A Smart Application Frame of Remote Sensing in Non-grain Production Data Governance

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Keywords: Non-grain Production, Intelligent Application, Remote Sensing, Knowledge Base, Model Base.

Abstract

This study addresses the intricate challenges encountered in the data governance process of Non-grain Production (NGP) on Arable land. This involves managing data from diverse sources, with varying accuracies and formats, and utilizing multiple specialized software tools. An object-oriented approach is adopted to encapsulate experiential knowledge related to the data and associated processing methods, thus creating an Application Knowledge Body Model (AKBM). This model acts as a conduit between users and computational resources, encompassing various types of data and their corresponding processing and analysis methods. Moreover, by employing model inference techniques to devise methods for transitioning from raw data models to target models, a foundation is laid for the accumulation, sharing, and intelligent application of expertise on data, methods, models, and knowledge.
The application examples demonstrate that users can directly construct new solutions containing relevant data and associated processing methods, rather than grappling with a multitude of data files and complex specialized software when encountering novel challenges. This promotes collaborative development in data governance on geospatial big data platforms, significantly enhancing governance efficiency, improving the quality of information support in NGP cultivation management, advancing current technological capabilities, and fostering the progression of related technologies.

1 Introduction

1.1 Non-grain Production (NGP)

Non-grain production (NGP) of cultivated land refers to the process of converting land previously used for cultivating staple crops like wheat, rice, and corn into spaces for growing cash crops, floriculture, planting trees, and excavating ponds, or even repurposing it for non-agricultural land, such as urban construction, industrial land, resorts, road, airport, and so on (Zhou et al., 2021 , Cai et al., 2024). NGP is widespread in China because of rapid economic growth and urbanization in recent decades. According to the latest statistics from China, the non-grain production rate (NGPR) in China is approximately 27%, while cultivated land has reduced by 7.53×10^6 ha over the past 20 year (LIU et al., 2021). Furthermore, the average annual reduction in area is expanding.

This poses a serious threat to the country's food security and contributes to ecological and environmental problems such as soil erosion, increased carbon emissions, reduced biodiversity, and additional non-point source pollution(Sun et al., 2022). Planting non-grain crops may lead to changes in rural structure, and may affect the development of traditional agriculture and the employment of farmers(Wang et al., 2022 , Su et al., 2022). NGP may change in the ecological environment of land, increase land use pressure, water resource consumption, and other issues. It may even damage the ecological environment, leading to problems such as ecosystem fragmentation and reduced biodiversity(Wang et al., 2022 , Su et al., 2022). As one of results of NGP, some farmers can also lose their arable land, lose their sources of livelihood and income, which easily lead to land property disputes, farmer rights protection issues, etc.

So, it has been a big challenge to solve the problem caused by NGP for governments and societies. It is necessary to formulate reasonable land use policies, encourage efficient agricultural production methods, promote rational urban planning and layout, and protect cultivated land resources. And there is an urgent need for a long-term, dynamic, and normalized monitoring mechanism.

1.2 Geo-spatial Data Governance for NGP

Geospatial information technique has been used widely to monitor, analyse, and manage NGP by various organizations such as governments, academic institutions, and enterprises (FU et al., 2022 , Li et al., 2021 , LIU et al., 2021). The current geospatial big data platforms, especial basic graphic information and the results of the Third National Land Resource Survey, can better understand and assess its impact, and provide support for decision-making and problem-solving. Besides, some geo-data, which mainly reflect population distribution, density, aggregation centres, rural economic development level, and farmers' income level, are mainly associated data for correlation analysis, exploring the causes of change, and development prediction. Furthermore, the environmental and ecological information is related to land quality, water resource distribution, ecosystem types, biodiversity, and environmental pollution.

Remote sensing technology, especially the domestically developed High-Resolution Earth Observation Satellite series, demonstrates excellent applicability in monitoring NGP (Zhi et al., 2023 , ZHU Cunwei, 2023). The land use and coverage data, obtained periodically through remote sensing technology, has been served as the primary basis(Chivasa et al., 2017).

However, there are still a series of challenges in the NGP data governance (Yun-ling et al., 2024 , Zuo et al., 2023 , Zhi et al., 2023). The main challenges include: 1) Data need to be cleaned and integrated to ensure data quality and integrity because they were usually from different sources, formats, and accuracies(ZHU Cunwei, 2023 , Zhi et al., 2023 , Guoliang et al., 2023 , Su et al., 2022 , FU et al., 2022). 2) It is another to make data privacy protection and prevention of data leakage, because some data can involve sensitive information such as personal, corporate, or government agency geographic locations and land use plans. 3) It requires powerful computing capabilities and efficient data processing and analysis methods due to the large scale of data. 4) NGP is a dynamic process that requires timely updates and monitoring of data (Zhu et al., 2022 , Wang et al., 2022 , Li et al., 2021). 5) It involves data sharing and collaboration among multiple departments and regions, and establishing effective cooperation mechanisms among policies, laws, and government departments is a challenge. 6) Data on land use decisions, urban planning, pollution status, and other sensitive information have profound social impacts, and social acceptance and ethical issues need to be considered to ensure the reasonable use of data.

So NGP data governance faces a series of complex challenges such as data quality, privacy and security, standard interoperability, data processing and analysis, data updating and monitoring, cross-departmental cooperation, and social ethics. Through literature review, there is few dedicated software system for NGP, and the application cases are relatively isolated with poor sustainability.

This study aims to conduct experimental and exploratory research on the sharing of experiential knowledge and skills in the governance of geospatial big data for NGP. It seeks to develop a novel mechanism to streamline processes, reduce complexity, lower talent threshold requirements, foster collaborative development in data governance within geospatial big data platforms, and significantly enhance overall data governance efficiency.

2 System Frame

2.1 System Goals

Successfully implementing NGP data governance requires comprehensive knowledge and skills, along with coordination among multiple departments, due to the need for various specialized software applications to handle diverse data from different sources. The process typically involves the following steps: 1) Regular acquisition of remote sensing data and construction of information extraction models using sophisticated artificial intelligence methods to generate distribution maps of rice planting status. 2) Differential analysis comparing previous results with the outcomes of land surveys to ascertain the state of NGP land use, followed by summarizing the distribution patterns of various transformations. 3) Integration of various basic geographic information data, economic development data, etc., to analyse the underlying reasons. 4) Identification of development trends and establishment of predictive models based on results from multiple periods.

The main tools utilized are remote sensing image processing systems and GIS software, with remote sensing images and digital maps serving as the primary data sources. Coordination among departments and proficiency in using specialized software applications are crucial for the successful execution of NGP data governance.

This study endeavours to devise a solution for the storage, management, and sharing of experiential knowledge concerning the utilization of geo-data and associated specialized software in NGP data governance. It aims to tackle a range of bottleneck technical challenges related to storing experiential knowledge on data collection, processing, data mining methods, models, analysis results, and the dissemination of pertinent knowledge. The ultimate goal is to propel the evolution of these practices towards networked, intelligent, and collaborative approaches.

The anticipated outcomes have the potential to streamline the integrated utilization of relevant data province-wide, fostering the extensive application of domestic remote sensing data and geographic big data platforms in NGP initiatives. This will furnish crucial technical backing for the establishment of the province's natural resources survey and monitoring system, consequently bolstering land protection efforts and ensuring strict adherence to cultivated land redlines. Moreover, the project aims to provide valuable technical insights applicable to the governance of other natural resource quality indicators using geographic big data platforms.

2.2 Basic Conception

The experience knowledge of the types of data used for analysis and the resulting outcomes are of considerable reference value. The optimal choices can be made only when they have a full understanding of the data and functional software. Under the current working mode, individuals must continuously learn and master this knowledge in order to apply various resources to solve specific problems. The core of this research lies in how to structurally store this knowledge and thus achieve knowledge accumulation and sharing.

The project utilizes an *application knowledge body model object* （AKBM） to structurally describe this part of the knowledge. In the AKBM, "data members" provide detailed descriptions of data in specific scenarios, while "method members" depict potential related analyses or process operation. It serves as a functional unit with specific semantic information and is a primary knowledge component in the NGP data governance process. Its structure is as follows:

AKBM object = metadata
+ Data member (data access way and their respective meanings)
+ Method collections (1)

For example, using artificial intelligence learning methods such as neural networks, random forests, and deep learning to construct paddy field extraction models from original remote sensing images; then obtaining data for the distribution map of rice planting status through predictive calculation methods (data members in analysis model).

The current data is oriented towards the general public, serving the majority of users. **Data members** in AKBM are associated with specific data through access way, such as the storage location for data files, user name and PSW for database. The internal database of this system mainly stores regularly acquired remote sensing data, extracted results of paddy field plots (vector data), various analysis results, etc. External data mainly includes land survey data and basic geographic information data provided by geographic big data platforms, mainly accessed through WMS and WFS methods. These data are managed and maintained by unified GIS software.

Method members are used to record various analysis functions performed on the specific data for the purpose of NGP, such as supervised classification, maximum likelihood classification, neural networks, genetic algorithms, random forests, deep learning, etc. artificial intelligence learning methods on remote sensing data; overlay, difference, hotspot, correlation, statistical analysis, regression analysis, etc., on other spatial data. Most of these functions are already implemented in GIS software, and there are also functions specifically developed for non-food land use governance. Method members record the specific meanings of methods in specific application scenarios, executing mechanism and necessary information. These methods may generate new data, and the access location and methods for the new data need to be provided by the data members of the new model; or they may be presented through special interactive interfaces to express the model's intentions. An AKBM without any output method is called a leaf model, which are often the data closest to the target, and cannot be further analysed to produce new results, also known as target models. It's content is often reports, documents, images, etc. Data file outside the model that lacks application significance will be automatically hidden by the system. Some methods require specific conditions to run, such as predictive calculation methods requiring well-trained models or regression equations.

The AKBM can be developed by inheriting data members and methods, and are connected through the outputs of model methods. In a specific application project, there may be multiple models, and these models form a workflow—from the original data model to the target model—through method of models. Users can create a solution by inferring from inputting original data models and target models, or they can generate new solution by modifying existing. All models and solution are knowledge, managed separately through model base and knowledge base system and can be shared on the network.

To specific application, users create a specific solution instance based on existing model sets or solution from the knowledge base. Sometimes, it need to modify and improve model by adding new data and method member, even design new model. After that, the specific data file or data services will be connected to create model instance.

After all input data member were set, the application would run corresponding methods in given order, and obtain final results (model instances). They can also extract models and schemes based on the running results to implement the accumulation of knowledge. Through existing models and schemes, fresher can quickly grasp and apply current knowledge without worrying about the implementation details of specific data and professional software functions; or they can add new methods based on existing projects to accumulate and develop knowledge.

2.3 System Architecture

In order to effectively utilize the data management and processing analysis functions of existing GIS, this system is developed based on the secondary development and implementation of existing GIS software. There are two components, and one independent client (shown in Figure 1) was designed for handling local tasks, responsible for managing local data and related knowledge, and assisting users in accomplishing various data governance tasks. The server aim to providing support for methods, models, and solutions, and accumulating and sharing knowledge for application.

The core of whole frame is that structural storage experience knowledge on processing, sampling, modelling and spatial analysis of different data. The knowledge was divided into four components, which are data, method, model, solution. And 4 subsystem was separately developed to manage the four parts of knowledge. The 4 system consists, shown in Fig1, data management, method base, model base, and knowledge base subsystem.

Data management subsystem main store and manage the access way of each data file or geodatabase, and provide data support for model instances. It can also be replaced with current GIS data management capabilities, such like ArcCatalog, if it was developed based on GIS.

The **Method-base System** is primarily designed to manage all functional procedures that directly process or analyse data or datasets during NGP data governance process. To provide better support for method members of subsequent model libraries. Key describing information, including a unique identifier, name, functional category (pre-processing, modelling analysis, spatial analysis), and functional description, will be encapsulated into methods object in the Method Library System. The methods are responsible for implementing specific functionalities and can directly invoke processing and analysis functions within GIS. It might be the filtering, encapsulation, and reorganizing of existing GIS functionality functions, with supplementation as necessary.

The **Model-base System** focuses on designing, modifying, storage, management, and integrated application of AKBM objects, which encapsulate potential data resources along with their corresponding processing methods and is the core of NGP data governess. The system's primary function is to assist users in defining new models and defining data members for the data management system of the new model and method members for the method library, maintaining relationships between models. The Model Library stores model parameters, related functional functions, and descriptive information, including model name, model type (corresponding to different functional functions), input data, output data, necessary parameters, and functional descriptions. It seamlessly integrates essential data resources with processing method resources, ensuring users can find the required models, clarify necessary data, and define the ultimate goals, laying the groundwork for generating intelligent processing solutions.

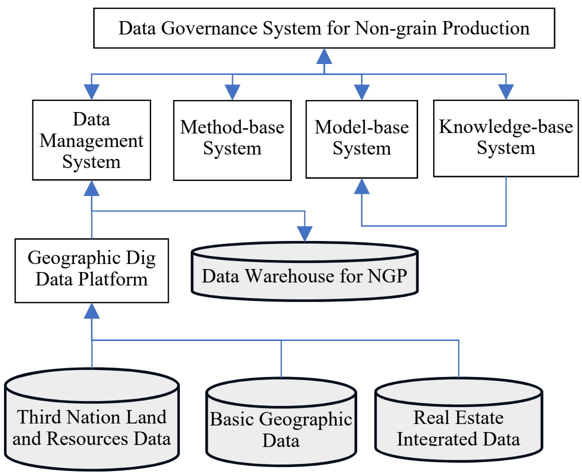

Figure 1 System Architecture of Client

The **Knowledge-base System** primarily assists users in creating, modifying, and managing solutions and instance based on Model-base System. Each solution instance includes details such as name, type, input data, output data or model, application effectiveness score, and a description of the results. The intelligent aspect of this system lies in the ability to generate a series of solutions based on the case library's scoring information, offering choices for users. Each phase of NGP remote sensing monitoring generates a records of solution instance in the knowledge base. Subsequent applications generate recommended solutions based on task types and existing case scores for user selection. Under the solution instance, one can create model instances, attach specific data file, execute methods of model, and generate new model instances and data files.

The proposed working process is as follows. 1) Create solution instance: Create and Modify the instance of solution for specific application; 2) Model Instancing: Attach associated data file for each model in solution instance. 3) Run solution instance: With the help of suggestion solution, some possible interesting region was suggested for supervised classed according to the historical data and land survey data. Then models, which is used to extracting planting areas of crops such as paddy rice, corn, wheat, etc. was created by artificial intelligence analysis methods, such as neural networks, random forests, support vector machines, deep learning, etc. Planting areas for crops was extracted by the constructed models to pre-processed remote sensing image. Then, some on-site investigations regions were identified after accuracy assessments. The final results will be prompt whether to save to the database. 4) Browsing and viewing results: the analysis results may be directly view through the target model after running.

3 Development and Implement

Following the proposed solution, a porotype system of model and knowledge base for NGP data governess was developed using the Python programming language under the Visual Studio Code. The study utilize existing software, such as GIS software, to implement data management functions.

The method base system realize structured storage of relevant method information using method information table, parameter information table and a folder. The **method information table** records the functionality description and type which are categorized based on implementation methods such like GIS function functions, internal functions, etc. And there are relevant information for all input and output parameters of each function includes: data type, input or output, description, etc. in **parameter information table**. In **the folder**, the method base system sets up different calling mechanisms for each method, shielding users from the underlying mechanisms of execution. The system has developed an **interaction interface**, implementing management functions such as adding, deleting, browsing, and querying methods. For each method object, dialog boxes have been developed to modify metadata, categories, set input/output parameter types and executable file. A uniform dialog would be pop up, allowing users to set input and output parameters as running independently. To meet the project requirements, the following analysis functionalities, besides GIS function, are to be implemented: spectral curve analysis, Pearson correlation analysis, Spearman correlation analysis, least squares regression, Partial least squares regression, adaptive reweighted partial least squares regression, support vector machine regression, and random forest regression and so on.

The model base system utilizes structured storage of relevant model information using **model metadata**, **data member**, **method member**, and **input-output parameter table**. Among these, the method member information table records relevant information regarding method calls, while the input-output parameter table documents the correspondence between input and output parameters of method functionalities and model data members. The system has developed an **interaction interface**, implementing management functions such as adding, deleting, browsing, and querying model. For each model object, dialog boxes have been developed to modify metadata, add, delete, and modify data member and method member. The operational interface is depicted in Figure 2.

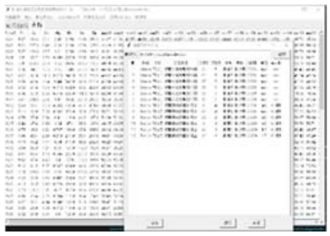

Figure 2 Prototype Model base system operation interface

The knowledge base system assists users in creating cases and related management functions. The Knowledge Base currently integrates processing and analysis cases for two phases of remote sensing data but lacks comprehensive support solution functionality.

Application Examples

This study takes the governance of NGP in Shuikoushan (Shown in Figure 3)as an example to elucidate the application Mechanism of this system. It is a town in Changning county, Hengyang city, Hunan province, and locates in southern Hunan Province and the middle reaches of the Xiang River. It stretches across the east-west direction along the southern bank of the Xiang River, nestled within a hilly terrain characterized by higher elevations in the southwest and lower ones in the northeast. Its area covers 128.92 square kilometres, with a cultivated land area of 32,000 mu (about 21.3 square kilometres). It has a subtropical warm and humid climate, with an annual average temperature of 18.1°C and an average annual precipitation of 1436 millimetres. Rice is the main grain crop. The local economy of the town has been developing rapidly, mainly relying on mining and smelting industries. It has successively been recognized as an advanced town in national village and town construction, one of the top 100 towns in China, and a national key town, winning the reputation of the first town in Hunan.

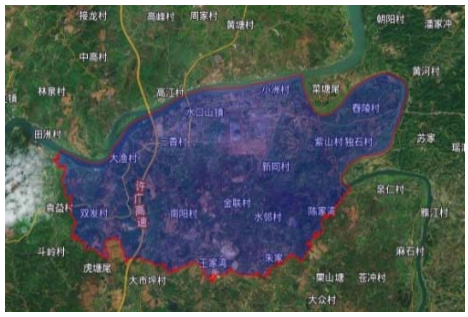

Figure 3 Research Area

However, long-term mining and smelting activities of lead, zinc, and copper mines have severely polluted the local environment. Zhou Min et al. found that except for mercury, which is mildly polluted, the rest are severely polluted (Zhou et al., 2021). The high-content areas of arsenic (As), copper (Cu), and lead (Pb) are mainly concentrated in the Shuikoushan Metal Limited Company and exposed mining areas, while the high-content areas of cadmium (Cd) and zinc (Zn) are mainly concentrated in the smelting area of factories (Zhou Min et al., 2021). Li Gui found that Cd, Hg, Pb, and other heavy metals in the area have caused pollution to the soil environment, and the pollution level has reached an extremely strong degree (Gui et al., 2012). According to national regulations, farmland with heavy metal content exceeding the control value is classified as strictly controlled non-grain land and cannot be directly used for the cultivation of grain crops. Soil heavy metal pollution is also one of the reasons for NGP in this area. Overall, the trend of NGP is quite evident, making it a typical area for the governance of NGP. Using this software, the progress of the project is as follows.

Data Collection and Management: High-resolution satellite imagery data of GF-2 captured on December 7, 2021, and August 2023, with a spatial resolution of 2 meters, were obtained and pre-processed using ENVI to generate orthorectified images. The cultivated land data distribution maps of the third national land and resources survey, land use maps, administrative divisions, transportation, terrain, etc., were obtained through the WFS-connectable Geographic Big Data Platform (Third Surveying and Mapping Institute of Hunan Province).

All were managed using the ArcCatalog of ArcGIS Desktop. A file-based geospatial database for storing and managing relevant data. TIFF files are used to store remotely sensed monitoring data, while feature classes are employed to store extracted land use maps (each phrase named as Y_yyyy_mm) and differential analysis result maps (named as B_yyyy_m_2_yyyy_mm) under the current land use feature dataset and differential result dataset, respectively. Additionally, due to the high content of heavy metals in some cultivated soils, which require strict control according to Chinese law, this study designed *Related Data* and *Result Data* folders to store related data such as soil heavy metal content and various analysis result data files.

This study designed three APBK models, detailed as follows: (1) Developed the ***Cultivated Land Non-Gracilization Monitoring Data Model (original model)*** based on remotely sensed monitoring data, used for extracting paddy fields and analysing the heavy metal content of cultivated land. The following method member were developed: 1) *Classification extraction methods* such as deep learning and maximum likelihood for generating model files for extracting paddy field plots (original model data members); 2) Python-based inversion calculation methods for extracting paddy field plot data (analysis model data members). 3) For analysing the heavy metal content of cultivated land, regression analysis modelling methods such as least squares, partial least squares regression, random forest, and support vector machine were developed to generate analysis result data files (original model data members); 4) A series of methods for estimating soil heavy metal content were developed to estimate the soil heavy metal content of the monitored area (analysis model data members). (2) ***Current Situation Analysis Model*** of Rice Planting (analysis model): Constructed based on the original model's extracted rice planting plot data, heavy metal content data, third survey data, basic geographic information data, etc. Main methods include change analysis, statistical analysis, correlation analysis, regression analysis, trend analysis, etc. Except for regression analysis and modelling analysis results, the results of the methods are saved in the result model. ***(3) NGP Analysis Result Model (result model)***: Constructed based on the results of methods such as change analysis, statistical analysis, trend analysis, etc., run on the analysis model (data generally consist of thematic maps, reports, documents, etc.); browsing and querying methods were developed, and no new results are generated, making it a leaf model. The detailed information of the three models is as follows:

Model 1: Original Remote Sensing Image {
Primary Metadata: Capture date, sensor type, resolution, etc.
Primary Data Members:
Remote sensing image files (.tiff)*
Paddy field identifying deep learning model files
Heavy metal regression analysis model files
Soil heavy metal content sampling data
Primary Method Members:
Rice planting plot learning methods
Rice planting status extraction methods: (generate rice planting status distribution)
Heavy metal pollution learning methods
Heavy metal pollution inversion methods: (heavy metal pollution distribution)
}

Model 2: Analysis Model {
Primary Metadata: Time range, vector polygon data, etc.
Primary Data Members:
Rice field distribution map;
One-year change data (named B1_yyyy_m_2_yyyy_mm);
Heavy metal content data
The Third National Land Resource Survey (WFS feature classes)

Primary Method Members:
1, 5, and 10-year difference analysis (change thematic maps and statistical tables)
Correlation analysis methods
Statistical analysis
Trend analysis
Others
}

Model 3: Result Model {
Primary Metadata: Name, creator, date, etc.
Primary Data Members:
Current status maps (in PDF format)
One-year NGP distribution maps and change statistical tables:
Five-year NGP distribution maps and change statistical tables:
Ten-year NGP distribution maps and change statistical tables
Correlation analysis reports
Trend analysis reports
Primary Method Members:
Result browsing
Viewing
}

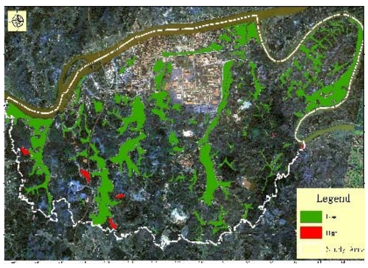

Figure. 4 Research Area

The first phase of monitoring began by creating a solution from scratch, selecting three models from the model base to create model instances. In the first phase, soil heavy metal pollution was not considered. Combining with the parameter types defined by the model data members, appropriate actual parameters were set, and then the scheme was executed to obtain the final result model instance. The second phase of monitoring involved creating a new solution instance based on existing ones; new models could also be added to obtain new results. The final results show in Figure 4, the red areas indicate clearly NGP, while the green areas represent rice cultivation zones.

4 Conclusion

This solution revolves around the storage of application knowledge, establishing the groundwork for accumulating and applying knowledge in remote sensing data pre-processing, classifier modelling, classification extraction, and non-grain cultivation analysis. The developed prototype system fulfils the pertinent requirements for NGP in Shuikoushan Town, Hengyang, Hunan, China. Nonetheless, the integrated analysis methods, model types, and related knowledge within the system are relatively limited. The capacity to generate comprehensive recommendation solutions based on knowledge remains to be fully developed and enriched in subsequent research and development phases.

The project stores commonly used data and corresponding analysis methods for NGP management of cultivated land in models, thereby obviating the necessity for users to directly engage with data and professional software, consequently reducing the learning curve. This facilitates users in swiftly grasping relevant knowledge and further building upon the existing foundation. The solution is realized through secondary development based on GIS software, leveraging GIS databases and associated functionalities to their fullest extent, thereby reducing development complexity and ensuring technical feasibility. Nevertheless, there is still scope for further enhancement in terms of user interaction and model enrichment.

Acknowledgements

This research received support from the Open Topic of Hunan Geospatial Information Engineering and Technology Research Centre (No. HNGIET2023003), the Natural Resources Research Project of Hunan Province (No. 2021-02), and the Research Boost Plan Project of Changsha University of Science and Technology (No. 2019QJCZ007). We extend our sincere appreciation for the generous support provided by these funding sources. Additionally, we would like to acknowledge the Hunan Province Cloud Remote Sensing Image Data Sharing Platform (www.img.net) for granting access to the remote sensing data utilized in this study.

References

CAI B-L, LIU T, CAO G-Z, et al. 2024. The impact of family differentiation on the pattern of farmland utilization in rural China: Based on a nationwide survey of thousands of households in one hundred counties. *JOURNAL OF NATURAL RESOURCES* [J], 39: 392-410.

CHIVASA W, MUTANGA O, BIRADAR C 2017. Application of remote sensing in estimating maize grain yield in heterogeneous African agricultural landscapes: a review. *International Journal of Remote Sensing* [J], 38: 6816-6845.

FU H, WANG G, QIAO H 2022. Study on Technologies of Non-grain Cultivation of Cultivated Land Monitoring Based on National Geographic Conditions Monitoring Data. *Geomatics & Spatial Information Technology* [J], 45: 37-38+43.

GUOLIANG X, LINGYING L, CAN Y 2023. Identification and driving mechanisms of non-grain cultivated land in hilly and mountainous areas based on multi-temporal Sentinel-1A images. *Transactions of the Chinese Society of Agricultural Engineering* [J], 39: 1-10.

LI Y, ZHAO B, HUANG A, et al. 2021. Characteristics and driving forces of non-grain production of cultivated land from the perspective of food security. *Sustainability* [J], 13: 14047.

LIU Z-J, ZHONG H-M, LI Y-R, et al. 2021. Change in grain production in China and its impacts on spatial supply and demand distributions in recent two decades. *JOURNAL OF NATURAL RESOURCES* [J], 36: 1413-1425.

SU Y, SU C, XIE Y, et al. 2022. Controlling Non-Grain Production Based on Cultivated Land Multifunction Assessment. *International Journal of Environmental Research and Public Health* [J], 19: 1027.

SUN Z, ZHU Q, DENG S, et al. 2022. Estimation of crop residue cover in rice paddies by a dynamic-quadripartite pixel model based on Sentinel-2A data. *International Journal of Applied Earth Observation and Geoinformation* [J], 106: 102645.

WANG Q, WANG H, CHANG R, et al. 2022. Dynamic simulation patterns and spatiotemporal analysis of land-use/land-cover changes in the Wuhan metropolitan area, China. *Ecological Modelling* [J], 464: 109850.

YUN-LING C, MAO-JUN W, GUANG-ZHONG C, et al. 2024. The impact of family differentiation on the pattern of farmland utilization in rural China: Based on a nationwide survey of thousands of households in one hundred counties. *JOURNAL OF NATURAL RESOURCES* [J], 39: 392-410.

ZHI J, CAO X, LIU W, et al. 2023. Remote Sensing Monitoring and Spatial Pattern Analysis of Non-Grain Production of Cultivated Land in Anhui Province, *China. Land* [J], 12: 1497.

ZHOU M, QI Z, LYV J, et al. 2021. Pollution Assessment and Spatial Distribution of Heavy Metals in Shuikoushan Town based on GIS. *Chinese and Foreign Architecture* [J], 240: 98-101.

ZHU CUNWEI C Y, SUN LIYUN, DUAN WENHUA, WANG TIEJUN 2023. Exploration on Monitoring Methods of "Non-agriculturalization" and "Non-grain growing" of Cultivated Land Based on Remote Sensing Images. *Geomatics & Spatial Information Technology* [J], 46: 104-107.

ZHU Z, DAI Z, LI S, et al. 2022. Spatiotemporal Evolution of Non-Grain Production of Cultivated Land and Its Underlying Factors in China. *International Journal of Environmental Research and Public Health* [J], 19: 8210.

ZUO J, ZHONG K, XU J, et al. 2023. Analysis on early rice distribution and spatio-temporal changes based on multi-temporal SAR data in Lingnan. *Science of Surveying and Mapping* [J], 48: 91-99.