Sustainability in Environment
ISSN 2470-637X (Print) ISSN 2470-6388 (Online)
Vol. 10, No. 4, 2025
www.scholink.org/ojs/index.php/se

Original Paper

Research on Environmental Monitoring Data Sharing Based on Blockchain Technology

Mingfeng Lv[1,2], Haijiang Liu[3], Cong Sun[3] & Xizhang Gao[1*]

[1] Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China

[2] College of Resources and Environment, University of Chinese Academy of Sciences, Beijing 100049, China

[3] China National Environmental Monitoring Centre, Beijing 100012, China

[*] Corresponding Author: gaoxz@lreis.ac.cn

Received: August 23, 2025 Accepted: November 05, 2025 Online Published: November 24, 2025

doi:10.22158/se.v10n4p160 URL: http://dx.doi.org/10.22158/se.v10n4p160

Abstract

The importance of secure and efficient sharing of environmental monitoring data is increasingly prominent. However, it still faces numerous challenges, including data silo barriers, conflicts between security and privacy, and difficulties in credible traceability. This paper organically integrates the spatial encoding capability of GeoHash algorithm, the distributed storage capability of InterPlanetary File System, and the fine-grained management capability of Hyperledger Fabric blockchain into an environmental monitoring data sharing framework. It innovatively proposes a sharing model tailored to spatiotemporal sensitivity, massive volume, multi-source heterogeneity, and station correlation characteristics of environment monitoring data, and constructs a consortium blockchain-based architecture for environment monitoring data sharing. Meanwhile, air quality monitoring data was selected as a typical sample to test and evaluate the system's functionality. Results demonstrate that this model resolves privacy conflicts and performance bottlenecks, ensures credible sharing and controllable permission, and confirms the feasibility and effectiveness of the system architecture. This model not only deepens the application value of blockchain technology in environmental monitoring and governance but also provides significant theoretical references and practical paradigms for constructing a nationwide unified, cross-regional collaborative environmental monitoring data credible sharing network.

Keywords

environmental monitoring, data sharing, blockchain, GeoHash, InterPlanetary File System,

Hyperledger Fabric

1. Introduction

Environmental monitoring data represents a multi-source heterogeneous information collection obtained from various monitoring stations through systematic scientific methods and technical means, reflecting the status and dynamic changes of environmental systems. As a core element of environmental governance, the secure and efficient sharing of environmental monitoring data has become a cornerstone for achieving precise environmental regulation and public health protection, while also serving as a fundamental requirement for cross-regional governance and global collaboration. Government departments need multi-source data to support environmental decision-making, research institutions rely on shared data to construct environmental models, and the public understands environmental risks through open data. In January 2022, the Ministry of Ecology and Environment mentioned in the "14th Five-Year Plan for Ecological and Environmental Monitoring" the necessity of organizing the nationwide networking of monitoring data at all levels and categories, standardizing data resource sharing and services, accelerating cross-regional and cross-departmental interconnection, and enhancing data integration, sharing and exchange, and business collaboration capabilities. In March 2024, the Ministry suggested in the "Implementation Opinions on Accelerating the Establishment of a Modern Ecological and Environmental Monitoring System" to improve relevant institutions for ecological and environmental monitoring data sharing, and enhance the capacity for monitoring data sharing and exchange among national, regional, and local levels through diversified approaches such as public releases, system queries, and data interfaces. In December 2024, the Ministry further emphasized in the "Regulations on Ecological and Environmental Monitoring" that the state should establish and improve mechanisms for the collection, integration and sharing of ecological and environmental monitoring data, and strengthen the management, development, sharing, and application of such data resources.

However, existing mechanisms for environmental monitoring data sharing still face multiple challenges. First, data silos are prevalent, with different institutions experiencing difficulties in cross-platform integration of environmental monitoring data due to differences in data standards, storage formats, and management approaches. Second, there exist significant contradictions between privacy, security, and interests in data sharing. When environmental monitoring data involves sensitive geographic locations, data providers often choose to restrict data access due to concerns over legal and compliance risks. Meanwhile, the involvement of multiple stakeholders further exacerbates the difficulties of sharing. In addition, ensuring data traceability remains challenging, as monitoring data may be tampered with during transmission, and traditional centralized platforms struggle to provide complete traceability chains, thereby weakening data credibility. Therefore, it is imperative to establish a transparent, efficient, and secure mechanism for environmental monitoring data sharing, so as to maximize the value of such data in assessing environmental quality compliance, revealing pollution evolution patterns, and supporting environmental risk warning and emergency response.

The rapid development of blockchain has brought new possibilities for environmental monitoring data sharing. In October 2008, Satoshi Nakamoto published the online paper "Bitcoin: A Peer-to-Peer Electronic Cash System", since which blockchain has gradually entered public view and attracted widespread social attention. Blockchain is a distributed ledger formed by using cryptographic techniques to sequentially append consensus-confirmed blocks, including a distributed and equally deployed system and a distributed shared database, where all network nodes participate in collaboration, applying digital signatures and integrity verification to ensure data authenticity, temporal ordering, and integrity. In response to the challenges of environmental monitoring data sharing, the academic community has conducted multiple innovative studies based on blockchain. Zhou W and Long M proposed a blockchain-based environmental monitoring data transmission scheme and a group-based PBFT consensus algorithm, ensuring the security, authenticity, and integrity of environmental monitoring data. Yan J, Zhang F et al. combined blockchain and intelligent trusted devices to uniformly manage environmental monitoring data, making data processing, consensus, and publication require multi-party authentication, and solving the problem of falsification in data sharing. Chen J, Liu Z et al. designed a blockchain-based environmental monitoring data sharing system by leveraging the commonalities between blockchain and the Internet of Things, enhancing the speed of data transmission in blockchain while ensuring secure communication between user nodes and the system. Gade P K improved the integrity and monitoring capabilities of environmental data through AI-driven blockchain technology to support real-time environmental monitoring data exchange and collaboration among government agencies, research institutions, and commercial sectors. Liu Y constructed an environmental monitoring data security sharing model for environmental pollution governance in remote areas by introducing blockchain technology and cloud storage, providing a new technical reference for secure sharing of environmental monitoring data in remote regions.

Previous studies have provided valuable new insights into the application of blockchain technology for the trusted sharing of environmental monitoring data, but certain limitations still exist. Some studies primarily focus on treating environmental monitoring data as generic data in blockchain, with limited emphasis on their high-frequency spatiotemporal characteristics. Some studies tend to directly store raw environmental monitoring data on-chain, with insufficient discussion of blockchain performance bottlenecks caused by large data volumes. In addition, some studies only propose conceptual models for blockchain-based environmental monitoring data sharing mechanisms, with relatively little experimental work using actual data to adequately validate their effectiveness. Based on this, this paper organically integrates the GeoHash algorithm, the InterPlanetary File System, and Hyperledger Fabric blockchain into a framework, innovatively proposing a blockchain-based environmental monitoring data sharing model. Through theoretical modeling and experimental validation, this paper aims to eliminate trust barriers between data providers and data demanders, promote open sharing of environmental monitoring data resources, and holds significant implications for both the expansion of blockchain technology application scenarios and innovation in environmental monitoring data sharing models.

2. Research Methods

Environmental monitoring data sharing involves multiple stakeholders, primarily including data providers (such as ecological and environmental monitoring centers, local environmental monitoring stations, and third-party monitoring agencies), data demanders (such as government decision-making departments, research institutions, and universities), and traceability verifiers (such as consortium regulatory agencies). Among them, data providers are responsible for uploading data and formulating access policies, data demanders must obtain authorization before requesting access, and all operations are immutably recorded for verification and auditing by traceability verifiers. To construct a highly trustworthy, traceable environmental monitoring data sharing system that also considers user privacy, the research needs to address three core issues: spatial data indexing and location privacy protection, distributed efficient storage and access to massive monitoring data, and multi-party collaborative access control with trustworthy traceability. After comprehensive analysis, the research selected three key technologies: the GeoHash algorithm, the InterPlanetary File System, and Hyperledger Fabric blockchain platform. GeoHash algorithm is used to achieve spatial location indexing encoding and privacy obfuscation processing; IPFS is responsible for distributed storage of source files and content-based reliable access; Hyperledger Fabric blockchain platform serves as the underlying support to ensure trustworthy storage of metadata, fine-grained permission management, and complete operational traceability chain. The fundamental principles of these technologies and their specific applications in this paper are as follows.

2.1 GeoHash Algorithm

GeoHash is a geographic encoding system based on spatial partitioning, invented by Gustavo Niemeyer in 2008. The algorithm divides the map into geometric blocks by encoding latitude and longitude into short alphanumeric strings. The core idea of GeoHash is to map the Earth's surface to a two-dimensional coordinate system, discretizing and encoding space through recursive partitioning. The plane is recursively divided into smaller sub-blocks, with each sub-block having the same code within a certain latitude and longitude range.

Specifically, the GeoHash algorithm generates a GeoHash encoding with precision p for a given point with coordinates (ϕ,λ), where latitude and longitude $\lambda \in [-180°,180°]$. Taking latitude as an example, recursive binary partitioning is performed, calculating the result of each partition to generate the binary encoding of latitude, as shown in Formula (1).

$$b_i^{\phi} = \begin{cases} 0, \ \phi < \dfrac{LatMin + LatMax}{2} \\ 1, \ \phi \geq \dfrac{LatMin + LatMax}{2} \end{cases} \tag{1}$$

LatMin and LatMax are then updated according to the value of b_i^{ϕ}, as shown in Formulas (2) and (3).

$$LatMin = \begin{cases} \dfrac{LatMin + LatMax}{2}, \ b_i^{\phi} = 1 \\ LatMin, \ b_i^{\phi} = 0 \end{cases} \tag{2}$$

$$LatMax = \begin{cases} LatMax, \ b_i^{\phi} = 1 \\ \dfrac{LatMin + LatMax}{2}, \ b_i^{\phi} = 0 \end{cases} \tag{3}$$

Similarly, the binary encoding of longitude is obtained through the same recursive partitioning, and the binary encodings of latitude and longitude are alternately combined to generate a complete binary sequence, as shown in Formula (4).

$$B = \left[b_1^{\lambda}, b_1^{\phi}, b_2^{\lambda}, b_2^{\phi}, \cdots, b_k^{\lambda}, b_k^{\phi}\right] \tag{4}$$

Each GeoHash character corresponds to 5 binary bits, The binary sequence is grouped in sets of five, as shown in Formula (5).

$$B = \left[b_1, b_2, b_3, b_4, \cdots, b_p\right] \tag{5}$$

Each group of binary sequences is converted to decimal numbers and then converted to corresponding characters through the Base32 table to obtain the GeoHash encoding, as shown in Formula (6).

$$GeoHash = Base32\left(\sum_{i=0}^{4} b_{p,i} \times 2^{4-i}\right) \tag{6}$$

This paper utilizes the GeoHash algorithm to encode the coordinate information in environmental monitoring data, forming spatial indexes and providing auxiliary information for subsequent digital watermark embedding. Moreover, although GeoHash is calculated from latitude and longitude, it does not represent the precise location of a point but rather describes the area containing that point, which can help to obfuscate user locations and support a certain degree of privacy protection.

2.2 InterPlanetary File System

The InterPlanetary File System (IPFS) is a peer-to-peer distributed hypermedia transfer protocol based on content addressing, designed to achieve persistent, efficient, and decentralized file storage and sharing. IPFS integrates the advantages of multiple technologies including Distributed Hash Table (DHT), incentivized block exchange (BitTorrent), version control systems (Git), and Self-certifying File System (SFS), thereby overcoming the single point of failure problem of traditional distributed storage systems and significantly enhancing system fault tolerance and robustness. The IPFS storage network consists of multiple nodes running the IPFS protocol, where data is divided into multiple blocks and distributed across different nodes during storage. When nodes request data from the network, the file is cached locally, ensuring that even if some nodes storing the resource exit the IPFS network, the resource can still be retrieved from other nodes, which improves both the availability and persistence of data.

The HyperText Transfer Protocol (HTTP) is the primary method for transmitting data files over the current Internet. HTTP employs location-based addressing, where users retrieve data through information such as IP addresses, domain names, and system paths. However, if the address changes or the hosting server fails, users cannot obtain the required resources. In contrast, IPFS adopts content-based addressing, where data files generate a unique Content Identifier (CID) through hash algorithms as their unique address. When users search for or download a file, they no longer depend on its storage location but can obtain it from any node possessing a copy of the content simply through the CID.

This paper utilizes the IPFS to store the raw data of environmental monitoring, ensuring access consistency across different devices and locations through the uniqueness of CIDs. Data with identical content exists only once in the system, effectively avoiding data redundancy, conserving storage space, and overcoming the performance limitations of blockchain when storing large files.

2.3 Hyperledger Fabric Blockchain

Hyperledger Fabric is a modular and scalable blockchain platform specifically designed for enterprise permissioned networks, developed by the Hyperledger project initiated by the Linux Foundation in 2015 with the aim of advancing blockchain technology through open-source community collaboration. Similar to other blockchain systems, Hyperledger Fabric consists of a ledger, employs smart contracts, and manages transactions through all participants. However, unlike public blockchains such as Bitcoin and Ethereum, which allow participants with unknown identities to join the network, Hyperledger Fabric is a consortium blockchain platform. It employs Membership Service Provider (MSP) to register all members, allowing only authorized users to query information or create transactions on authorized channels. In this way, users share data exclusively with known participating parties.

Hyperledger Fabric includes multiple core technologies. First, Hyperledger Fabric adopts a modular and pluggable architecture, with components customizable according to business requirements, offering excellent flexibility and scalability. Second, Fabric introduces a Channel mechanism supporting parallel operations of multiple virtual ledgers. The isolation of channels allows network participants to share data within a specified scope without disclosure to the entire network, thereby enhancing privacy protection. Third, the Hyperledger Fabric network employs the built-in Kafka ordering service as its consensus mechanism. Kafka, a high-performance distributed commit log system, provides high-throughput and low-latency transaction ordering services, making it highly suitable for consortium blockchain scenarios of environmental monitoring data sharing. The consensus process is executed by Orderer nodes, which are operated by trusted institutions jointly recognized by consortium members. These nodes are responsible for ordering transactions, packaging them into blocks, and ensuring consistent state across all Peer nodes. Finally, smart contracts in Hyperledger Fabric are called Chaincode, supporting multiple programming languages such as JavaScript, Golang, or Java.

Chaincode can be invoked through specific commands to initiate transactions or query requests, implementing the business logic of blockchain applications.

This paper utilizes the Hyperledger Fabric blockchain to store and manage metadata of environmental monitoring data, and relies on its flexible permission management mechanism, multi-channel architecture, and modular component design to achieve fine-grained control over data access. User operations for data upload and download are all recorded and immutable, ensuring complete traceability queries at any time. This design effectively supports multi-party collaboration in distributed environments. It not only meets diverse data processing needs, but also ensures the security, independence, and trustworthiness of environmental monitoring data.

2.4 System Architecture

Based on the above research methods and key technologies, the technical roadmap of this paper is shown in Figure 1. This technical roadmap describes the overall architecture of the blockchain-based environmental monitoring data sharing system, covering three main stages: data upload, data acquisition, and data traceability.

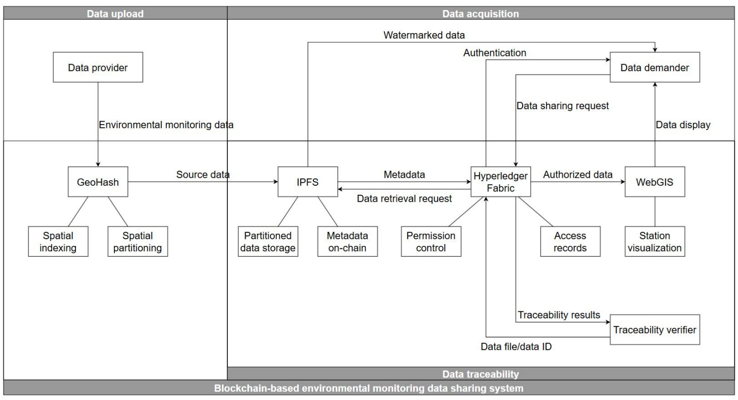

Figure 1. Technical Roadmap of the System

In the data upload stage, environmental monitoring data is uploaded by data providers, and spatial index construction and location partitioning are completed through the GeoHash algorithm. After processing, the raw data is stored in a distributed manner in the IPFS, while the metadata is uploaded to the Hyperledger Fabric blockchain network for subsequent data retrieval. In the data acquisition stage, data demanders need to submit data sharing requests. The Hyperledger Fabric blockchain first performs identity authentication of requesters based on digital certificates, executing permission control and access record management. After authorization, demanders can access data stored in IPFS and visualize the monitoring data. Downloaded data will be embedded with digital watermark information derived from the GeoHash and transaction hash codes, serving as identifiers for subsequent traceability verification. In the data traceability stage, any user can act as a traceability verifier to verify the authenticity and path of the data. Traceability verification can be conducted in two ways. First, verifiers can upload the downloaded data file, and the system will verify whether the file belongs to the system based on watermark information and precisely trace its acquirer. Second, verifiers can input the data ID, and the system will present the complete traceability chain results from upload, distribution and circulation to final download.

Meanwhile, the time-sequenced behaviors of functional objects in each stage are modeled. First, the sequence diagram of the data upload stage is shown in Figure 2. The functional objects in this stage include the data provider, data addition window, map visualization module, GeoHash module, IPFS module, and blockchain module.

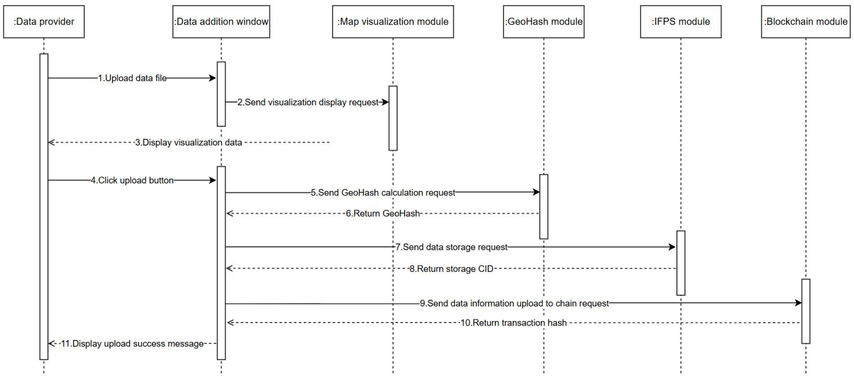

Figure 2. Sequence Diagram of Data Upload Stage

Second, the sequence diagram of the data acquisition stage is shown in Figure 3. The functional objects in this stage include data demander, data list window, request list window, blockchain module, and IPFS module.

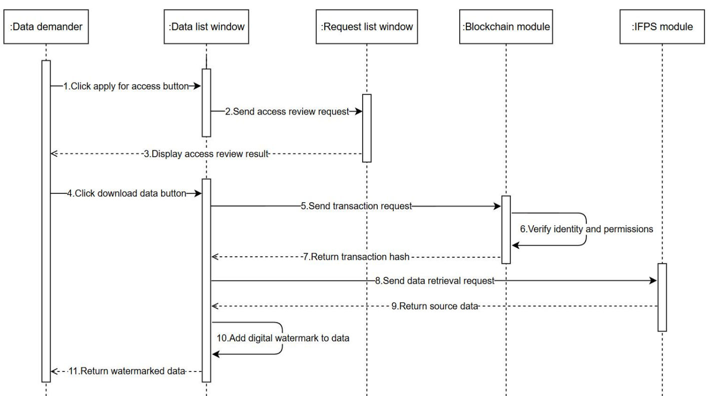

Figure 3. Sequence Diagram of Data Acquisition Stage

Finally, the sequence diagram of the data traceability stage is shown in Figure 4. The functional objects in this stage include traceability verifier, traceability list window, QSCC chaincode, and BASIC chaincode.

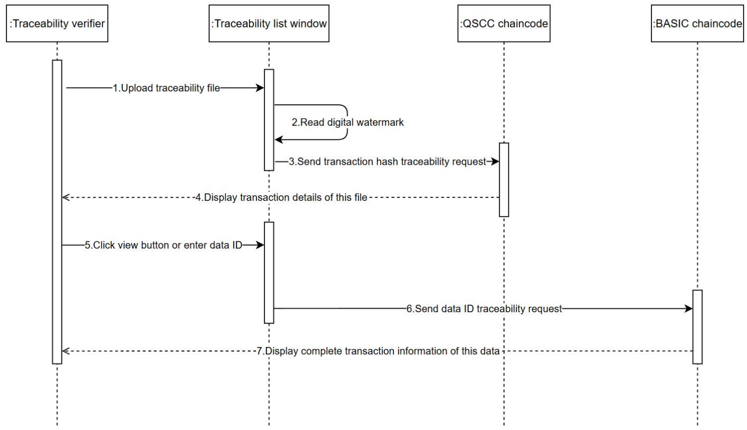

Figure 4. Sequence Diagram of Data Traceability Stage

3. Experimental Data

The business data shared by the system primarily consists of non-classified raw environmental monitoring data (such as pollutant concentration indicators for air, water and soil quality) and metadata (such as station codes, spatiotemporal identifiers and data generation timestamps). Sensitive data involving national security or personal privacy (such as precise coordinates and unpublished monitoring station information) must be processed before sharing.

As shown in Figure 5, environmental monitoring data includes parameters such as air quality, water quality, and soil quality, typically possessing time series characteristics that can dynamically reflect the evolution patterns of environmental factors. As a special type of scientific observation data, environmental monitoring data differs from general data in several aspects. First is spatiotemporal sensitivity: each monitoring data record is strictly bound to its precise geographic coordinates and timestamp, with geographic location directly linked to administrative regions, population distribution, and even sensitive facilities. Second is massive volume: due to high monitoring frequency, numerous monitoring stations, and multiple indicator dimensions, the cumulative dataset of national monitoring is extremely massive. Third is multi-source heterogeneity: data originates from numerous monitoring stations across different regions and levels, with differences in data structure and communication protocols. Finally is station correlation: monitoring data cannot exist independently from its source station. All monitoring values must be linked back to their spatial metadata through station codes to ensure accurate interpretation and use.

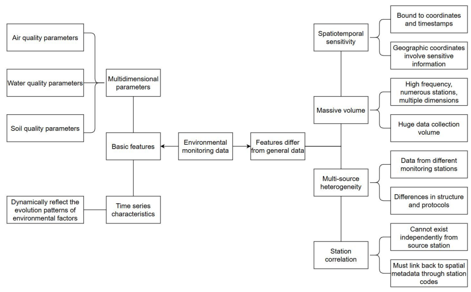

Figure 5. Characteristics of Environmental Monitoring Data

Therefore, to validate the feasibility and effectiveness of the proposed sharing model, this paper selected air quality monitoring data as a typical sample for experimental testing in the environmental monitoring data sharing scenario. The method remains universally applicable and can be applied to all environmental monitoring data sharing scenarios with spatiotemporal sensitivity, massive volume, multi-source heterogeneity, and station correlation characteristics.

The dataset employed consists of national air quality monitoring data from 2014 to 2024, published and updated daily by the National Urban Air Quality Real-time Publishing Platform of the China National Environmental Monitoring Center. The data is provided in text-based CSV format, including the nationwide monitoring stations dataset and the nationwide monitoring points list files, covering the concentrations of six major pollutants - PM2.5, PM10, SO_2, NO_2, O_3, CO and the Air Quality Index (AQI).

The nationwide monitoring stations dataset uses standardized station codes as observation units and is organized in a structured format. The first row contains column names including date, hour, indicator type and codes for each monitoring station, with subsequent rows recording synchronized observation values of a single indicator across all nationwide stations at a specific time. An example of this dataset is shown in Table 1.

Table 1. Example of Nationwide Monitoring Stations Dataset

Date	Hour	Type	1001A	1002A	1003A	1004A	...
20240211	0	AQI	85	30	85	82	...
20240211	0	PM2.5	63	19	63	60	...
20240211	0	PM10	90	30	82	79	...
20240211	0	SO2	4	3	5	1	...
20240211	0	NO2	25	5	18	14	...
20240211	0	O3	58	61	52	63	...
20240211	0	CO	0.4	0.3	0.5	0.4	...
...	...	...	...	...	...	...	...

The nationwide monitoring points list provides spatial metadata, associating spatial information, administrative affiliation, station name, and reference point attributes for each station through its station code. An example of this list is shown in Table 2.

Table 2. Example of Nationwide Monitoring Points List

Monitoring Point Code	Monitoring Point Name	City	Longitude	Latitude	Control Point
1001A	Wanshou West Palace	Beijing	116.3621	39.8784	N
1002A	Dingling (Control Point)	Beijing	116.2202	40.2915	Y
1003A	Dongsi	Beijing	116.4174	39.9289	N
1004A	Temple of Heaven	Beijing	116.4072	39.8863	N
...	...	...	...	...	...

4. Test Results

Based on the experimental data described above, the system functions were tested and evaluated. The system mainly contains four functional pages. The visualization upload test results are shown in Figure 6. Users set the air quality monitoring data ID through the data addition window and upload the corresponding monitoring dataset file. By selecting the air quality monitoring data in the interactive data list, the system reads the monitoring points list file and visualizes the spatial distribution of monitoring stations on the map.

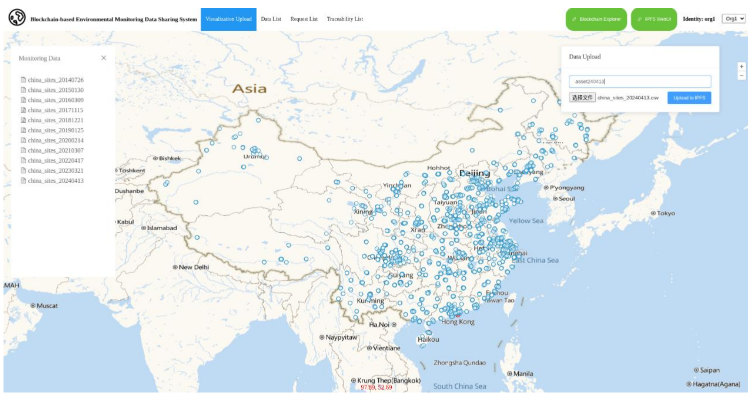

Figure 6. Test Effect of Visualization Upload

The data list test results are shown in Figure 7. Users review the upload information and download status of air quality monitoring data. Users without access permission may send access requests to the data uploader, while users with permission download through the button to obtain data with added digital watermarks. The digital watermarks are used for traceability in case of subsequent data leakage.

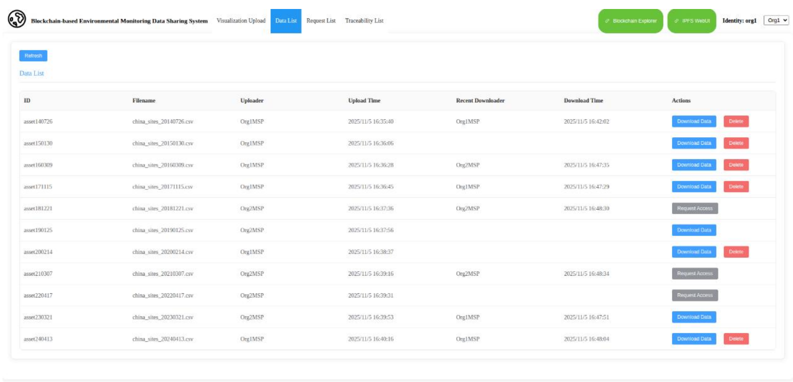

Figure 7. Test Effect of Data List

The request list test results are shown in Figure 8. Users manage access request transactions for air quality monitoring data. According to the user's own identity, uploaders view and approve received data access requests, while demanders view the status and results of their submitted requests. After access permission approval, required data can be obtained from the data list.

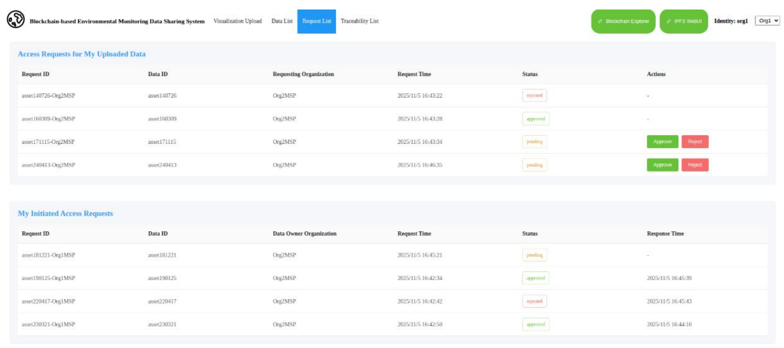

Figure 8. Test Effect of Request List

The traceability list test results are shown in Figure 9. Users conduct trustworthy tracking of air quality monitoring data flow. When submitting a shared data file, the system verifies the embedded digital watermark and displays specific transaction details of data flowing out from this system. When entering the data ID, the system presents the complete traceability chain of the air quality monitoring data throughout its entire lifecycle.

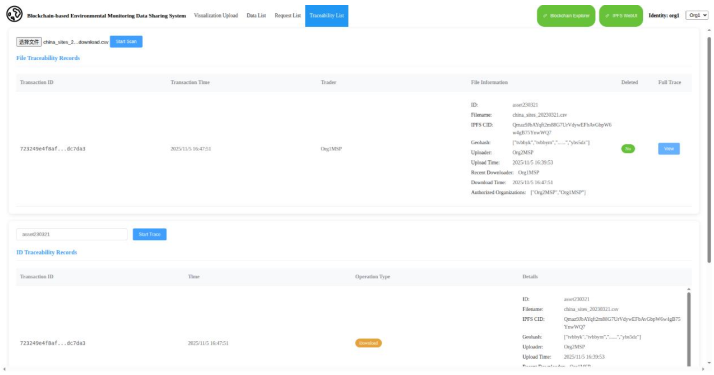

Figure 9. Test Effect of Traceability List

5. Conclusion

Addressing the core challenges of data silos, security risks, and traceability difficulties faced in environmental monitoring data sharing, this paper innovatively proposes a sharing model tailored to the spatiotemporal sensitivity, massive volume, multi-source heterogeneity, and station correlation characteristics of environmental monitoring data. This model deeply integrates the spatial encoding capability of the GeoHash algorithm, the distributed storage capability of the IPFS, and the fine-grained management capability of the Hyperledger Fabric blockchain, constructing a consortium blockchain environmental monitoring data sharing architecture with on-chain notarization, off-chain storage and collaborative governance. The main conclusions are as follows:

GeoHash and IPFS resolve privacy conflicts and performance bottlenecks. By encoding the spatial coordinates of monitoring stations using the GeoHash algorithm, the system achieves efficient spatial indexing while obfuscating specific coordinates, thereby alleviating privacy concerns related to data sharing in sensitive regions. Meanwhile, IPFS is employed for distributed storage of massive raw environmental monitoring data. Its content addressing ensures data integrity and uniqueness while overcoming the storage limitations of blockchain.

Hyperledger Fabric ensures credible sharing and controllable permission. Based on the membership service and multi-channel mechanisms of the permissioned blockchain, the model enforces strict identity authentication and fine-grained permission control among data sharing participants, protecting the data rights of providers. The hash chain structure and timestamp mechanism guarantee that data stored on-chain is fully traceable and immutable throughout, establishing a strong trust endorsement across the entire data lifecycle. Furthermore, the digital watermark mechanism constructed by combining transaction hash and GeoHash enhances the traceability capability for data leakage or unauthorized usage.

Data testing confirms the feasibility and effectiveness of the system architecture. Using urban air quality monitoring data as a test case, all sharing operations in the experimental environment are executed successfully as expected. The results demonstrate that the proposed technical framework can stably support decentralized storage, fine-grained control, on-chain traceability, and map visualization of environmental monitoring data.

In summary, the blockchain-based environmental monitoring data sharing model constructed in this paper successfully explores an innovative path that balances data trustworthiness, security control, privacy protection and efficient utilization, providing strong technical support for breaking down interdepartmental data silos, improving the quality of environmental monitoring data, and ensuring secure and transparent data circulation. This not only deepens the application value of blockchain technology in environmental monitoring and governance but also provides significant theoretical references and practical paradigms for constructing a nationwide unified, cross-regional collaborative environmental monitoring data credible sharing network.

In addition, the research still has several limitations and deficiencies. The privacy protection strength for geographic locations in this paper is limited by encoding precision. How to explore more refined or dynamically adjustable privacy-preserving geographic encoding schemes while ensuring the efficiency of spatial index is one of the future research directions. The design of cross-chain interoperability mechanisms has not been fully considered in the proposed framework. With the expansion of environmental monitoring data sharing networks and the integration of complex blockchain systems, efficient and secure cross-chain data verification and transmission protocols need to be designed to ensure trustworthy sharing and interoperability of environmental monitoring data across heterogeneous chains. Furthermore, future research also needs to extend the application of this paper's system to scenarios with higher real-time requirements, stronger spatial correlations, or more complex data models to verify its universality and robustness.

Acknowledgement

This work was supported by the National Key Research and Development Program of China (2021YFD1300501).

References

Balkić, Z., Šoštarić, D., & Horvat, G. (2012). GeoHash and UUID Identifier for Multi-Agent Systems. In Proceedings of the KES International Symposium on Agent and Multi-Agent Systems: Technologies and Applications, Berlin, Heidelberg: Springer Berlin Heidelberg, 2012; pp. 290-298.

Benet, J. (2014). *Ipfs-Content Addressed, Versioned, P2P File System*. arXiv preprint arXiv:1407.3561, 2014.

Chen, J., & Liu, Z. (2020). Research on the Security Sharing of Environmental Monitoring Data Based on Blockchain. *Management & Technology of SME 2020*, (07), 82-83+87.

Chen, L. (2016). Current Status, Problems and Countermeasures of Atmospheric Environment Monitoring Data Sharing Technology in Our Country. *Environmental Monitoring in China 2016*, *32*(06), 146-147.

Dai, J., & Chen, X. (2023). Discussion on the Role and Development Measures of Environmental Monitoring in Ecological Environment Protection. *Cleaning World 2023*, *39*(04), 115-117.

Feng, X., Liu, T., Wu, S., et al. (2018). *Blockchain Development in Practice: Key Technologies and Case Analysis of Hyperledger Fabric*. China Machine Press: Beijing, China..

Gade, P. K. (2023). AI-Driven Blockchain Solutions for Environmental Data Integrity and Monitoring. *NEXG AI Review of America 2023*, *4*(1), 1-16.

Huang, Y., Lu, F., Sang, X. et al. (2022). Precise Epidemic Control Based on GeoHash. In *Proceedings of the 2022 9th International Conference on Dependable Systems and Their Applications (DSA)* (pp. 1040-1048).

Kounadi, O., & Leitner, M. (2014). Why Does Geoprivacy Matter? The Scientific Publication of Confidential Data Presented on Maps. *Journal of Empirical Research on Human Research Ethics 2014*, *9*(4), 34-45.

Li, L., & Huang, M. (2023). Design of Distributed Storage System Based on the IPFS. *Data Communications 2023*, (04), 5-8.

Liu, Y. (2024). A Secure Sharing Model of Environmental Monitoring Data for Remote Environmental Pollution Control. *Journal of Biotech Research 2024*, *18*, 15-25.

Ministry of Ecology and Environment of the People's Republic of China. (2025). *Notice on Issuing the "14th Five-Year Plan for Ecological Environment Monitoring"*. Retrieved from https://www.mee.gov.cn/xxgk2018/xxgk/xxgk03/202201/t20220121_967927.html

Ministry of Ecology and Environment of the People's Republic of China. (2025). *Notice on Issuing the "Implementation Opinions on Accelerating the Establishment of a Modern Ecological Environment Monitoring System"*. Retrieved from https://www.mee.gov.cn/xxgk2018/xxgk/xxgk03/202403/t20240315_1068473.html

Ministry of Ecology and Environment of the People's Republic of China. (2025). *Letter on Public Solicitation of Opinions on the "Ecological Environment Monitoring Regulations (Draft for Comments)"*. Retrieved from https://www.mee.gov.cn/xxgk2018/xxgk/xxgk06/202412/t20241219_1098871.html (accessed on 1 July 2025).

Nakamoto, S. (2025). *Bitcoin: A Peer-to-Peer Electronic Cash System*. Retrieved from https://bitcoin.org/bitcoin.pdf

Ni, Y., Zheng, M., Zhou, Q. et al. (2024). Discussing the Impact of Data Assetization on Promoting the Sharing and Utilization of Ecological and Environmental Monitoring Data. *Environment and Sustainable Development 2024*, *49*(3), 57-65.

Uddin, M., Memon, M. S., Memon, I. et al. (2021). Hyperledger Fabric Blockchain: Secure and Efficient Solution for Electronic Health Records. *Computers, Materials & Continua 2021*, *68*(2), 2377-2397.

Yaga, D., Mell, P., Roby, N. et al. (2019). *Blockchain Technology Overview*. arXiv preprint arXiv:1906.11078, 2019.

Yan, J., Zhang, F., Ma, J. et al. (2019). Environmental Monitoring System Based on Blockchain. In *Proceedings of the 4th International Conference on Crowd Science and Engineering* (pp. 40-43).

Yang, D., & Lin, K. (2006). Data Sharing Technique in Automatic Entironmental Survey System. *Environmental Monitoring in China 2006*, (05), 1-5.

Yin, L., & Wang, H. (2016). Research on Distributed Data Sharing System Based on the IPFS. *Internet of Things Technologies 2016*, *6*(06), 60-62.

Zhou, W., & Long, M. (2020). Secure Transmission Scheme for Environmental Monitoring Data Based on Blockchain. *Computer Science 2020*, *47*(01), 315-320.