Chinese Industry and Technology of Eco-environment
2025, VOL. 6, NO. 2, 37-42
DOI: 10.47297/wspciateWSP2633-772X07.20250602

Research on the application of GIS system in ecosystem

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ABSTRACT

This article provides a comprehensive analysis of the current application status of Geographic Information Systems (GIS) in ecosystems and demonstrates the practical effects of GIS technology through specific case studies. It begins by introducing the basic concepts and development history of GIS technology, followed by a detailed discussion on its current applications in ecosystem monitoring, assessment, planning, and management. Through several typical cases, it highlights the practical applications of GIS in wildlife conservation, vegetation monitoring, and ecosystem management. Finally, it explores the challenges faced by GIS in ecosystem applications and discusses future trends. The study indicates that GIS technology offers robust support for ecosystem research and management, with broad application prospects.

KEYWORD

GIS; ecosystem;application status; case; analysis;challenges and prospects

1 Foreword

1.1 Research Background

Ecosystem is an important part of the earths life support system, and its health directly affects the survival and development of human beings. With the increasingly prominent global environmental problems, the protection and sustainable management of ecosystems have become a major challenge facing human society.

1.2 Research purpose and significance

As a spatial information processing tool integrating computer science, geography, surveying and mapping, and environmental science, geographic Information System (GIS) is playing an increasingly important role in the field of ecosystem.

GIS can effectively collect, store, manage, analyze, and display spatial data, providing robust technical support for ecosystem research and management. This article aims to comprehensively examine the current application status of GIS in ecosystems, showcasing its practical effects through specific cases, and exploring the challenges and future trends, to provide a reference for research and practice in related fields.

1.3 Literature review

Geographic Information System (GIS) is widely used in the field of ecosystem research because of its powerful spatial analysis and data processing ability.

In the realm of ecological data management, ecosystem research involves a wide range of data sources, including meteorological, hydrological, and biological data, which are complex in format and origin. Drawing on the theory of information ecosystems [1], an integrated multi-level data interaction framework can be established. By leveraging GIS technology, these diverse data can be consolidated into a unified spatial database, enabling centralized management and efficient queries, thus enhancing data utilization efficiency. For instance, in forest ecology research, integrating data from forest resource surveys and remote sensing imagery can help construct a comprehensive database.

Ecosystem monitoring and assessment also rely on GIS. By integrating with remote sensing (RS) technology, dynamic monitoring of ecosystems can be conducted. For instance, in wetland ecosystems, RS captures images at different times, which, when analyzed using GIS, can accurately identify changes in wetland boundaries and vegetation cover, thereby timely assessing the health of the ecosystem.

2 Overview of GIS system technology

A Geographic Information System (GIS) is a computer system designed to collect, store, manage, analyze, and display geographic spatial data. It integrates spatial and attribute data, providing users with robust spatial analysis and decision support capabilities. The core components of a GIS include hardware, software, data, and personnel. Hardware forms the foundation for GIS operations, software serves as the core, data acts as the soul, and personnel are crucial for the successful application of the system.

The development of GIS technology has evolved from simple to complex and from isolated to integrated. The concept of GIS was first introduced in the 1960s; in the 1970s, the first commercial GIS software was released; in the 1980s, GIS began to be widely applied across various fields; since the 1990s, with the rapid advancement of computer technology and the Internet, GIS technology has continuously innovated, leading to the emergence of new technologies such as WebGIS, 3D GIS, and temporal GIS, which have significantly expanded the scope and capabilities of GIS applications.

2.1 Key technology description

2.1.1 Data acquisition technology

Remote sensing technology: through sensors on platforms such as aviation or satellite, collect electromagnetic wave information reflected or radiated by the earths surface to obtain large areas of geographic data.

Global Positioning System (GPS): Using satellite signals to determine the precise position, speed and time of an object, providing accurate spatial positioning data for GIS.

2.1.2 Data storage and management technology

Database management system (DBMS): Geographic data is stored in the database with a specific structure to realize the effective organization, storage and management of massive geographic data. For example, relational databases (Oracle, SQL Server, etc.) and non-relational databases (MongoDB, etc.) can store spatial and attribute data of GIS.

2.1.3 Visualization technology

Map making: to display geographic data in the form of maps, through symbols, colors, notes and other elements, to intuitively present geographic information, such as making city maps, tourist maps and so on.

3D visualization: using 3D modeling technology, the geographic data is constructed into a 3D scene to truly display the three-dimensional form of geographical elements such as landform and buildings.

Dynamic visualization: Through animation, interaction and other ways, the change process of geographic data with time or other factors is displayed, such as population growth, climate change and other dynamic information.

2.2 Analysis of GIS system functions

2.2.1 Data Collection and Input

Data can be obtained through various methods, such as digitizing paper maps using digital instruments; converting scanned map images into vector data using scanning vectorization technology; and directly receiving data collected by global positioning systems (GPS), remote sensing (RS), and other devices, ensuring that all types of geographic information are accurately entered into the system.

2.2.2 Data storage and management

With a unique spatial database management mode, the spatial location, attribute information and topological relationship of geographic elements are stored at the same time.

2.2.3 Data processing and transformation

Edit, format conversion, projection transformation and other operations on the original data. For example, map data in different coordinate systems are uniformly converted to the same coordinate system, or irregular polygon data are smoothed to improve the quality and availability of the data.

2.2.4 Spatial Analysis

This is a core function that includes overlay analysis, which involves overlaying elements from different layers to comprehensively analyze the spatial relationships between them; buffer zone analysis, which generates buffer zones of a certain distance around point, line, and area elements to assess their impact areas; and network analysis, which is used to analyze transportation networks, water systems, and other networks, addressing issues such as route planning and resource allocation.

2.2.5 Cartography and visualization

Make various kinds of maps according to user needs, set map symbols, colors, labels, etc., and display geographic information in the form of intuitive maps, charts, 3D models, etc.

2.3 Spatial analysis functions in GIS system

2.3.1 Overlay analysis

Principle: The spatial data of multiple layers are superimposed to combine the elements of different layers and produce new spatial features and attribute information.

Application: It can be used in land use planning. By superimposing land use status map, topography and geomorphology map, ecological protection red line map, etc., suitable areas for development or protection can be determined.

2.3.2 Buffer analysis

Principle: Based on the geographical entities such as points, lines and surfaces, a buffer area of certain width is established around them to analyze the influence range or radiation degree of the geographical entities on the surrounding areas.

Application: In traffic planning, buffer zones can be established for roads, stations and other transportation facilities to analyze the impact range on surrounding land use, commercial development, etc.

2.3.3 Network analysis

Principle: Based on the network data model, analyze the path, traffic, connectivity and other problems in the network to optimize resource allocation, path selection, etc.

Application: In logistics distribution, network analysis can be used to determine the best distribution route, so that the transportation cost is the lowest and the time is the shortest.

2.3.4 Relief analysis

Principle: the slope, slope direction, elevation, undulation and other characteristics of the terrain are calculated and analyzed by using digital elevation model (DEM) and other data.

Application: In agricultural production, through terrain analysis, we can understand the terrain conditions of different regions, rationally plan the crop planting area, and improve the efficiency of agricultural production.

2.3.5 Spatial interpolation analysis

Principle: According to the known discrete point data, the unknown area is calculated through certain mathematical models and algorithms, so as to realize the transformation from discrete data to continuous data.

Application: In the field of meteorology, continuous distribution of meteorological elements such as temperature and precipitation in a region can be obtained through spatial interpolation analysis based on limited data from meteorological observation stations.

2.3.6 Spatial statistical analysis

Principle: Statistical methods are used to analyze spatial data, including spatial autocorrelation analysis, spatial clustering analysis, spatial regression analysis, etc., in order to reveal the distribution law, correlation and trend of spatial data.

Application: In the study of disease transmission, spatial statistical analysis can be used to study the spatial distribution characteristics, aggregation and relationship with environmental factors of diseases, so as to provide a basis for disease prevention and control.

3 The application status of GIS in ecosystem

3.1 Ecological assessment and analysis

In ecosystem assessments, GISs spatial analysis capabilities play a crucial role. By overlaying data from multiple sources, such as topography, soil, climate, and vegetation, the sensitivity and vulnerability of ecosystems can be comprehensively evaluated. To enhance accuracy, ecosystem health assessment models should incorporate multi-source monitoring data, such as the [2] Marine Automatic Monitoring System. For instance, when assessing biodiversity in a specific area, overlaying species distribution data with environmental factors like altitude, temperature, and precipitation in GIS can help identify suitable habitats for different species, thereby pinpointing key areas for biodiversity conservation. In evaluating ecosystem services, GIS technology can quantify the value of various services provided by ecosystems to humans, such as water conservation, soil stabilization, and carbon sequestration, providing a scientific basis for the formulation of ecological protection policies.

3.2 Ecosystem monitoring and assessment

GIS plays a crucial role in ecosystem monitoring and assessment. By integrating technologies such as remote sensing and GPS, GIS enables real-time monitoring and dynamic analysis of ecosystem elements. For instance, GIS can be used to develop models for assessing ecosystem health, simulating the spatial distribution and patterns of ecosystem changes. In water environment monitoring, GIS can integrate water quality data from systems like [3], aiding in water quality assessments and tracing pollution sources. Additionally, GIS can integrate water quality data for water quality assessments and pollution source tracing; in biodiversity monitoring, GIS can be used for species distribution mapping, habitat analysis, and bioregional planning.

3.3 Ecosystem planning and management

In the realm of ecosystem planning and management, GIS provides decision-makers with robust spatial analysis tools. By utilizing GIS functions such as spatial overlay analysis and buffer zone analysis, it is possible to scientifically delineate ecological protection boundaries and optimize the layout of nature reserves. In environmental impact assessments, GIS can integrate multi-source data to predict and evaluate environmental impacts, providing a basis for project site selection and plan optimization. Furthermore, GIS is widely applied in areas such as ecological restoration planning, environmental risk assessment, and emergency management.

3.3.1 Cross-regional ecosystem collaborative management

Ecological linkage management of river basin: When evaluating the ecological function of wetland through GIS overlay analysis, the standardized framework of river basin restoration should be combined[2]To ensure the scientific nature of the evaluation system, GIS-supported ecological restoration project planning can integrate artificial wetland technology[4] to optimize the location and design of sewage treatment facilities. GIS can integrate data on topography, geomorphology, water quality, quantity, and land use from both upstream and downstream, as well as left and right banks, to build a basin ecological information sharing platform[5]. For example, in the Yangtze River Basin, GIS analysis can assess the impact of human activities such as pollution discharge and water conservancy projects on the entire basins ecological environment, breaking down administrative barriers to achieve unified planning and coordinated governance of basin ecological protection.

3.3.2 Integration of artificial intelligence in ecosystem planning and management

Intelligent Recognition and Classification: By integrating deep learning algorithms, such as Convolutional Neural Networks (CNNs), GIS spatial data is utilized to achieve intelligent recognition and classification of ecological elements. For example, it can automatically identify different vegetation types and wetland forms in remote sensing images, offering faster and more accurate data support for ecological baseline surveys compared to traditional manual interpretation methods.

4 A typical case of GIS system in ecosystem application

4.1 Case 1: Suitability evaluation of wetland waterfowl habitat supported by remote sensing and GIS in Panjin

In the field of ecosystem research, GIS (geographic information system) has become an indispensable technical means with its powerful spatial analysis and data processing capabilities. "Remote sensing and GIS supported adaptive evaluation of wetland waterfowl habitat in Panjin" is a representative case, which fully demonstrates the unique value of GIS in ecosystem research.

As a vital habitat for waterfowl, the ecological health of the Panjin Wetland is crucial for their survival and reproduction. In this study, GIS technology played a pivotal role in multiple aspects. By using remote sensing technology, a vast amount of spatial data on the Panjin Wetland was collected, including information on topography, vegetation, hydrology, and other elements. After these raw data were imported into the GIS system, they underwent preprocessing to integrate and standardize data from various sources and formats, laying the groundwork for subsequent analysis.

During the analysis phase, GIS spatial analysis functions, such as buffer analysis and overlay analysis, are utilized to comprehensively evaluate the various elements of wetlands. For instance, buffer analysis helps determine the relationship between waterfowl foraging and resting areas and water sources and vegetation distribution. Overlay analysis combines topographic, hydrological, and vegetation data to assess the suitability of different areas for waterfowl habitats. The resulting habitat adaptability evaluation map clearly shows the ecological quality of each wetland area, highlighting the most suitable, relatively suitable, and unsuitable areas for waterfowl habitation.

4.2 Case 2: Application in the zoning of ecological restoration of territorial space

In the study and protection of ecosystems, GIS system has become a vital technical tool due to its powerful data processing and spatial analysis capabilities. The paper "Application in Ecological Restoration Zoning of Territorial Space" is a typical case of GIS system in the application field of ecosystem, highlighting its key value in the ecological restoration work of territorial space.

The ecological restoration of national territory is a complex and systematic project that involves the processing and analysis of multi-source data. In this paper, remote sensing technology is used to acquire vast amounts of spatial data on terrain, vegetation, and land use status. After these raw data are imported into the GIS system, they undergo comprehensive data cleaning and integration. By leveraging the data management capabilities of GIS, data from various formats and sources are uniformly stored, forming a national territory ecological database that provides a solid foundation for subsequent analyses.

In the critical phase of ecological restoration zoning, GIS spatial analysis plays a central role. By overlaying data on land use types, ecological sensitivity, and ecosystem services, it identifies areas with significant ecological issues and urgent restoration needs. Buffer zone analysis is used to define buffer zones around key ecological areas such as rivers, lakes, and nature reserves, clarifying the boundaries for ecological protection and restoration. Network analysis is employed to study the connectivity of ecological corridors, ensuring the material and energy flow within ecosystems.

Through these analyses, the generated ecological restoration zoning maps of national territory vividly illustrate the current ecological conditions and restoration directions in different regions, providing precise scientific support for national territory planning and ecological restoration decisions. This research is highly significant at the ecosystem level, as it effectively promotes the refinement and scientific implementation of ecological restoration efforts, ensures the rational allocation of restoration resources, enhances the quality and stability of ecosystems, and serves as a successful example of how GIS systems can assist in ecosystem protection and restoration. It also provides a model and method that can be referenced by other regions in their ecological practices.

4.3 Case 3: Study on the layout of urban park green space based on GIS network analysis

Research background and significance: With the acceleration of urbanization, urban ecological environment problems have become prominent. As a key part of urban ecosystem, the rational layout of park green space is crucial to the performance of ecological functions.

Data collection and processing: urban topographic map, park green space distribution status map, traffic network data, population density data, etc., using GIS data collection, editing, format conversion and other functions, all kinds of data are integrated into a unified geographic space framework, and a spatial database is constructed to lay the foundation for subsequent analysis.

Application of GIS Network Analysis Methods: Using network analysis to construct a network of urban park green spaces, where parks and green spaces are treated as nodes, and roads and rivers as connecting corridors. The network attributes are defined. Shortest path analysis is used to calculate the shortest distances from different areas to park green spaces, assessing accessibility. Service area analysis is conducted to determine the service coverage of each park green space and identify any service blind spots. Network flow analysis is employed to simulate the movement of people between park green spaces and other urban areas, providing insights into the distribution of park green space usage intensity.

5 Challenges and prospects of GIS in ecosystem applications

5.1 Challenges

Despite its significant achievements in ecosystem research, GIS still faces several challenges. Firstly, issues with data quality and standardization limit the depth and breadth of GIS applications. Ecosystem data comes from diverse sources and varies in format, making effective integration and sharing a pressing issue. Secondly, the accuracy and reliability of GIS models need further improvement. Given the complexity and variability of ecosystems, existing GIS models have limitations in simulation and prediction. Additionally, the shortage of GIS professionals hinders their application in grassroots ecosystem management.

5.2 Outlook

Looking ahead, the application of GIS in the ecosystem field will exhibit the following trends: First, it will integrate deeply with new technologies such as big data and artificial intelligence to enhance the intelligence of ecosystem analysis. Second, it will evolve towards three-dimensional, dynamic, and real-time applications to better simulate and predict changes in ecosystems. Third, it will foster interdisciplinary and cross-sector collaboration to promote the use of GIS in comprehensive ecosystem management. Fourth, it will develop public-oriented GIS applications to boost public awareness and capabilities in ecological conservation.

5.3 Conclusion

GIS integrates remote sensing and ground observation data to achieve real-time, dynamic monitoring of species distribution, habitat changes, and ecosystem health, providing comprehensive spatial analysis tools for ecological research. Furthermore, GIS plays a crucial role in the assessment of ecosystem services by accurately mapping their spatial distribution and evaluating their value using economic models, thus providing scientific support for policymakers.

GIS technology has opened up new ways for ecosystem research, and its application will continue to deepen our understanding of ecosystems and make important contributions to ecological protection and sustainable development.

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