other pictures and texts came from various planning documents of Jinan, including the "Master Plan of Jinan City (2011–2020)", "The 13th Five Year Plan for Ecological and Environmental Protection of Jinan", and "The Red Line Plan for Ecological Protection of Shandong Province (2016–2020)". In addition, the "Jinan Statistical Bulletin of National Economic and Social Development", the "Jinan Statistical Yearbook", and published academic achievements have also published relevant data.

4.3. Results

4.3.1. Spatial Distribution Characteristics of Service-Providing, -Connecting and -Demand Areas

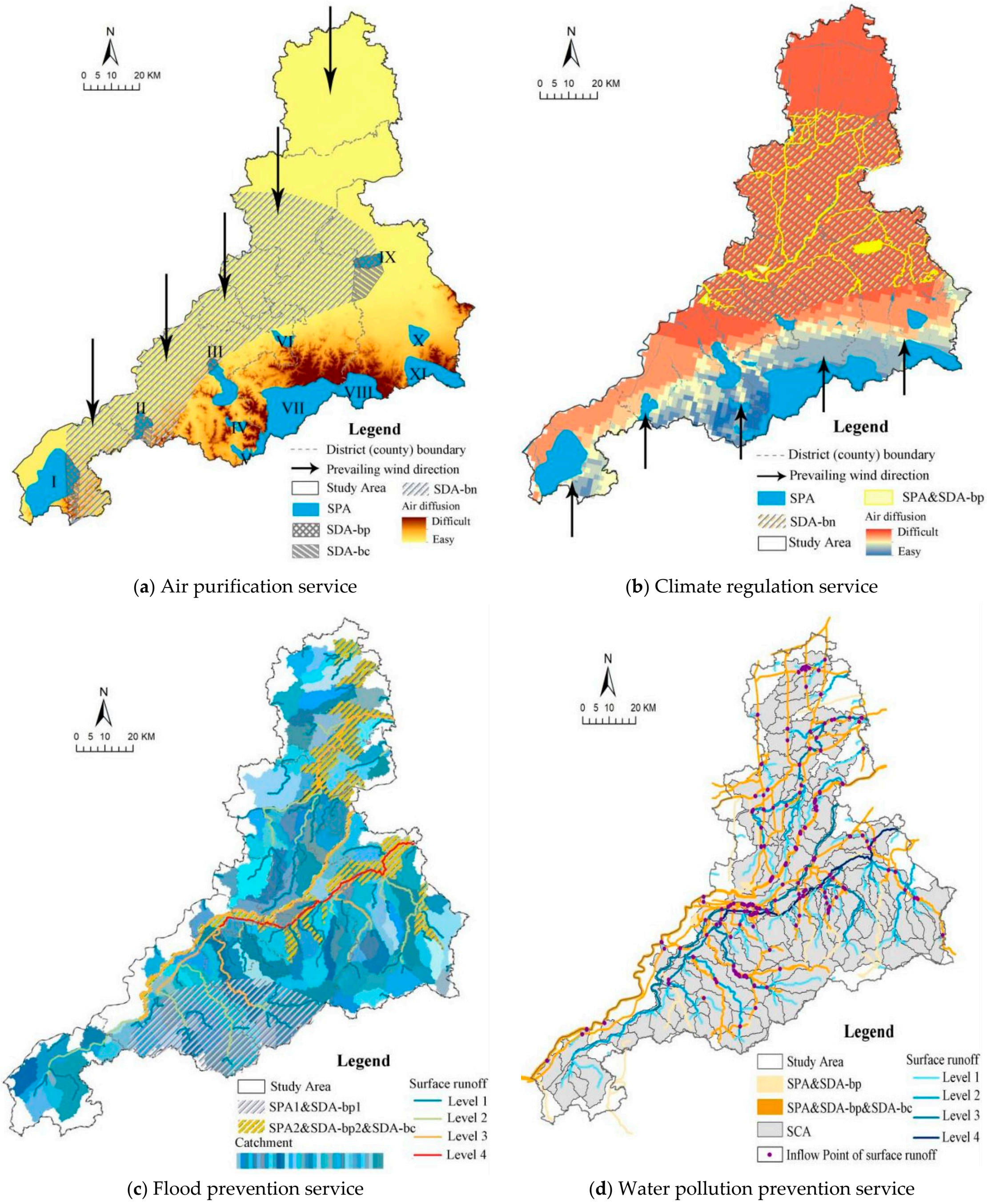
The identification results of service-providing, -connecting and -demand area under different service types is shown in Figure 2, with spatial distribution characteristics as follows:

(I) Air purification service

The results of the recognition are shown in Figure 2a. The service-providing areas (SPAs) were mainly related to the ambient air functional zones of class I, which were discontinuously distributed in the southern mountainous area; service-connecting areas (SCAs) were mainly related to wind direction and elevation factors. Since the prevailing wind direction in the studied area was a northerly wind, the area with lower elevation was the area where air diffusion could be more easily reached, and the area with higher elevation was the area that air diffusion struggled to reach. Therefore, the corresponding service-connecting area was a low-elevation area, which was mainly located in the piedmont plain. The concentration range of PM 2.5 in Jinan city is 60.45~80.65 $\mu g/m^3$. The natural break point method was used to divide the PM 2.5 concentration range into five levels, and the highest level of PM 2.5 concentration (greater than 77.56 $\mu g/m^3$) was extracted as the identification result of the air purification service demand area in Jinan. This area was mainly distributed in areas of the central plain in front of the mountain. There were two main spatial relations as follows:

Case 1: The service-providing areas (SPAs) were located inside the service-demand areas (SDAs), which mainly included service-demand areas that overlapped with the service-providing areas II and IX, and part of the service-providing areas I and III. These areas benefitted from the air purification service provided by the SPA, which was recorded as SDA-b_p, accounting for 3.45% of the total area of the SDA;

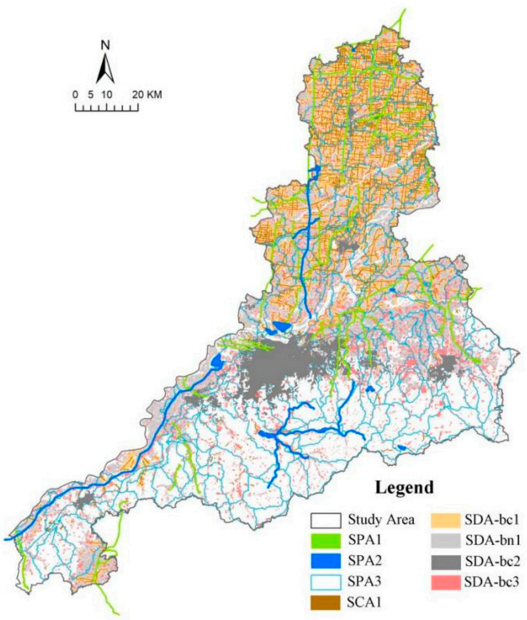
Case 2: The service-providing areas (SPAs) were located outside of the service-demand areas (SDAs) and on the same side of the direction of SPA service delivery at a low altitude, that is, within the scope of service delivery in the service-connecting area. For example, the part adjacent to the south side of service-providing areas I, II and IX was marked as SDA-b_c, accounting for 3.41% of the total area of SDA. However, the areas located on the same side of the SPA service delivery direction, but at a higher altitude, and the areas on the other side of the SPA service delivery direction did not benefit from the air purification service, which was recorded as SDA-b_n, such as when the service-demand area was located to the east of service-providing area I, the north of service-providing area III, the north of service-providing area VI, and the north and west of service-providing area IX. Additionally, SDA was isolated from service-providing zones IV, V, VII, VIII, X and XI, and did not benefit from their air purification services.



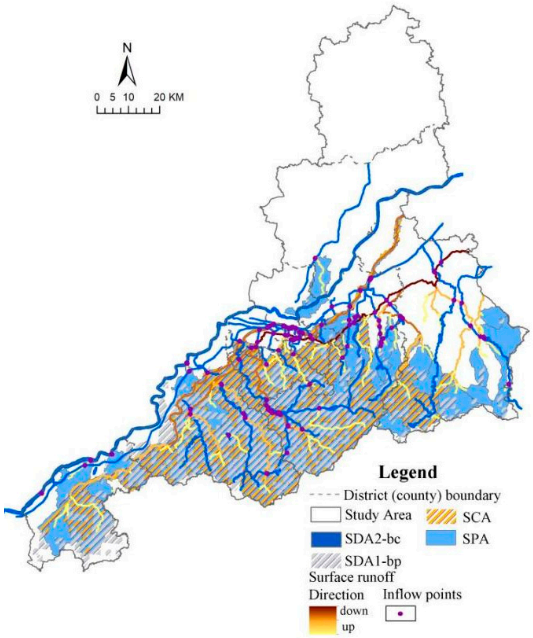
(**a**) Air purification service (**b**) Climate regulation service

(**c**) Flood prevention service (**d**) Water pollution prevention service

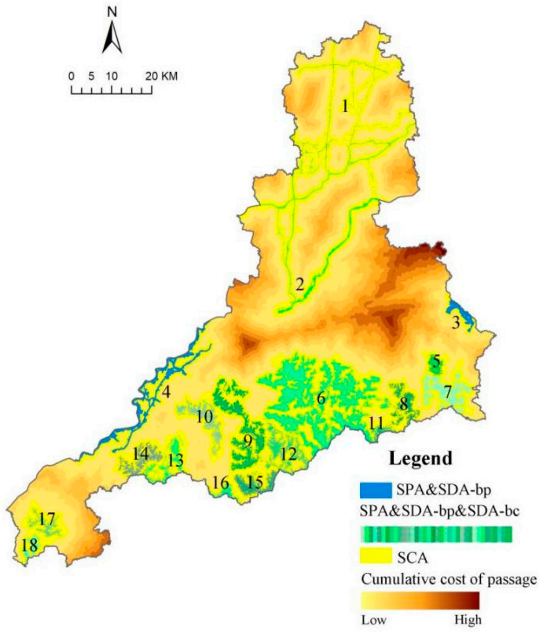
Figure 2. *Cont.*



(**e**) Water supply service



(**f**) Soil erosion prevention service



(**g**) Habitat supply service

Figure 2. The spatial distribution of service-providing, -connecting and -demand areas of different ecological service types in Jinan City.

(II) Climate regulation service

The result of the recognition is shown in Figure 2b. The service-providing areas (SPAs) mainly comprised areas with ambient air functional zones of class I rivers, lakes, reservoir water surfaces, inland tidal flats and marsh wetlands. These were distributed in a patchy pattern in the south and distributed in a network in the middle and north. The service-connecting areas (SCAs) were mainly related to the degree of difficulty of cold air diffusion in space. The cold air spreads from the mountainous areas in the south to the plains in the north. With the expansion of the spatial diffusion distance and scope, its diffusion capacity gradually decreases. As the slope gradually slows down, the temperature difference is further reduced, and the wind speed in the plain area is further reduced, meaning that the cold air diffusion tends to be static. Therefore, the corresponding service-connecting area was an area that was easily reached by cold air diffusion, mainly located in the southern mountainous and hilly area. The results of Jinan's urban temperature interpolation were divided into five levels. The area with the highest temperature level was extracted as Jinan's climate regulation service-demand area, that is, the "heat island area". This area was mainly distributed in the middle of the study area. There were two main spatial relations as follows:

Case 1: The service-providing areas (SPAs) were located inside the service-demand areas (SDAs), and the SPAs involved were mainly part of the water areas in the central area, and at the same time, located in areas where cold air diffusion was difficult. Parts of the SDAs overlapped with the SPA benefits from the climate regulation service provided by the service-providing area. This type of SDA was recorded as SDA-b_p, accounting for 3.64% of the total area of the SDAs;

Case 2: The service-providing areas (SPAs) were located outside of the service-demand areas (SDAs), and the SPAs involved were located in areas where cold air was more easily diffused and the maximum range was to the boundary of an area, where cold air struggled to diffuse. Although SDAs were located on the same side of the service delivery direction, they did not benefit from the climate regulation services provided by this type of SPA, because they were within the range of services that were not easily accessible. This type of SDA was recorded as SDA-b_n.

(III) Flood prevention service

The result of the recognition is shown in Figure 2c. The service-providing areas (SPAs) were also service demand areas, mainly including water catchment areas with higher rainfall (recorded as SPA1) and low-lying water catchment areas (recorded as SPA2), which were distributed on a single piece of land in the southern mountainous area and in the central and eastern regions. The low-lying terrain was distributed in a patch pattern; the service-connecting area (SCA) was the surface runoff area flowing through the water collection space, which was distributed in a large area in the middle and north. There were two main spatial relations as follows:

Case 1: The service-demand area (SDA) directly benefited from the service provision of the service-providing area (SPA). For example, SPA1 was located in the southern region. This area provided services in the form of timely, fast and large amounts of rainfall and rainwater; SPA2 was located in the northern and central regions. This area provided service in the form of surface runoff that was reduced, stored and collected to a great extent. Both service-demand areas received the benefit, and were recorded as SDA-b_{p1} and SDA-b_{p2};

Case 2: The service-demand area (SDA) indirectly benefited from the service provision of the service-connecting area (SCA). The service-connecting area was related to the water collection process. The water collection process was affected by gravity factors. The water flowed from a high place to a low place, and the low-level water system merged into the high-level water system. In this process, the spatial medium of the service-connecting area reduced the total amount of rainwater reaching the service-demand area. The northern and central SDA benefited from the water catchment reduction service provided by the service-connecting area, which was recorded as SDA-b_c.

(IV) Water pollution prevention service

The result of the recognition is shown in Figure 2d. The service-providing area (SPA) mainly consisted of rivers, lakes, reservoirs and their affiliated wetlands. The service-connecting area (SCA) was a catchment area associated with various pollution sources. Before the pollutants carried by surface runoff in the catchment area were absorbed into various water-use functional areas, the total amount of pollutants into various water-use functional areas was effectively reduced through the adsorption of vegetation roots or soil in the space through which they flowed. The service-demand area included the surface drinking water source protection area and the non-drinking surface water environmental function area. The surface drinking water source protection area included the source protection area and drinking water source area, and the non-drinking surface water environmental functional area included the agricultural water functional area, industrial water functional area, landscape water functional area, and fishery water functional area. There were two main spatial relations as follows:

Case 1: The service-demand area (SDA) directly benefited from the service provision of the service-providing area (SPA). That is, the areas where rivers, lakes, reservoirs and their affiliated wetlands were located were not only functional areas for surface water use, but also relied on the self-purification function of their own water bodies to provide water pollution prevention services. The benefit of the service demand area was recorded as SDA-b_p;

Case 2: The service-demand area (SDA) indirectly benefited from the service provision of the service-connecting area (SCA). Plant roots, soil or microorganisms in the service-connecting areas intercepted, adsorbed and decomposed heterogeneous nutrients and compounds in the process of collecting rainwater runoff, so as to prevent pollutants from flowing directly into various surface water functional areas along with rainwater runoff. The service-demand area connected to stormwater runoff within the SCA and was located below the point of inflow of surface runoff, and was recorded as SDA-b_c.

(V) Water supply service

The result of the recognition is shown in Figure 2e. Service-providing areas mainly included agricultural water sources, urban water sources and village water sources. Different service-providing areas were related to different service-connecting areas and service-demand areas. The main spatial distribution characteristics were as follows.

For the agricultural water source area (SPA1), the ditches were the service-connecting areas (SCA1) which served paddy fields and irrigated land in different areas. The service scope of the ditch was the paddy field and the irrigated land connected to the ditch. At this time, the area composed of the paddy field and irrigated land was the service-demand area in this situation. Most of the ditches run through paddy fields or irrigated land plots, so the service-providing area carries water into the service-demand area. In this case, the service-providing area (SPA1) was located outside the service-demand area (SDA). All paddy fields or irrigated land connected to the SPA and within the service scope of the ditches were recorded as SDA-b_{c1}. However, the paddy fields or irrigated land that were not connected with the ditch failed to realize water diversion irrigation through the ditch, and did not receive benefits, and were recorded as SDA-b_{n1}.

For the urban water source area (SPA2), the urban built-up area was the service-demand area, and the pipeline laying space was the service-connecting area (SCA2). The area where the town was located was spaced apart from the location of each water source, so the service-providing area (SPA2) was located outside of the service-demand area (SDA). Water was supplied to cities and towns through a water pipeline network, and the reach of the service was determined by the laying distance and direction of the pipe network. However, in this study, the pipeline laying data were not obtained, so the specific location of the service-connecting area could not be expressed spatially. According to the statistics of Jinan city, the current towns in Jinan city have achieved a 100% water supply rate. Therefore, this part of the service-demand area receives the water supply from the service-providing area recorded as SDA-b_{c2}.

For the village water sources (SPA3), the villages were the main service-demand areas. The catchment area where the villages were located replenished shallow groundwater, and each village obtained groundwater resources by pumping groundwater. In this case, the service-demand area (SDA) was located inside the service-providing area (SPA3). In addition, the internal pumping pipes of villages and towns were service-connecting areas (SCA3). However, in this study, the pumping pipeline data were not obtained, so the specific location of the service-connecting area could not be expressed spatially. According to the statistics of Jinan city, the current villages in Jinan city have achieved a 100% water supply rate. Therefore, this part of the service-demand area received the water supply from the service-providing area, which was recorded as SDA-b_{c3}.

(VI) Soil erosion prevention service

The result of the recognition is shown in Figure 2f. Based on the four factors of rainfall erosivity, slope sensitivity, soil erodibility and vegetation coverage sensitivity, the zoning evaluation of soil erosion sensitivity was carried out. Additionally, superimposed with the catchment space, the catchment areas which were highly sensitive to soil erosion were extracted as the service-providing areas (SPAs) and were mainly located in the catchment area of the southern mountainous hills; the service-connecting area (SCA) was mainly the flow space of surface runoff passing through the area highly sensitive to soil erosion before it entered the water system, and was mainly centered around the spatial area surrounding the surface runoff in the southern mountainous area; the service demand area included the area highly sensitive to soil erosion (SDA1) and the water system with surface runoff flowing through the area highly sensitive to soil erosion flowed into (SDA2). There were two main spatial relations, as follows:

Case 1: The service-demand area (SDA1) directly benefited from the service-providing area (SPA). The area highly sensitive to soil erosion was SDA1, which was located in the SPA catchment area. SDA1 benefited from the services of soil and water conservation and soil erosion resistance provided by the vegetation roots in SPA, which was recorded as SDA1-b_p;

Case 2: The service-demand area (SDA2) indirectly benefited from the service-connecting area (SCA). The SCA service scope started from the boundary of the catchment where the area that was highly sensitive to soil erosion was located and ended at the runoff entry point of the water body, during which the rainwater runoff flowed through the catchment space. The service-demand area (SDA2), in this case, was the water system that the surface runoff flowing through the area highly sensitive to soil erosion flowed into. It benefited from the effect of the service-connecting area to intercept sediment and reduce the sediment flowing into the water body with the surface runoff, and was recorded as SDA2-b_c.

(VII) Habitat supply service

The result of the recognition is shown in Figure 2g. The service-providing area (SPA) was composed of different nature reserves, large forest parks, natural scenic spots, large water bodies, and other forest and grassland patches, including 18 large ecological patches. It was distributed irregularly in the mountainous and hilly areas of the south and had a linear network distribution in the northern plains; the service-connecting area (SCA) was mainly identified based on the cumulative cost of living organisms moving between different ecological patches, and the space with lower cumulative cost was the service-connecting area. Animals and plants in the area mainly lived in large ecological patches. Therefore, the service-providing area itself was also a service-demand area. There were two main spatial relations as follows:

Case 1: The service-demand area (SDA) directly benefited from the service-providing area (SPA). In this case, ecological patches were served by providing nests, water, food, or nutrients for the population of plants and animals living within each patch, which was recorded as SDA-b_p;

Case 2: The service-demand area (SDA) indirectly benefited from the service-connecting area (SCA). This mainly involved the behavior of animals foraging and migration among different ecological patches. The adjacent ecological patches were connected to each other in the same low cumulative cost space, such as the combination of ecological patches 17 and 18, the combination of ecological patches 4, 13 and 14, the combination of ecological patches 6, 8, 9, 10, 11, 12, 15 and 16, the combination of ecological patches 5 and 7, and the combination of ecological patches 1 and 2. The service-connecting area provided services for the animal communication space between adjacent ecological patches, and was recorded as SDA-b_c. However, the species in ecological patch 3 struggled to migrate to other ecological patches through space with high cumulative cost, so they did not benefit from the service provision in the service-connecting area.

4.3.2. The Impact of Service-Providing and -Connecting Areas on Ecosystem Service Assessment

The quantitative analysis results are shown in Table 3. The S_{hk} index of the service-providing area (SPA) is 99.99, and the S_{hk} index of the service-connecting area (SCA) is 99.92. The calculation results can fully verify the following results: SPA and SCA are related to the regional overall ecosystem service provision, and they jointly determine the regional overall ecosystem service provision level. By comparison, the service-connecting area has the greatest correlation with the level of ecosystem service provision, and its contribution to the effective provision of regional ecosystem service is the largest.

Table 3. Calculation results of correlation verification.

Related Index	Related Index Value of SPA	Related Index Value of SCA	Related Index Value of Overall Area
Service diversity index	7.79	5.91	11.21
Service diversity participation rate (%)	39.86	34.50	68.30
Benefit area rate of service demand area (%)	65.91	54.89	94.79
Service benefit contribution rate (%)	61.86	38.14	100.00
S_{hk} index	99.99	99.92	-

5. Discussion

(1) Classification of spatial relations among service-providing, -connecting and -demand areas

The above-mentioned seven different service types can be further summarized into two types, namely, the provision-oriented type and the prevention-oriented type. Among them, the provision-oriented type mainly includes the air purification service, climate regulation service, water supply service, and habitat service; the prevention-oriented type mainly includes the flood prevention service, water pollution prevention service, and soil erosion prevention service. The main reasons for classifying service types in this way are as follows.

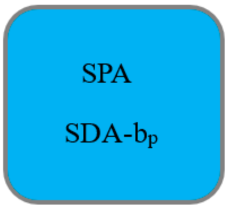
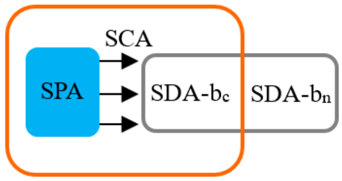
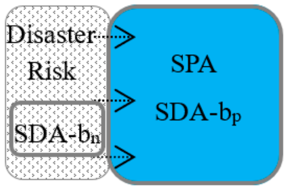
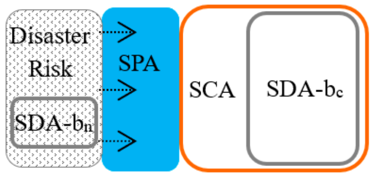
For the provision-oriented type, first of all, service-providing areas provide certain resources, materials or information to satisfy the welfare of human society. This kind of service has the property of spatial transitivity, and so it also belongs to the transitive type. Secondly, when the service-providing area is separated from the service-demand area and the service transmission function of the service-connecting area is not strengthened by artificial or natural means, the service-connecting area will weaken the level of service provision.

For the prevention-oriented type, first of all, the service-providing areas provide the service by reducing certain disaster risks in order to guarantee the welfare of human society. This kind of service does not have the property of spatial transitivity, and so it belongs to the local type. Secondly, when the service-providing area is separated from the service-demand area, the service-connecting area may further reduce disaster risk.

The spatial location relations of service-providing, -connecting and -demand areas and the corresponding benefit situation of service-demand areas under different service types are summarized in Table 4:

The blue square represents the service-providing area (SPA), the yellow circle represents the service-connecting area (SCA), and the gray circle represents the service-demand area (SDA). SDA is further refined into SDA-b_p, SDA-b_c, and SDA-b_n. SDA-b_p indicates that the service-demand area directly receives the service provision from the service-providing area; SDA-b_c indicates that the service-demand area benefits from the service-connecting area; and SDA-b_n indicates that the service-demand area does not benefit.

Table 4. Classification results of spatial relations among service-providing, -connecting and -demand areas.

Service Type	Services in the Case	SDA Benefits from the SPA	SDA Benefits from the SCA
Provision-oriented type (transitive type)	Air purification service; Climate regulation service; Water supply service; Habitat service.		
Prevention-oriented type (local type)	Flood prevention service; Water pollution prevention service; Soil erosion prevention service.		

(2) The key to the improvement of the overall regional ecosystem service provision level

Based on the calculation results of the impact of service-providing areas and service-connecting areas on ecosystem service assessment, it can be seen that optimizing service-providing areas and service-connecting areas at the same time will help to enhance the overall regional ecosystem service provision level. For the provision-oriented type, on the one hand, the provision level of service-providing areas should be improved; on the other hand, the weakening effect of service-connecting areas on service provisions reaching service-demand areas should be reduced. For the prevention-oriented type, on the one hand, the provision level of service-providing areas should be improved; on the other hand, the weakening effect of service-related areas on disaster or risk reaching service-demand areas should be strengthened.

(1) Developing zoning optimization strategies based on the theory of natural geographical differentiation

According to the theory of natural geographical differentiation, non-zonal factors such as topography, geomorphology, vegetation and hydrology cause the differences in unit attributes in different regions. An optimization study of service-providing areas and service-connecting areas should consider the differences in unit attributes and service levels in different regions on the basis of fully recognizing the differences in the spatial distribution of non-zonal elements. The regional units with similar attributes and service levels are divided into the same region to ensure that there are obvious differences in attribute characteristics and service levels between different regions, so as to take targeted optimization measures to enhance the overall regional ecological service provision level.

(2) Identifying and optimizing the main limiting factors of regional service performance based on the short-board effect

The short-board effect is also known as the barrel effect, and dictates that the maximum capacity of the barrel is determined by the shortest board in the barrel. According to this theory, problems can be solved in the most effective way by grasping the weak links existing in problems and finding out the key to solving these problems. Therefore, according to the short-board effect, the main limiting factors causing low service performance in service-providing areas and service-connecting areas are identified, and corresponding improvement methods and strategies are formulated according to the attribute categories of the limiting factors. The process of overcoming the main limiting factors of service-providing areas and service-connecting areas is the key to improving the regional ecosystem service level. Therefore, in future studies, polynomial regression analysis [29,30] will be used to explore the effect of attributes and characteristics of different regional units on ecosystem services, and a diagnostic model of obstacle degree will be constructed to quantitatively identify the main obstacles to the ecosystem service provision of different regional units.

(3) The scales of the providing, connecting and demanding areas of ecosystem services

The identification of ecosystem service-providing, -connecting and -demand areas involves the exploration of spatial scale, and the spatial scale of the providing, connecting and demand areas of ecosystem service under the same service type is different. The main reason for this is that the scales involved in ecosystem service processes sometimes cross scales. For example, in relevant studies, the scale of climate regulation service-providing areas is regional or local, but the biophysical processes such as the evaporation and cooling of climate regulation are cross-scale, so the service-connecting areas are global or without boundaries. Therefore, it is not easy to define the scope of service-benefiting areas [7,31]. Clarifying the different spatial scales of providing, connecting and demand areas of different ecosystem service types is a key and difficult problem to be solved by the current academic community.

The scale of this study was limited to the municipal scale. There are few studies on the identification of ecosystem service-providing, -connecting and -demand areas at the municipal scale. Based on the above analysis, it can be seen that there are cross-scale phenomena in the providing, connecting and demand areas affecting the identification of ecosystem services at the municipal scale. Cross-scale research requires a large amount of data and technical support, which goes beyond the scope of this paper. Therefore, this paper focuses on the spatial relations of service- providing, -connecting and -demand areas within the municipal scale of the study area and their impact on the level of ecosystem service provision, that is, the actual level with which service-demand areas within the municipal scope benefit from service-providing areas and service-connecting areas. This study has certain significance for recognizing the attribute differences of spatial structure units related to ecosystem services and formulating optimization measures to improve the level of ecosystem service provision within the region at the municipal scale.

6. Conclusions

Service-providing areas and service-connecting areas are key units that affect the level of regional ecosystem service provision. The assessment of regional ecosystem service provision level is inseparable from the identification of service-providing areas and service-connecting areas, and the study of their attribute characteristics and spatial relations. For the provision-oriented type, when the spatial location relations between service-providing areas and service-demand areas overlap, the service-demand area directly benefits the service-providing area. When the spatial location relations between service-providing area and service-demand area are separate, the service-connecting area may play a role in guaranteeing service provision level. For the prevention-oriented type, when the spatial location relations between service-providing area and service-demand area overlap, the service-demand area directly benefits from the service-providing area; when the spatial location relations between service-providing area and service-demand area are separate, the service-connecting area may play a role in reducing disaster risk and enhancing service provision level. In the future, service-providing areas and service-connecting areas should be differentiated when developing strategies to optimize and improve the level of regional ecosystem service provision. Different optimization measures should be formulated according to the differences in unit attributes and service barriers in different areas. The results provide guidance for the optimization of ecosystem services to ensure the efficient and sustainable provision of regional ecosystem services and to improve the actual benefits of service-demand groups and service-demand areas.

Author Contributions: Q.L. conceptualized and designed the research, collected and cleaned all the data, analyzed the results, and completed the calculation and original draft; G.D. supervised the research and acquired the funding; H.L. designed the methodology, validated the results and reviewed the manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Natural Science Foundation of China for Youth (40801059).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available from the authors on request.

Acknowledgments: We thank the reviewers and editors for their help in improving this manuscript. The contents of this paper are solely the responsibility of the authors and do not represent the official views of the institutes and funding agencies.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Reyers, B.; O'Farrell, P.; Schutyser, F.; Bidoglio, G.; Dhar, U.; Gundimeda, H.; Paracchini, M.L.; Gomez Prieto, O. Measuring biophysical quantities and the use of indicators. In *The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations*; Kumar, P., Ed.; Earthscan: London, UK, 2010; pp. 113–148.
2. Fisher, B.; Turner, R.K.; Burgess, N.D.; Swetnam, R.D.; Green, J.; Green, R.E.; Kajembe, G.; Kulindwa, K.; Lewis, S.L.; Marchant, R.; et al. Measuring, modeling and mapping ecosystem services in the Eastern Arc Mountains of Tanzania. *Prog. Phys. Geog.* **2011**, *35*, 595–611. [CrossRef]
3. Turner, W.R.; Brandon, K.; Brooks, T.M.; Gascon, C.; Gibbs, H.K.; Lawrence, K.S.; Mittermeier, R.A.; Selig, E.R. Global biodiversity conservation and the alleviation of poverty. *Bioscience* **2012**, *62*, 85–92. [CrossRef]
4. Haines-Young, R.; Potschin, M.; Kienast, F. Indicators of ecosystem service potential at European scales: Mapping marginal changes and trade-offs. *Ecol. Indic.* **2012**, *21*, 39–53. [CrossRef]
5. Perrings, C.; Naeem, S.; Ahrestani, F.; Bunker, D.E.; Burkill, P.; Canziani, G.; Elmqvist, T.; Ferrati, R.; Fuhrman, J.A.; Jaksic, F.; et al. Ecosystem services for 2020. *Science* **2010**, *330*, 323–324.
6. Bagstad, K.J.; Johnson, G.W.; Voigt, B.; Villa, F. Spatial dynamics of ecosystem service flow: A comprehensive approach to quantifying actual services. *Ecosyst. Serv.* **2013**, *4*, 117–125. [CrossRef]
7. Serna-Chavez, H.M.; Schulp, C.J.E.; van Bodegom, P.M.; Bouten, W.; Verburg, P.H.; David, M.D. A quantitative framework for assessing spatial flows of ecosystem services. *Ecol. Indic.* **2014**, *39*, 24–33. [CrossRef]
8. Silvestri, S.; Kershaw, F. (Eds.) *Framing the Flow: Innovative Approaches to Understand, Protect and Value Ecosystem Services across Linked Habitats*; UNEP World Conservation Monitoring Centre: Cambridge, UK, 2010.
9. Bastian, O.; Grunewald, K.; Syrbe, R.-U. Space and time aspects of ecosystem services, using the example of the EU Water Framework Directive. *Int. J. Biodivers. Sci. Ecosyst. Serv. Manag.* **2012**, *8*, 5–16. [CrossRef]
10. Syrbe, R.-U.; Walz, U. Spatial indicators for the assessment of ecosystem services: Providing, benefiting and connecting areas and landscape metrics. *Ecol. Indic.* **2012**, *21*, 80–88. [CrossRef]
11. Hoekstra, A.; Hung, P. Globalisation of water resources: International virtual water flows in relation to crop trade. *Glob. Environ. Change* **2005**, *15*, 45–56. [CrossRef]
12. Deutsch, L.; Graslund, S.; Folke, C.; Troell, M.; Huitric, M.; Kautsky, N.; Lebel, L. Feeding aquaculture growth through globalization: Exploitation of marine ecosystems for fishmeal. *Glob. Environ. Chang.* **2007**, *17*, 238–249. [CrossRef]
13. Kastner, T.; Erb, K.-H.; Nonhebel, S. International wood trade and forest change: A global analysis. *Glob. Environ. Chang.* **2011**, *21*, 947–956. [CrossRef]
14. Costanza, R. Ecosystem Services: Multiple Classification Systems are Needed. *Biol. Conserv.* **2008**, *141*, 350–352. [CrossRef]
15. Fisher, B.; Turner, R.K.; Morling, P. Defining and Classifying Ecosystem Services for Decision Making. *Ecol. Econ.* **2009**, *68*, 643–653. [CrossRef]
16. Burkhard, B.; Kroll, F.; Nedkov, S.; Mueller, F. Mapping ecosystem service supply, demand and budgets. *Ecol. Indic.* **2012**, *21*, 17–29. [CrossRef]
17. Palomo, I.; Martín-López, B.; Potschin, M.; Haines-Young, R.; Montes, C. National Parks, buffer zones and surrounding lands: Mapping ecosystem service flows. *Ecosyst. Serv.* **2012**, *4*, 104–116. [CrossRef]
18. Marks, R.; Müller, M.J.; Leser, H. *Anleitung zur Bewertung des Leistungsvermögens des Landschaftshaushaltes*; Zentralausschuß für Deutsche Landeskunde, Selbstverlag: Trier, Germany, 1992.
19. Röder, M. *Mittlere jährliche Gebietsabflusshöhe, Bestimmung von Landschaftsfunktionen und Naturraumpotentialen: Grundlagen, Methoden und exemplarische Ergebnisse, Grundwasserschutzfunktion, Abflussbereitschaft und Regulationsfunklion, Grundwasserneubildung*; Forschungen zur deutschen Landeskunde: Flensburg, Germany, 2002.

20. Nelson, E.J.; Mendoza, G.; Regetz, J.; Polasky, S.; Tallis, H.; Cameron, D.R.; Chan, K.M.A.; Daily, G.C.; Goldstein, J.; Kareiva, P.M.; et al. Modeling Multiple Ecosystem Services, Biodiversity Conservation, Commodity Production, and Tradeoffs at Landscape Scales. *Front. Ecol. Environ.* **2009**, *7*, 4–11. [CrossRef]
21. Horn, W. *Selbstreinigungsvermögen von Gewässern*; Spektrum: Heidelberg, Germany, 1999; pp. 263–266.
22. Cowling, R.M.; Pressey, R.L.; Sims-Castley, R.; Le Roux, A.; Baard, E.; Burgers, C.J.; Palmer, G. The Expert or the Algorithm? Comparison of Priority Conservation Areas in the Cape Floristic Region Identified by Park Managers and Reserve Selection Software. *Biol. Conserv.* **2003**, *112*, 147–167. [CrossRef]
23. Hoctor, T.S.; Carr, M.H.; Zwick, P.D. Identifying a Linked Reserve System Using a Regional Landscape Approach: The Florida Ecological Network. *Biol. Conserv.* **2000**, *14*, 984–1000. [CrossRef]
24. Syrbe, R.-U. *Biotisches Ertragspotential, Widerstandfähigkeit gegen Wassererosion, Erholungspotential (landschaftlicher Erholungswert)*; Forschungen zur deutschen Landeskunde: Flensburg, Germany, 2002.
25. EPA. *Frequent Questions*; EPA: Washington, DC, USA, 2011.
26. Bastian, O. *Zur ökologischen Bewertung von Habitationsinseln*; Beiträge der Martin-Luther-Universität: Wittenberg, Germany, 1991; pp. 219–224.
27. Hellwig, Z. *Toward a System of Quantitative Indicators of Components of Human Resources Development*; UNESCO: Paris, France, 1968.
28. Łopucki, R.; Kiersztyn, A. Urban Green space conservation and management based on biodiversity of terrestrial fauna-a decision support tool. *Urban For. Urban Green.* **2015**, *14*, 508–518. [CrossRef]
29. Qian, X.; Lee, S.; Soto, A.; Chen, G. Regression Model to Predict the Higher Heating Value of Poultry Waste from Proximate Analysis. *Resources* **2018**, *7*, 39. [CrossRef]
30. Yang, L.-Q.; Levine, E.L.; Smith, M.A.; Ispas, D.; Rossi, M.E. Person-environment fit or person plus environment: A meta-analysis of studies using polynomial regression analysis. *Hum. Resour. Manag. J.* **2008**, *18*, 311–321. [CrossRef]
31. Foley, J.; Costa, M.; Delire, C.; Ramankutty, N.; Snyder, P. Green Surprise? How Terrestrial Ecosystems Could Affect Earth's Climate. *Front. Ecol. Environ.* **2003**, *1*, 38–44.