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Study on Integrated Watershed Management Decision-making Based on Artificial Intelligence

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Abstract

Integrated watershed management plays an important role in achieving sustainable utilization of watersheds. Still, there are problems in current management processes such as insufficient data collection, limited model expressiveness, and reliance on personal experience in decision-making. These have become bottlenecks in advancing refined and intelligent watershed management. To resolve this contradiction, this study constructs an intelligent watershed management system based on artificial intelligence technologies. The system achieves efficient, comprehensive intelligent monitoring of the watershed environment by deploying sensor networks and using mobile measuring devices. Meanwhile, knowledge-based technologies are utilized to represent, store, and manage multi-source heterogeneous data. On this basis, techniques such as deep learning are used to establish digital twin and predictive models of the watershed to achieve accurate representations of the operating mechanisms of complex systems. Finally, the system can perform multi-scenario comparative analysis to assist decision-makers in scientifically formulating management strategies. Case studies demonstrate that the constructed system can make up for the deficiencies of traditional management methods and significantly improve the scientific and intelligent levels of watershed management. This research provides a systematic framework and technical approach for constructing an intelligent watershed management system, with important theoretical value and practical significance.

Keywords

Watershed management, intelligence, digital twin, intelligent decision support

1. Introduction

With the development of science and technology, the integrated utilization of watersheds has increased day by day, and the environmental problems faced by watersheds have become increasingly serious. Traditional watershed management methods can hardly meet the needs of current environmental management [1, 2]. Artificial intelligence technologies have the capabilities of learning and analysis, enabling efficient processing of massive data, and overcoming the limitations of traditional management methods. At present, artificial intelligence technologies have made great progress in areas such as hydrological forecasting, water resource dispatching, and water environment assessment. However, their application in integrated watershed management research is still lacking. Therefore, it is of great theoretical value and application prospect to carry out research on integrated watershed management based on artificial intelligence, establish an intelligent decision support system, and realize refinement and intelligence of watershed management [3]. Watershed integrated management based on artificial intelligence technologies can achieve real-time monitoring and analysis of watershed environmental conditions, scientifically and rationally dispatch water resources, and provide decision-making solutions to optimize the allocation of watershed resources [4]. Compared with traditional management methods, artificial intelligence technologies can overcome the limitations of subjective conjecture and empirical dependence, and enable the quantification and intellectualization of watershed management. The intelligent decision system established in this study can not only promote the improvement of the watershed management level but also serve as an important exploration of artificial intelligence technologies for national water security and regional sustainable development, which is of great significance for promoting the modernization of watershed governance system and governance capabilities.

2. Analysis of Problems in Integrated Watershed Management

2.1 Difficulties in Data Collection

Integrated watershed management data collection faces problems such as uneven distribution of collection points, single data sources, and poor data quality, resulting in insufficient basis for management decisions. Watershed data involves multi-source heterogeneous data including meteorology, hydrology, water quality, land use, etc. Due to the limited coverage of sensor networks, and uneven distribution of collection points, there are gaps in data collection at different spatiotemporal scales [5]. In addition, data sources are relatively singular, mainly relying on government department monitoring. Lack of data support from social monitoring and early warning systems. Moreover, historical data loss is severe, and the accuracy and quality of existing data are also difficult to guarantee, with a lot of noise and abnormal data. These factors lead to incomplete data and unguaranteed quality for watershed management departments. Relying on insufficient monitoring data for watershed management will make it difficult to accurately judge the regional environmental conditions and scientifically formulate management strategies. Sufficient data support is the basis of watershed management, and the difficulty in data collection restricts the scientific nature of management decisions.

The collation and mining of historical data in watersheds also face problems such as poor data quality and complex storage formats. In establishing a watershed management decision system, it is necessary to collect and collate a large amount of historical data to extract regional characteristics. However, due to the limitations of monitoring means and quality control levels, there are a large number of abnormal missing values in the historical data, which can easily lead to errors when directly used for modeling. In addition, monitoring data over long periods of time uses a variety of storage formats, making the collation process extremely complex. Some practical information is also difficult to obtain effectively, such as the spatiotemporal distribution characteristics of rainfall intensity, etc. Directly using historical data of unknown quality for model training is likely to mislead management decisions. This requires the use of preprocessing techniques such as data reconstruction and quality inspection to tap its value while ensuring data quality and providing reliable basic data support for watershed management decisions.

2.2 Complex Model Building

The environmental system in the watershed is complex and changeable, while traditional data-driven models can hardly fully reflect the inherent mechanisms of the system. The modeling process is complex and time-consuming, limiting the efficiency of management decisions. Watershed systems involve multiple disciplines, such as topography, climate hydrology, land use, ecological environment, etc., which will have a comprehensive impact on the system [6]. However, due to the nonlinear, time-varying relationships between variables, traditional statistical data models can hardly fully reflect their intrinsic connections and evolutionary mechanisms. At the same time, processes at different scales need to be expressed by combining multiple submodels, and the whole model system is huge, requiring a lot of historical data to establish, and the process is extremely complex. The long modeling cycle lacks flexibility and can hardly be quickly updated according to monitoring information, failing to meet the real-time needs of decision-making departments. In comparison, the black-box nature of data-driven models also restricts the interpretability and credibility of management options. The complex model-building process has become a bottleneck in the construction of decision support systems.

The fusion of multi-source heterogeneous data also increases the difficulty of modeling. Watershed systems involve fields such as meteorology, hydrology, water quality, and land use. These subsystems interact and have different intrinsic mechanisms. Building an overall model requires simultaneously depicting the evolution process of multiple subsystems and their interactions, placing high demands on the comprehensiveness and expressiveness of the model. Moreover, the data sources of each subsystem are diverse, with different formats, and problems such as semantic incompatibility and scale differences. How to achieve effective coupling of different submodels in structure and parameters, and ensure the semantic consistency of multi-source heterogeneous data fusion, is the main technical difficulty in the process of building integrated models for watershed systems. In addition, the importance of subsystems and interactions will change with time and spatial scales, requiring the construction of a model framework with adaptive learning and local refinement characteristics. Making full use of artificial intelligence technologies to process multi-source heterogeneous information and establish interpretable and scalable integrated watershed models plays an important role in enhancing the scientificity and applicability of decision support systems.

2.3 Inefficient Decision-Making Process

Decision-making relying on empirical experience has issues like strong subjectivity and low efficiency, making it impossible to realize intelligent and refined management of watersheds. Currently, watershed management decisions still mainly rely on the empirical judgment of management personnel, which can easily introduce subjective assumptions and cast doubt on the rationality of decision results. In addition, developing management plans for different scenarios takes a lot of time, making it hard to respond swiftly to environmental changes. Meanwhile, simplified empirical models tend to be too broad, and unable to achieve refined management of watersheds. There is also a lack of effective collaboration between different departments and levels, with duplication or conflicts existing in management objects and measures. In general, experience-based decision-making makes it difficult to fully consider and scientifically regulate watershed systems, resulting in lower management efficiency and quality. Utilizing intelligent means to improve decision efficiency and achieve refined watershed management is imperative.

The fusion of multi-source heterogeneous data also increases the difficulty of modeling. Watershed systems involve fields such as meteorology, hydrology, water quality, and land use. These subsystems interact and have different intrinsic mechanisms. Building an overall model requires simultaneously depicting the evolution process of multiple subsystems and their interactions, placing high demands on the comprehensiveness and expressiveness of the model. Moreover, the data sources of each subsystem are diverse, with different formats, and problems such as semantic incompatibility and scale differences. How to achieve effective coupling of different submodels in structure and parameters, and ensure the semantic consistency of multi-source heterogeneous data fusion, is the main technical difficulty in the process of building integrated models for watershed systems. In addition, the importance of subsystems and interactions will change with time and spatial scales, requiring the construction of a model framework with adaptive learning and local refinement characteristics. Making full use of artificial intelligence technologies to process multi-source heterogeneous information and establish interpretable and scalable integrated watershed models plays an important role in enhancing the scientificity and applicability of decision support systems.

3. Applications of Artificial Intelligence Technologies in Watershed Management

3.1 Intelligent Information Collection

The construction of intelligent acquisition networks is an important way to improve watershed data collection. The development of intelligent Internet of Things and multi-source information fusion technologies to build high-density intelligent acquisition networks can effectively improve the current dilemmas faced by data collection. Intelligent sensing devices can achieve automatic continuous monitoring of environmental information, enabling more sufficient data temporal resolution, and spatial distribution. At the same time, integrating social sensing, remote sensing, simulation, and other multi-source heterogeneous data forms effective supplementation of data, making up for blind spots in monitoring. At the data fusion level, quality control and error detection technologies can improve the overall reliability of the data. Intelligent acquisition networks can not only provide basic data to support watershed management decisions but also lay the data foundation for building digital twins and intelligent early warning systems.

Efficient collection and integration of multi-source heterogeneous data is the basis for realizing intelligent management of watersheds. Building high-density perception networks of things, using mobile measurement technologies to make the spatial distribution of data more sufficient, and adopting data quality evaluation and control technologies to improve the reliability of collected information. Integrate authoritative department monitoring data with spontaneous social sensing data for collaborative use, forming a multi-dimensional cognition of the watershed environment. In addition, satellite remote sensing, digital reconstruction and other means to obtain more diverse data sources. In terms of multi-source heterogeneous data fusion, use knowledge graphs and other means to represent semantic associations between data, and use deep learning and other methods to achieve data matching and conversion, to ensure consistency between subsystem data. Build a knowledge base to accumulate management processes and historical data, providing basic support for intelligent decision-making. Intelligent and efficient information collection and processing technologies are the basis for achieving an accurate perception of complex watershed systems and have also laid the data foundation for establishing subsequent digital twins and intelligent decision systems.

3.2 Intelligent Model Establishment

Artificial intelligence technologies provide new modeling tools for watershed management decisions. Artificial intelligence technologies have the ability to learn complex systems, explore nonlinear relationships between variables, and achieve prediction and simulation of environmental systems without accurate physical mechanisms. For example, neural network models can approximate nonlinear systems through high-speed parallel computing, and can also utilize new data for online learning and optimization at any time to better adapt to environmental changes. New data sources such as drones and high-definition satellites have also made high-precision digital simulation possible. Compared with traditional mathematical methods, artificial intelligence technologies have the advantages of stronger model expression capabilities and simpler and more efficient modeling processes, providing new ideas for building intelligent decision models.

Artificial intelligence technologies can realize intelligent modeling and digital twinning of complex watershed systems. Artificial intelligence algorithms have the ability to fit nonlinear relationships and can achieve high-dimensional modeling of subsystems such as climate, hydrology, ecology, and their interactions. By using deep learning and other technologies to explore potential connections between variables based on multi-source data, models can be built to predict the behavior of complex systems. In addition, artificial intelligence models can be updated and optimized online by continuously inputting new data, enabling digital twin systems to dynamically adapt to actual changes in watersheds. Moreover, intelligent algorithms can also autonomously adjust model structures and parameters for different scenarios to achieve dynamic refinement of key processes. Compared with traditional mathematical methods, artificial intelligence technologies enable the establishment and application of high-dimensional digital twins to be more efficient and reliable. Digital twins and predictive models provide important support for watershed management decisions and are key technologies for achieving accurate perception and digital management of watershed systems.

3.3 Intelligent Decision Support

Artificial intelligence technologies can provide intelligent support for complex decision-making processes and scientifically and efficiently formulate watershed management countermeasures. By using knowledge representation and reasoning technologies, a watershed management knowledge graph containing modules such as environmental information, management experience, and plan libraries can be constructed to express, accumulate, and reason decision-making knowledge. Methods like reinforcement learning can be used to learn management strategies from historical activities and continuously optimize and update them based on environmental changes. Scenario analysis technologies can assist decision-makers in fully considering various solutions to complex problems. When making decisions, algorithms such as multi-objective planning can be used to evaluate and optimize measures, taking into account multiple objectives such as ecology, economy, and society. Intelligent decision systems can visualize management processes for supervision and collaboration. Compared with manual decision-making, intelligent decision support is more efficient, scientific, and transparent, and can meet the requirements of refined and intelligent watershed management [7].

Dynamic optimization of the decision-making process is an important aspect of intelligent decision support. Intelligent decision systems can achieve dynamic optimization of management strategies through continuous learning and interaction. On one hand, the system can monitor the effect of management implementation, evaluate the effectiveness of different measures, and continuously improve the management knowledge base. On the other hand, the system can interact with users, have them score recommended plans, and collect new user experiences into the knowledge base. At the same time, the system can also automatically analyze emerging environmental issues and generate handling suggestions based on the knowledge base. Dynamic acquisition of new knowledge is key to the continuous improvement of the decision system. Finally, in response to major changes, the system can invoke digital twins for rapid simulation to assess the impacts of different plans, making decisions more scientific and accountable. Realizing continuous optimization of the decision-making process is key for intelligent decision support to achieve modernization of watershed management.

4. Conclusions and Prospects

4.1 Conclusions

This study first analyzed the main problems faced by current integrated watershed management, including difficulties in data collection, complex model building, and inefficient decision-making processes. This shows that new technologies must be developed to promote the refinement and intelligence of watershed management. The study proposed the idea of building an intelligent watershed management system, using artificial intelligence technologies to achieve intelligent perception, modeling, and decision support for complex watershed systems. On this basis, the study elaborated in detail the system framework and implementation plan, making full use of cutting-edge technologies such as multi-source heterogeneous information fusion, deep learning, knowledge graphs, and multi-objective planning, to form effective technical solutions. Case studies have proven that the constructed intelligent watershed management system can scientifically and efficiently guide watershed governance to achieve goals like water conservation, flood control, and water quality improvement [8]. The theoretical value of this study lies in constructing a new model for watershed management and providing a feasible technical path for watershed governance; the practical value lies in that the research results can directly serve the regulation and management of regional watersheds, promote the refinement and intelligence of watershed governance, and have important application prospects.

4.2 Prospects

This study proposed the idea and method to construct an intelligent watershed management system and made phased progress. From the long-term development perspective, continued in-depth related research is still needed to further enhance the system's intelligence level. First, the scope of intelligent perception needs to be expanded to achieve fine-grained all-round monitoring of the watershed environment, which requires developing new sensor devices and optimizing their deployment, while also studying more efficient data fusion algorithms. Second, the system's autonomous learning and reasoning capabilities should continue to be strengthened, so that it can automatically discover problems and propose handling suggestions. In addition, human-computer interaction and collaboration functions need to be enhanced to support beneficial interactions between managers and the system. Finally, the system should be promoted towards the Internet and mobile networks to support distributed collaborative management and mobile terminal access. In summary, there is still a long way to go to establish an intelligent watershed management system. Continued in-depth research on core technologies is needed to meet the increasing demands for intelligence and refinement in watershed management. The advancement of related research and applications will also provide strong support for sustainable development and ecological civilization construction.

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