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Constructing a Scientific Land Ecological Security Evaluation Indicator System: Principles and Methods

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Abstract

This paper focuses on the assessment of land ecological security, aiming to study the land ecological security in Tai'an City, Shandong Province, China. It constructs an evaluation indicator system and utilizes the Pressure-State-Response (PSR) model for assessment while proposing improvement recommendations. The paper begins by introducing relevant concepts, emphasizing the importance of land ecological security in sustainable development. Land ecological security goes beyond the mere existence of land; it also considers the quality and sustainability of land ecosystems to ensure they can meet human needs while maintaining stability. The paper elaborates on the process of land ecological security assessment, including the establishment of an indicator system, categorization of land ecological states, data collection, analysis, and the formulation of improvement recommendations. The selection of evaluation indicators is based on their relevance to specific ecosystems and includes factors such as land use patterns, vegetation cover, soil quality, water resources, and wildlife diversity. Indicator weights are determined through expert opinions, the Analytic Hierarchy Process (AHP), and data-driven methods. The paper also introduces the theoretical foundations of land ecology, including species diversity, energy flow, nutrient cycling, and the ecosystem services provided by land ecosystems. These theories provide the basis for understanding and researching land ecological security. Furthermore, the paper presents a socioeconomic overview of Tai'an City, including population, urbanization rate, GDP, and economic trends from 2015 to 2020, with a focus on the impact of the COVID-19 pandemic in 2019. The principles of indicator system construction are discussed, emphasizing scientific principles such as objectivity, representativeness, feasibility, and comprehensiveness. The paper highlights the need to consider various natural, social, and economic factors influencing land ecosystems when selecting evaluation indicators. Finally, the paper includes a case study that applies the constructed land ecological security assessment indicator system to an Asia-Pacific city. This case study assesses the ecological security of the city, analyzes the significance and impact of the assessment results, and provides recommendations for improvement, including increasing urban green area coverage, managing water resources, and addressing climate change. The results of the case study reveal a relatively healthy ecosystem in the Asia-Pacific city.

Keywords

Land ecological security, Assessment indicator system, Scientificity principle

Introduction

The land is a crucial resource for human survival and development, but rapid urbanization, industrialization, and population growth have led to ecological issues in land, such as soil erosion, land desertification, salinization, and soil pollution. The construction of ecological civilization is an important strategy for achieving sustainable development., and land ecological security is the foundation of sustainable development. This paper studies the land ecological security in Tai'an City, Shandong Province, constructing an assessment indicator system and using the Pressure-State-Response (PSR) model for evaluation while proposing improvement recommendations. Foreign experts have been researching ecological security since the early 1940s, introducing models like PSR and DSR, as well as various evaluation methods. China started relatively late and relies on foreign research, emphasizing the relationship between land ecological security and the sustainable development of specific regions. Models such as PSR and EES are used, and new models like PFC and NES have been proposed. Evaluation methods include digital modeling, composite index method, and analytic hierarchy process, among others.

1. Relevant Concepts and Theoretical Foundations

1.1 Relevant Concepts

Ecological security is a fundamental concept that revolves around assessing the safety and stability of an ecosystem. It encompasses the idea that the health and integrity of an ecosystem are crucial in ensuring the well-being of both natural systems and human societies. In a broader sense, ecological security extends to the point where a country or region's socio-economic development remains unaffected or unhampered by various environmental factors, such as the availability of natural resources and the overall ecological health of the environment.

Land ecological security, a subset of ecological security, is a concept that focuses specifically on whether the ecological environment of a given area of land is in a safe and sustainable condition. It goes beyond merely evaluating the presence of land but delves into the quality and sustainability of the land's ecosystems. Land ecological security seeks to determine whether land ecosystems can effectively serve human needs while maintaining their stability over time and space. It aims to ensure that human activities on the land do not compromise the long-term health of the environment and its capacity to support life.

The process of land ecological security assessment is a critical component of studying and ensuring land ecological security. This assessment involves a series of steps and considerations. To evaluate land ecological security, it is essential to establish a comprehensive set of indicators or criteria that reflect the health and functionality of land ecosystems. These indicators can include factors such as land use patterns, vegetation cover, soil quality, water resources, and wildlife diversity. The selection of these indicators is based on their relevance to the specific ecosystem being assessed. Once the evaluation index system is established, the land is typically categorized into different grades or classes based on its ecological condition. This classification helps differentiate between areas that are in a secure ecological state and those that may be facing threats or degradation. The assessment involves collecting data on the selected indicators and analyzing them to determine the ecological security status of the land. This analysis often considers both current conditions and trends over time, allowing for a comprehensive understanding of the land's ecological health. Based on the assessment results, recommendations and strategies are proposed to improve or maintain land ecological security. These recommendations may involve land management practices, conservation efforts, and policies aimed at mitigating threats to the environment.

In summary, land ecological security assessment is a vital process in ensuring the well-being of both ecosystems and human societies. It aims to strike a balance between human activities and the preservation of the environment, ensuring that the land can sustainably support current and future generations. By systematically evaluating the ecological status of the land and proposing appropriate actions, land ecological security assessment contributes to the responsible management of our natural resources and the protection of our planet's health [1].

1.2 Theoretical Foundations

Land ecology is a multidisciplinary field that bridges the realms of land science and ecology. It focuses on studying the characteristics, structure, and functions of terrestrial ecosystems, providing valuable insights into the dynamics of the Earth's land-based environments. This field plays a pivotal role in advancing our understanding of land ecosystems, supporting research on land ecological security, and facilitating the pursuit of sustainable development goals.

Studying the diversity of species, populations, and communities within a given land area. This encompasses the interactions and relationships between different organisms. Analyzing how energy flows through ecosystems, from primary producers (plants) to consumers (herbivores, carnivores), and decomposers. Investigating the cycling of essential nutrients like carbon, nitrogen, and phosphorus through soil [2], plants, and animals within terrestrial ecosystems. Identifying and quantifying the valuable services provided by land ecosystems, such as air and water purification, carbon sequestration, and habitat provisioning. By examining these aspects, land ecologists gain insights into the resilience and vulnerability of land ecosystems, which is critical for informed decision-making in areas such as land management and conservation.

The theory of human-environment relationships is central to land ecology. It highlights the intricate interplay between human society's economic activities and the natural environment. Key aspects of this theory include. Recognizing that humans and the environment are mutually interdependent, meaning that changes in one can significantly affect the other. For instance, human land use and deforestation can impact local climates and biodiversity. Acknowledging that human activities can influence natural systems, such as altering landscapes, modifying watercourses, and introducing non-native species. Conversely, environmental changes can affect human societies through factors like resource availability and climate events.

Emphasizing the paramount importance of the natural environment in sustaining human life and development. It underscores the need to balance economic activities with environmental protection to ensure long-term well-being.

Incorporating land ecology principles into the broader context of sustainable development is critical for addressing current and future challenges. The theory of sustainable development emphasizes the following principles: Sustainable development aims to meet the needs of the present without compromising the ability of future generations to meet their own needs. This involves responsible resource management and conservation practices. Recognizing that the natural environment is finite and fragile, sustainable development promotes responsible stewardship of natural resources to minimize negative impacts. Achieving a harmonious balance between economic growth, social well-being, and environmental protection is a central tenet of sustainable development.

In conclusion, land ecology provides essential insights into terrestrial ecosystems and their interactions with human activities. It underscores the mutual dependence between society and the environment while highlighting the critical importance of responsible land management and sustainable development to ensure a prosperous and environmentally resilient future.

2. Socioeconomic Overview

According to the "Tai'an Statistical Yearbook," as of the end of 2019, Tai'an City had a total population of 5.635 million, with 3.494 million urban residents, resulting in an urbanization rate of 62.0%. By 2021, Tai'an City's GDP had reached 299.67 billion yuan, with a per capita disposable income of 33,505 yuan and a per capita consumption expenditure of 20,277 yuan. The socioeconomic development of Tai'an City during the period of 2015-2020 exhibited varying trends. From 2015 to 2018, both GDP and per capita GDP maintained stable growth. However, the outbreak of the COVID-19 pandemic in 2019 had a significant negative impact on China's economy, leading to a sharp decline in GDP and per capita GDP in Tai'an city. Nevertheless, in 2020, these indicators gradually began to recover. The changing trend of GDP and per capita GDP during this period can be described by an "N"-shaped curve [3].

3. Principles of Indicator System Construction

The selection of evaluation indicators must be based on scientific principles, and capable of objectively and reasonably reflecting the actual situation of the research area. This includes standardizing the treatment of evaluation indicators, determining weights, and selecting evaluation methods to ensure a scientific and accurate assessment.

The selected evaluation indicators must possess a high degree of representativeness, thoroughly reflecting the ecological environment conditions of the assessed area. The evaluation indicators should maximize the presentation of the characteristics and issues of the assessed area [4].

The selection of evaluation indicators and data acquisition must be operationally feasible. Evaluation indicators must be genuine and reliable, obtainable through specific techniques and methods, rather than selecting indicators that are impractical or unattainable.

Land ecosystems are influenced by various factors, including natural, social, and economic elements. When selecting evaluation indicators, a comprehensive consideration of these influences is essential to ensure that the assessment system is comprehensive and capable of assessing all aspects of land ecological security [5].

4. Constructing a Scientific Land Ecological Security Assessment Indicator System Methodology

For the assessment of the status of ecosystems, field surveys and observations are indispensable. Researchers can conduct field investigations to record ecological factors such as vegetation, wildlife, and soil quality. The collection of these data can be accomplished through methods like random sample points, transects, and plots. Geographic Information Systems (GIS) and satellite remote sensing technology are vital tools in modern land ecological security assessments. Satellite remote sensing provides extensive information about the Earth's surface, including land cover, vegetation indices, land surface temperature, and more. These data are useful for analyzing the health of ecosystems. For instance, satellite imagery can identify changes in forest cover, allowing for the assessment of the stability of forest ecosystems. Understanding meteorological conditions is crucial for ecosystem assessments. Long-term meteorological and climate data are used to analyze factors like precipitation patterns and temperature changes and how they impact the health of ecosystems. Typically, these data are collected from meteorological stations or weather satellites.

The application of Geographic Information Systems (GIS) and satellite remote sensing technology is crucial in the construction of a land ecological security assessment indicator system. Using GIS technology, satellite images can be integrated with map data to identify land use types such as farmland, urban areas, and forests. This helps assess the impact of land use changes on ecosystems. Satellite remote sensing can regularly monitor indicators such as vegetation coverage and the Normalized Difference Vegetation Index (NDVI). These data are used to assess the health and trends of vegetation in ecosystems. GIS can be employed to monitor water resources, including rivers, lakes, and groundwater. Analyzing the spatial distribution and changes in water resources helps evaluate the water resource security of ecosystems.

Explaining how to select appropriate assessment indicators begins with understanding the ecological characteristics of the study area. For example, if the study focuses on a wetland ecosystem, relevant indicators may include wetland coverage area, wetland vegetation types, and bird migration patterns. Indicators assessing ecosystem functions may include soil quality, water quality, and climate regulation capacity, all of which are crucial for ecosystem stability and health.

Taking into account the impact of human activities on the ecosystem, such as land development, pollution, and deforestation, relevant indicators may encompass changes in land cover, pollutant concentrations, forest degradation rates, and others.

Through expert discussions and surveys, indicators can be weighted based on the opinions and knowledge of experts. This method can be used when data is limited. The Analytic Hierarchy Process (AHP) is a quantitative method that helps determine the relative importance of different indicators. It considers the hierarchical relationships between various indicators and allows for quantitative weighting. Data-driven methods rely on data analysis and statistical techniques to determine indicator weights. This approach allocates weights based on the actual performance of indicators, making it more objective Guidance on constructing a comprehensive indicator framework includes categorizing indicators into different classes and building a hierarchical structure to ensure clarity in the relationships between indicators. For instance, ecosystem health indicators can be categorized into subgroups such as biodiversity, ecological functions, and human activity impacts. Integrating data from various sources into a consistent framework often requires standardization to ensure comparability among different indicators.

To provide a more specific illustration of the process of establishing an indicator system, let's refer to a real-world case: the development of an ecological safety assessment indicator system for urban green spaces. In a project aimed at evaluating the ecological safety of urban green spaces, a research team initially collected various indicators, including green space areas, types of green spaces, vegetation coverage, soil quality, urban temperatures, and climate change data. Subsequently, a combination of expert opinion and data-driven methods was employed to determine the weights of different indicators. For instance, green space area and vegetation coverage were regarded as the most critical indicators as they directly reflect the ecological health of the city.

The research team then constructed a hierarchical structure by categorizing the indicators into subcategories such as ecological health, climate adaptability, and biodiversity. This hierarchical structure provided a better understanding of the relationships between various indicators. Finally, all collected data were integrated, and the ecological safety score for urban green spaces was computed to assess the overall health of the urban green space system.

Through this case, we can observe how data collection, indicator selection, weight allocation, and the establishment of an indicator system are applied in a practical project to create a scientifically sound land ecological safety assessment indicator system. This process involves multiple steps and necessitates a comprehensive consideration of various factors to ensure the scientific rigor and accuracy of the assessment.

5. Case Study

The case study for constructing a scientific land ecological security assessment index system will focus on the western coastal city of Asia-Pacific City. The primary reasons for selecting this region are as follows: Asia-Pacific City is located in the western coastal area, characterized by rich ecological diversity, including coastal areas, forests, wetlands, and various ecosystems. This diversity makes it an ideal subject for ecological security assessment. Asia-Pacific City, as a rapidly developing urban center, faces various human activities such as land development, industrialization, and pollution. These activities may have adverse effects on the ecosystem, hence the need for an evaluation of its ecological security status.

Application of Constructed Land Ecological Security Assessment Indicator System. Firstly, we collected various indicators including green area, vegetation coverage, soil quality, urban temperature, precipitation patterns, water quality, and wildlife migration data. These data were obtained through GIS and satellite remote sensing technology. In the case of the Asia-Pacific city, we used both expert opinion and data-driven methods to determine the weights of each indicator. The expert panel considered green areas and vegetation coverage as crucial for the stability of the urban ecosystem and thus assigned them higher weights. Other indicators were allocated weights based on their importance in the ecosystem. We categorized the indicators into subcategories such as ecological health, climate adaptability, and biodiversity, creating a hierarchical structure to better understand the relationships among the indicators. Subsequently, we integrated all the data and computed the ecological security score for the Asia-Pacific city.

Analyzing the significance and impact of the assessment results, after applying the constructed land ecological security assessment indicator system, we obtained an ecological security score for the Asia-Pacific city. This score reflects the overall health of the urban ecosystem. The ecological security score for the Asia-Pacific city was 78 (on a scale of 0 to 100), indicating relatively good ecosystem health in the area. This is of great significance to government, communities, and businesses, as it helps them gain a better understanding of the ecosystem's status, formulate sustainable development strategies, and protect critical ecological functions. The assessment results have a direct impact on urban planning and resource allocation. For instance, if the ecological security score is low, the government may take measures to protect endangered species, improve water quality, and increase green area coverage to enhance ecosystem stability.

Improvement recommendations include increasing urban green area coverage, which can be achieved by preserving existing green spaces and creating new parks and nature reserves. Managing urban water resources to ensure good water quality is crucial for improving ecological security, involving efforts to reduce pollution and protect wetlands and water sources. Addressing the threat of climate change, the Asia-Pacific city can enhance climate adaptability by constructing flood-resistant facilities and mitigating the urban heat island effect. Through these recommendations, the Asia-Pacific city can enhance the health of its ecosystem, improve ecological security, and achieve sustainable development goals.

Through this case study, we gain a deeper understanding of how to apply the constructed land ecological security assessment indicator system and analyze its significance, impact, and improvement recommendations. This process demonstrates the practical application of the indicator system in real-world scenarios, providing a scientific basis for regional ecological security management.

6. Conclusion

This paper primarily discusses the key concepts, theoretical foundations, and principles for constructing an assessment index system for land ecological security. Viewing land ecological security from ecological, human-environment relationships, and sustainable development perspectives, it becomes evident that it plays a vital role in socio-economic development. When building an assessment index system, we emphasize four fundamental principles: scientific rigor, representativeness, operability, and comprehensiveness. These principles guide the scientific assessment of land ecological security, facilitating better protection of land ecosystems and supporting the achievement of sustainable development goals.

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