DESIGN AND CONSTRUCTION OF A KNOWLEDGE SERVICE SYSTEM FOR GLOBAL LAND COVER SPATIOTEMPORAL CHANGE

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ABSTRACT

Global land cover (GLC) change reflect the distribution and evolution process of various material types on the earth's surface. It is an important basic data for global natural resources survey and ecological environment research. Although many sets of GLC information service systems have been developed at home and abroad, but the knowledge stock of GLC has not been sufficiently mined, problems such as the knowledge sharing service of spatiotemporal change of GLC have not been solved. This paper reports how to design and construct a GLC spatiotemporal change knowledge service system, which provides users with accurate and in-time knowledge services for GLC spatiotemporal change through knowledge visualization, browsing and querying, knowledge recommendation, knowledge diagnosis, knowledge sharing, process simulation, knowledge graph building and spatiotemporal deduction.

1. INTRODUCTION

Since the 1990s, the international community has been devoted to using space remote sensing technology to study GLC, and has formed multiple sets of global and regional land cover products. For example, the United States Federal Geological Survey, the European Union Joint Research Center and the University of Maryland have released 6 sets of GLC data with a spatial resolution of 1000 meters or 300 meters (Chen et al., 2015; Xie et al., 2021; Loveland et al., 2000). The United States Department of Agriculture, the Canadian Environment Department's Ice Service Center, and the Spanish Institute of Geography provide land cover data of the country or part of the country. The Food and Agriculture Organization of the United Nations has released land cover data of Africa. Since 2014, China has successively released GlobeLand30 datasets with coverage of 2000, 2010 and 2020 , which is the first 30m resolution global land cover data product in the world (Liang, L. and Gong, P., 2015; Quinton, W.L., 2011; Begueria, S., 2006; Brink, A. B. and Eva, H. D., 2009; Arsanjani, J.J, 2018).

The spatial distribution of GLC directly affects the material and energy cycle process of the earth's surface, and its time change comprehensively reflects the impact of human activities and climate change on the natural environment. As the basic data resources, the GLC information and its spatiotemporal change is valuable in various fields, such as studying Global change, promoting the construction of the "the Belt and Road", and implementing the UN 2030 Agenda for Sustainable Development (Estoque, R.C. et al., 2021). At present, most of the GLC information service platforms running online only provide data services and information services such as data browsing, verification, classification, labelling and statistics, etc.

User need can't be met with the problem of the lack of land cover knowledge mining and deficiency of land cover knowledge services. Therefore, it is urgent to establish an intelligent knowledge service system which can diagnose, simulate and analyse the spatiotemporal change of GLC.

Based on the analysis of the current situation of the construction of the knowledge service system for GLC spatiotemporal change, this paper reports how to design and construct a knowledge service system for spatiotemporal change of GLC, which realizes the intelligent management, simulation, deduction, sharing and utilization of the knowledge of spatiotemporal change of GLC, so as to provide accurate and in-time knowledge service for the implementation of major strategy. The rest of this paper is organized as follows. Section 2 introduces current situation and existing problems of GLC service system. Section 3 introduces the design and construction of GLC spatiotemporal change knowledge service system in detail. Section 4 introduces system implementation. Section 5 concludes this work.

2. CURRENT SITUATION ANALYSIS AND EXISTING PROBLEMS OF GLC KNOWLEDGE SERVICE SYSTEM

2.1 Current Situation Analysis of GLC Service system

With the development of computer network technology ,driven by users' demand for the application of GLC products, many domestic and international scientific research institutions have developed land cover information service system respectively (as shown in Table 1). The US Geological Survey has developed the MRLC land cover information service system (https://www.mrlc.gov/), support the browsing of land cover metadata in the form of Web Map Service (WMS), and also provide the MRLC Viewer tool and mapping tool (MRLC

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NLCD Mapping Tool) for browsing data in the form of online map. The Austrian International System Research Institute (IIASA) has developed the Geo-Wiki information service system, which provides the online reporting and verification function of land cover information. The United States Department of Agriculture has developed the CropScape information service system, which provides nationwide crop online browsing, area statistics and customized download functions. The version 1.0 of the GlobeLand30 information service system developed by National Geomatics Center of China (NGCC) supports the production, verification, reporting, statistics and other functions of the 30-meter GLC data.

Service System	Functions	Institution Name
GlobeLand30	Production, verification, labelling and statistics of land cover data	NGCC
CropScape	Land cover data browsing and statistics	George Mason University
GeoWiki	Verification of land cover data	Austrian Institute of Systems
LACO-Wiki		
VIEW-IT	Land cover data labelling	Somano State University
Online Classification Service System	Classification of land cover data	National Technical University of Athens

Table 1. List of mainstream land cover information service systems.

With the development of information technology, information acquisition is becoming more convenient. However, there are still outstanding contradictions of "massive data, information explosion, knowledge is difficult to obtain " (Zhang, X.Y., et al., 2020). Geographical information service can't meet people's demand on spatiotemporal knowledge services. In recent years, relevant experts at home and abroad have proposed methods for geographical knowledge services, expounded the technology of geographical knowledge services and implementation, and key scientific problems that need to be solved at present.

The development of geographical knowledge service system is imperative. China Academy of Engineering has organized many units to develop the platform of China Engineering Science and Technology Knowledge Center (https://www.ckcest.cn/entry/). The platform includes knowledge service systems in multiple fields. For example, the geography resources and ecology knowledge service system can provide ecological data, remote sensing data, model analysis and thematic knowledge application; the geographic information professional knowledge service system can provide basic geographic information data resource services, spatial knowledge services and spatialization tools. However, these platforms only provide relatively few land cover knowledge services. The American Nature Conservation Association has condensed some knowledge points about the impact of global development on nature, and provides the "Anthropocene" knowledge map service with preliminary knowledge navigation, basing on remote sensing images data, land cover data and other data. The GlobeLand30 information service system provides two kinds of knowledge services: typical global land cover landscape and knowledge navigation.

2.2 Analysis of Existing Problems

Firstly, in the field of GLC, simply providing data services, information services and individual knowledge navigation service can't fully exploit the role of GLC data, and limits the application of GLC data. Secondly, the functions of domestic and foreign GLC knowledge service systems are extremely single, which aren't universal, and limit public participation in creating geographic information knowledge. Thirdly, mining of the knowledge stock of GLC is not enough, the processing services for GLC knowledge are extremely lacking, the association and organization of knowledge are lacking. It is difficult to meet the deep needs of users. Therefore, how to face the specific application, correlate knowledge of temporal and spatial changes of GLC, and dynamically construct the spatial knowledge map is the main challenge to build a online knowledge service system.

3. DESIGN OF GLC SPATIOTEMPORAL CHANGE KNOWLEDGE SERVICE SYSTEM

3.1 Overall Design Conception

In view of the problems existing in the current GLC knowledge service, the GLC spatiotemporal change knowledge service system is designed from the following aspects:

(1) By combining semantic information, temporal information, spatial scale and other attributes, a knowledge expression model and classification system for GLC spatiotemporal change is established, to guide the collection and edit of knowledge points, such as the location, morphology, and spatiotemporal change of geographical entities. It builds a global spatiotemporal knowledge base for land cover, covering 10 types of farmland, forests, grasslands, shrublands, wetlands, water bodies, tundra, artificial surfaces, bare land, glaciers, and permanent snow cover.

(2) Based on the spatiotemporal knowledge base of GLC, the spatiotemporal knowledge graph of GLC is constructed by coupling discrete knowledge points through structural modelling and association processing. For example, the key word "Yangtze River" is matched to the knowledge entity "Yangtze River (River)" in the Knowledge graph, and knowledge points with hierarchical and structural characteristics are provided. It includes the basic attribute information such as the alias, length, drainage area of the Yangtze River, and the association relationships such as the birthplace and the entities of each tributary, as well as the geographical spatial distribution, morphology, etc., and are matched with real photos and map images.

(3) Using basic map templates, user demand models and dynamic map generation rules are constructed to achieve on-demand map generation. For example, based on user demand, a map of global changes in arable land can be produced.

(4) Knowledge-based service is developed for browsing, searching, answering questions, and recommending GLC spatiotemporal change knowledge for application requirements in different fields. It is designed to build a GLC spatiotemporal change knowledge service system that covers descriptive, diagnostic, predictive, and programmatic knowledge services. Descriptive knowledge services provide qualitative or quantitative knowledge statements, such as the Nile River, which is the longest river in the world. Diagnostic knowledge services provide diagnosis of problems and phenomena, such as lakes that have decreased in size in the past decade and the

genetic mechanism. Predictive knowledge services, providing simulation and deduction services, such as analysis of changes in specific urban agglomerations after ten years. Programmatic knowledge services can provide systematic solutions to specific problems, such as analyzing the causes and solutions for the reduction of Amazon rainforest area.

3.2 System Framework Design

The framework of the GLC spatiotemporal change knowledge service system is composed of five parts, including infrastructure layer, collection service layer, storage service layer, professional knowledge service layer, and general knowledge service layer. The overall conceptual design of the GLC spatiotemporal change knowledge service system is shown as Figure 1. The system framework is shown in Figure 2.

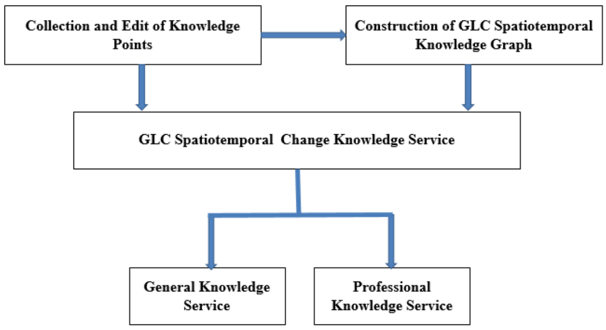

Figure 1. Overall conceptual design of the GLC spatiotemporal change knowledge service system.

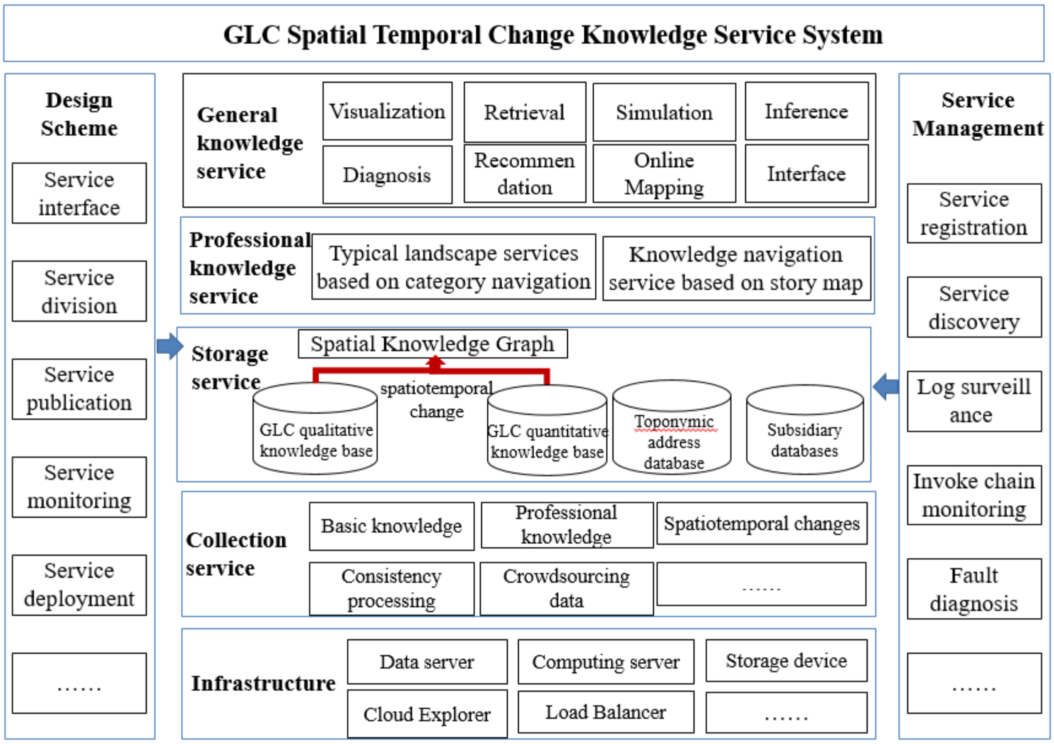

Figure 2. Framework of the GLC spatiotemporal change knowledge service system.

Infrastructure layer is the physical foundation of other layers, mainly including network, server, security equipment, storage equipment and supporting software. It provides basic support for the system.

The collection layer collects and compiles the GLC basic knowledge, professional knowledge, and spatiotemporal change, based on the GLC spatiotemporal change knowledge system and processed GLC data. By establishing the association of objects with the same name, the redundancy of knowledge points is eliminated, and knowledge points are structured though semi-automatic or automatic way.

The storage layer stores the multi-source spatiotemporal data and spatiotemporal corpus of the system. It provides data sources for knowledge services on demand.

The professional knowledge service layer includes typical landscape service based on category navigation and knowledge navigation service based on story map. Taking the GLC spatiotemporal change knowledge points as the knowledge source, and the knowledge graph dynamically constructed as the knowledge service model, the typical landscape service based on category navigation is designed and implemented. It conveniently provides typical knowledge browsing services. The knowledge navigation service based on story map is developed by integrating online GLC data and qualitative and quantitative knowledge. It provides visual spatial pattern, changing trend, causal mechanism and other GLC spatiotemporal change knowledge.

According to the design principle of "hierarchical design and module construction", the general knowledge service layer adopts a service-oriented architecture (SOA) to ensure the rationality and scalability of the system structure. With the support of spatial information analysis technology, visualization technology, spatiotemporal knowledge retrieval and spatiotemporal knowledge combination technology, it develops data integration, data analysis, knowledge visualization, knowledge browsing and query, knowledge push, knowledge diagnosis and spatiotemporal change knowledge simulation, deduction and other functions, forms knowledge maps, realizes the spatiotemporal integration service and management of GLC change knowledge. It develops the GLC online mapping subsystem to provide data services, knowledge services and map services for scientific research, government decision-making and public application.

3.3 Key Technologies

3.3.1 Application-oriented GLC Knowledge Graph Dynamic Construction Technology: With the changes of GLC knowledge, the GLC knowledge graph needs to be constantly updated. However, the GLC knowledge graph should show the spatiotemporal and attribute information of the elements. The manual construction cannot meet the application requirements because of the diversity and complexity of data types. The system realizes the temporal, spatial and semantic association of knowledge by analysing the GLC spatiotemporal change knowledge and the data structure of knowledge points, calculating time series topological relationship, qualitative reasoning of spatial relationship, co-occurrence of word frequency and category matching. For different knowledge graph data models such as resource description framework (RDF), web ontology language (OWL) and attribute, methods based on relationship and native graph are adopted to develop the structured storage technology scheme of GLC spatiotemporal knowledge. Based on the specific application requirements of the service system, the ontology technology is used to study the relationship between the GLC spatiotemporal change knowledge and the application field knowledge in the form of triple. Then with the application field as the primary node and the application field goal as the secondary node, the relationship between land cover and application goals is studied from the dimensions of spatial pattern, regional differences, time changes and attribution mechanism to dynamically construct spatial knowledge graph.

3.3.2 Online knowledge service technology for efficient human-computer interaction: The efficient human-computer interaction capability is the key technology to be solved in the GLC spatiotemporal change knowledge service system. In order to realize the efficient human-computer interaction, not only is it necessary to decompose the GLC spatiotemporal knowledge at the semantic level, forming a representation hierarchy of condition description, interpretation knowledge and supporting information, but it is also necessary to associate and co view knowledge at different scales. In addition, it is also necessary to design the GLC knowledge visual expression, easy-to-operate navigation function, convenient knowledge browsing and querying, and user friendly interface.

4. IMPLEMENTATION OF THE GLC SPATIOTEMPORAL CHANGE KNOWLEDGE SERVICE SYSTEM

The system adopts the browser/server technology architecture, based on hypertext mark-up language 5 (HTML5) + cascading style sheets (CSS) + Javascript and Java 2 platform enterprise edition (J2EE) architecture, using MyBatis as the programming language, and Mapbox as the development tool. The Neo4j is used to store the GLC knowledge points and establish the relationship between the knowledge points. PostgreSQL is used to store spatial databases. Geo server is used to publish map and to realize intelligent management, simulation, deduction, sharing and utilization of the GLC spatiotemporal change knowledge, to meet in-depth application needs of users.

4.1 Statistics of the GLC Spatiotemporal Change Information

The statistical tool of the GLC spatiotemporal change information has been developed, integrating relevant statistical calculation algorithms. It realizes the calculation, statistics and mapping of indicators for global national and user-defined regions.

Statistical indicators include spatial statistics and spatial pattern information indicators (Table 2) and dynamic change information indicators (Table 3). These statistical indicators are encapsulated into services that support dynamic calculation of user input parameters. These indicators are used to guide spatiotemporal change data mining. For example, the Diversity index of landscape size is reflected by calculating landscape expansion changes.

Indicator Name	Symbol/Calculation Method
Area	S_i
Longitude and latitude distribution	$S_i(lon)$, $S_i(lat)$
Proportion	$P_i=S_i/S$
Patches number	N_i
Average patch area	$\overline{A}=\frac{1}{N_i}\sum_{i=1}^{N_i}A_{ij}$
Percentage of landscape area occupied by patches	$PLAND=\frac{\sum_{j=1}^{n}A_{ij}}{A}\times 100\%$
Compactness	$C=\frac{2\sqrt{\pi A}}{L}$
Landscape size diversity index	$PSCoV=\frac{1}{\overline{A}}\sqrt{\frac{\sum_{i=1}^{m}\sum_{j=1}^{n}\left[a_{ij}-\left(\frac{A}{N}\right)\right]^2}{N}}$
Local blank autocorrelation	$G_i=\frac{\sum_{j=1}^{t}w_{i,j}x_j-\overline{X}\sum_{j=1}^{t}w_{i,j}}{s\sqrt{\left[t\sum_{j=1}^{t}w_{i,j}^2-\left(\sum_{j=1}^{t}w_{i,j}\right)^2\right]/(t-1)}}$

Table 2. Spatial statistics and spatial pattern information indicators.

Indicator Name	Symbol/Calculation Method
Transition matrix	$S_{ij}=\begin{bmatrix} S_{11} & S_{12} & \cdots & S_{1n} \\ S_{21} & S_{22} & \cdots & S_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ S_{n1} & S_{n2} & \cdots & S_{nn} \end{bmatrix}$
ariation	$U_t=S_b-S_a$
Net change index	$N_t=\frac{S_b-S_a}{S_a}\times 100\%$

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Single dynamic degree	$Q_t = \frac{S_b - S_a}{S_a} \times \frac{1}{T_b - T_a} \times 100\%$
Landscape expansion index	$LEI = \frac{A_0}{A_E - A_p} \times 100$
Average plaque expansion index	$MEI = \sum_{i=1}^{N} \frac{LEI_i}{N}$

Table 3. Dynamic change information indicators.

4.2 Knowledge Point Visualization, Deduction and Simulation

This system has realized the display of knowledge points from the global perspective, including the total number of knowledge points and categories across seven continents and countries (as shown in Figure 3). On the left section of Figure 3, circles are used to represent knowledge points, and different colors represent different types of knowledge points. The circles are connected by lines to indicate their association. The text inside the circle describes the type of knowledge point. On the right section of Figure 3, circles are an aggregation of knowledge points, and numbers represent the number of knowledge points of this type.

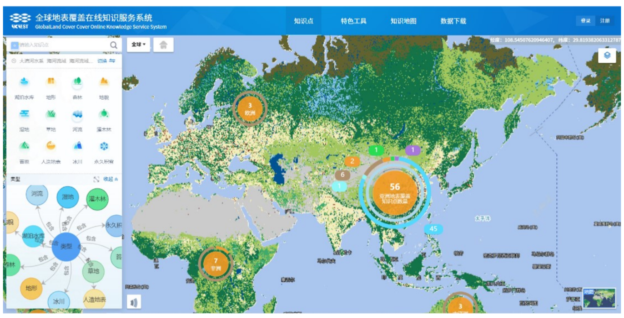

Figure 3. Global knowledge points display.

The system can search the key words of knowledge points and browse the directory structure of knowledge points. The system can simulate and deduce the GLC spatiotemporal change knowledge, such as the spatiotemporal change knowledge deduction and simulation of land cover in Haihe River basin based on a patch-generating land use simulation (PLUS) model (as shown in Figure 4 and Figure 5).

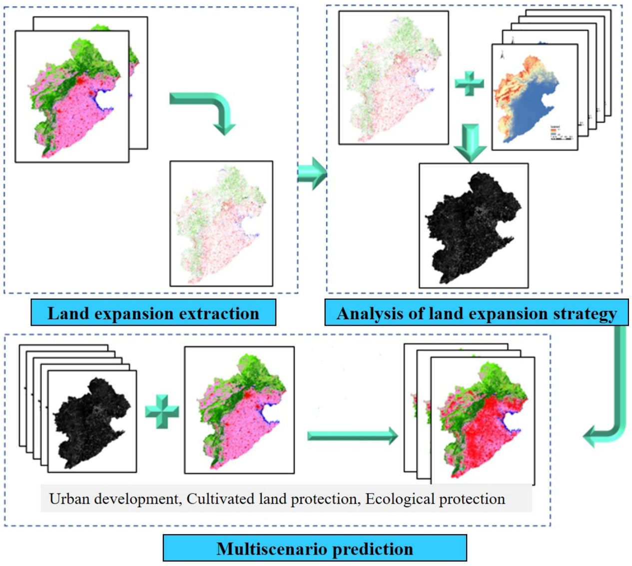

Figure 4. Knowledge deduction process of LC spatiotemporal change in Haihe River Basin on PLUS model.

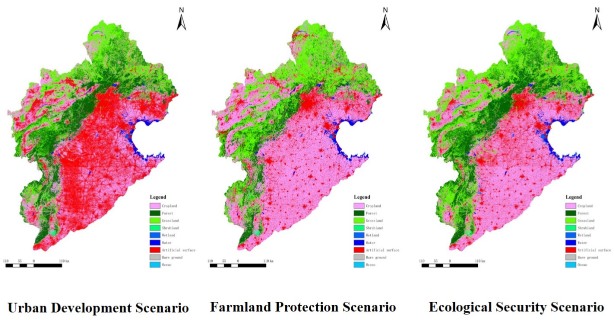

Figure 5. Simulation results of multiple scenarios in Haihe River Basin with PLUS model in 2030

5. CONCLUSION

Based on the analysis of the current situation of the GLC knowledge service system, we adopted the correlation technology such as hierarchy, space and event, to effectively associate and organize massive amounts of information on global land cover spatiotemporal change. A networked and intelligent GLC spatiotemporal change knowledge service system has been built, achieving intelligent management, simulation, deduction, sharing, and utilization of GLC spatiotemporal change knowledge, providing accurate and in-time GLC spatiotemporal change knowledge services for the implementation of major strategies.

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