International Journal for Housing Science and Its Applications
Publish August 10, 2025. Volume 46, Issue 4 Pages 8323-8334

https://doi.org/10.70517/ijhsa464710a

Data-Driven Innovation in Environmental Monitoring Systems: Opportunities and Challenges in China's Environmental Governance Modernization

Ye Yue[1,*]
[1]School of Law, Beijing Institute of Technology, 100081, China
Corresponding authors: (e-mail: lawyyyue@163.com).

Abstract In the era of big data, the modernization of national governance systems and capabilities requires a transformation of governance concepts and the optimization of governance mechanisms. It also calls for the full utilization of the Internet, big data, and artificial intelligence to establish and refine supervisory and management methods and rules, ultimately achieving precision and intelligence in administration. Environmental monitoring serves as a critical foundation for China's environmental governance and decision-making. With the formal integration of ecological civilization into China's "five-in-one" overall framework, and as environmental issues become increasingly prominent, leveraging big data to enhance ecological and environmental monitoring through intelligent means has become a key initiative in government-led environmental governance. It is also a prerequisite for ensuring that environmental actors fulfill their obligations and assume legal responsibility under the law. This approach is effective in enhancing the standardization, precision, and scientific underpinnings of China's environmental governance. This study explores how the integration of big data is driving profound changes in governance concepts and practices within the ecological and environmental monitoring system. It also analyzes challenges in China's current ecological and environmental regulatory system, including inadequate and fragmented environmental monitoring legislation, the absence of a well-established data-sharing mechanism, incomplete platform construction, and insufficient management of socialized environmental monitoring institutions. Finally, the study proposes recommendations to strengthen legislation on ecological and environmental monitoring and data, improve the legal framework for data sharing, enhance the development of environmental information and data platforms, and refine the management system for socialized environmental monitoring institutions.

Index Terms big data integration, environmental monitoring, ecological governance, environmental legislation, data-sharing mechanism

I. Introduction

As a fundamental component of China's environmental law framework, the ecological monitoring system plays a pivotal role in informing policy decisions, assessing environmental capacity, verifying total sewage discharge, enforcing environmental standards, ensuring effective law enforcement, evaluating environmental costs, and providing early warnings for pollution incidents. Moreover, it serves as an important channel for the public to exercise their right to access environmental information. Strengthening both the environmental monitoring system and the associated standard framework is essential for establishing a comprehensive environmental legal system and ensuring the effective enforcement of environmental laws [1].

The Fifth Plenary Session of the 19th Central Committee of the Communist Party of China set forth new objectives, including intensifying the fight against pollution and promoting green development. Currently, the ecological monitoring system—serving as a key foundation for ecological civilization and environmental protection—is facing unprecedented opportunities and challenges. In September 2020, China committed to achieving carbon peak by 2030 and carbon neutrality by 2060, thereby integrating climate action with environmental governance and ecological restoration. To adapt to this new climate agenda, it is imperative to monitor and assess climate-related risks, as well as to observe the effects of global warming on vulnerable regions and evaluate their adaptive capacity [2].

As China's eco-environmental governance advances towards greater standardization and precision, there is a pressing need to fully leverage emerging technologies such as the Internet, big data, and artificial intelligence. During the "13th Five-Year Plan" period, significant progress was made in the construction of China's ecological environment monitoring network. Nevertheless,

persistent challenges remain, particularly in system development and environmental law enforcement under big data conditions. The key issues include:

1) Relatively fragmented legislation on ecological environment monitoring;
2) Inadequate mechanisms for the sharing of environmental monitoring data;
3) Incomplete platform development and limited public participation channels;
4) Insufficient regulation and oversight of socialized monitoring institutions.

This study examines the transformative impact of big data on China's ecological environment monitoring system through the lens of governance concepts and practices. It underscores the necessity of enhancing data collection and processing capabilities in the big data era to align with China's broader ecological development goals. This involves strengthening environmental monitoring legislation, improving the legal framework for data sharing, building robust environmental information platforms, and refining the management of socialized monitoring institutions. By implementing these measures, the role of monitoring data in environmental governance decision-making can be elevated, thereby improving the standardization, precision, and scientific foundation of environmental governance in China.

II. Impact of Big Data on Ecological and Environmental Monitoring Systems

The term "big data" was first introduced in 1997, marking the emergence of an era characterized by rapid data growth [3]. Fueled by advances in computing power, storage capacity, and data processing technologies, big data has gradually transformed into a key driver of innovation. Although academia and industry have yet to adopt a universally accepted definition, the most widely recognized concept is the "3V" model. Originally proposed by META Group, Inc. (now Gartner, Inc.) in 2001, this model defines big data as "information assets characterized by high volume, velocity, and variety" [4].

In China's *Ecological Environment Big Data Overall Construction Program*, big data is described as a collection of datasets with large capacity, diverse types, high-speed accessibility, and significant application value. It is rapidly evolving into a new generation of information technology and service industries that involve the collection, storage, correlation, and analysis of massive volumes of heterogeneous data, aiming to uncover new knowledge, generate value, and enhance capabilities [5]. While definitions vary across countries, research institutions, and consulting organizations, the focus here is not on a detailed definitional debate. Instead, it is important to note that big data is closely intertwined with artificial intelligence, as both involve analyzing large datasets to produce predictive insights, assist decision-making, and effectively enhance system intelligence.

II. A. Concept of Governance: From Government Management to Collaborative Governance

Environmental governance has long been a persistent challenge in public administration. One major obstacle is the difficulty of establishing clear accountability due to information asymmetry, compounded by the lack of efficient collaboration between governance entities [6]. For example, in central–local government relations, the central government bears the primary responsibility for addressing environmental issues. However, local governments—often prioritizing economic development—may adopt a more lenient approach to environmental enforcement. This asymmetry of information and priorities limits the central government's ability to ensure effective policy implementation. Similarly, in state–society interactions, the public may demand strict penalties for polluting enterprises, but insufficient evidence or inadequate reporting often hampers the establishment of a strong deterrent.

Just as the Internet transformed communication and information exchange, advancements in emissions monitoring and big data technologies are laying the groundwork for improved environmental monitoring, data processing, and data sharing. In the statistical era, random sampling has been widely adopted as a key measurement method [7]. However, its inherent limitations—such as small sample sizes and challenges in achieving true randomness—can result in overlooked details or missed critical data points. Big data represents more than a technical upgrade: it signifies a paradigm shift from analyzing small samples to examining complete datasets, from prioritizing data accuracy alone to embracing data complexity, and from focusing solely on causality to emphasizing correlation. This shift facilitates new opportunities for multi-actor, multi-level collaborative governance.

Collaborative governance refers to the effective management of public affairs through coordinated action and division of labor among multiple stakeholders, and is widely applied in environmental governance [8], [9]. Due to the public and mobile nature of environmental resources such as air and water, which transcend administrative boundaries, this approach is particularly relevant for addressing cross-border and global environmental challenges, including climate change. Mainstream governance theories emphasize the "virtuous interaction of multiple actors" as essential for effective governance, with collaboration ensuring mixed provision of public goods, improved efficiency, lower transaction costs, and responsiveness to diverse societal needs.

Fundamentally, collaborative governance requires governments to build equitable and cooperative relationships with society and the market, enabling joint management of public affairs through open dialogue and consultation [10]. Its success depends on the creation of enabling mechanisms and institutions, including:

- Government-led coordination frameworks;

- Mechanisms for shared responsibilities and cooperation;
- Incentive structures and operational safeguards;
- Equal consultation processes and collective action mechanisms;
- Tools for balancing stakeholder interests;
- Information-sharing platforms;
- Monitoring and evaluation systems.

A robust coordinated governance system rests on three key pillars:

1) Development of governance actors, including transformation of government functions and strengthening of social organizations;
2) Establishment of mechanisms that clearly define the responsibilities of governance bodies;
3) Creation of a multi-party coordination framework that enhances information technology infrastructure, connects organizational networks, and aligns operational processes.

According to Article 2 of the *Regulations on Ecological Environment Monitoring (Draft for Comment)*, issued by the Ministry of Ecology and Environment on October 24, 2019, ecological environment monitoring encompasses "activities involving sampling, observation, surveys, remote sensing, analysis, testing, evaluation, forecasting, and prediction of environmental quality, ecological conditions, and pollutant emissions and trends, in accordance with relevant laws, regulations, and standards." The monitoring system integrates environmental quality monitoring, pollution source monitoring, and ecological condition monitoring, adopting a systematic perspective of mountains, waters, forests, fields, lakes, and grasslands. Its primary objective is to provide an accurate, timely, and comprehensive picture of ecological status and trends.

As industrial-scale production and pollutant emissions intensify, and as pollutant migration pathways grow increasingly complex, the ecological and environmental monitoring system must evolve. This transformation requires:

1) Expanding participation mechanisms to include diverse actors in environmental monitoring;
2) Strengthening management and quality control of monitoring activities;
3) Enforcing accountability for legal compliance;
4) Enhancing the development of integrated data and information-sharing platforms.

II. B. Governance Practices: Moving from Pollution Control to Risk Management

Human society has entered an era of risk. While scientific and technological advancements have greatly improved quality of life, they have also introduced increasing potential hazards [11]. Consequently, environmental governance has evolved from an end-of-pipe pollution control model toward a proactive risk management approach. Risk regulation, a typical domain of "decision-making under uncertainty," is characterized by significant unknowns in methodology, epistemology, and even ontology [12].

Scholars have argued that one of the major shortcomings of 21st-century environmental policy is its insufficient focus on monitoring and supervision. Variations in data collection standards, formats, and sampling methods among different organizations impede comprehensive, objective, and accurate assessments of pollution levels, pathways, and associated risks. This in turn hinders effective cost–benefit analyses of environmental governance initiatives [13].

The promulgation of the *Soil Pollution Prevention and Control Law* marked a legislative milestone in China, embedding the principle of risk management into law and signaling a shift from the previously dominant "prevention-oriented" approach [14]. Article 3 enshrines the concept of "risk management and control," while Chapter 4 is dedicated entirely to establishing a legal framework for managing and controlling soil pollution risks.

In the era of big data, this shift aligns closely with broader transformations in governance thinking. Since the 18th National Congress, big data and artificial intelligence have been elevated to the level of national strategy. Reforms in the ecological environment monitoring system have emphasized the development of monitoring information platforms, the enhancement of data sharing mechanisms, and improvements in public information disclosure.

Key policy documents—including the *Outline of Action for Promoting the Development of Big Data* (National Development [2015] No. 50), the *"Internet+" Green Ecology Three-Year Action Implementation Plan* (Development and Reform Office of the Environment and Capital [2016] No. 70), the *General Program for Ecological and Environmental Big Data Construction* (Office of the Environment [2016] No. 23), and the *New Generation Artificial Intelligence Development Plan*—have identified persistent challenges in China's environmental informatization. These include institutional inefficiencies, fragmented infrastructure and systems, isolated data repositories, low levels of business collaboration, and underdeveloped utilization of information resources. Together, these weaknesses limit comprehensive decision support and reduce the quality of public environmental services.

The above documents propose measures to integrate environmental data, strengthen platform construction, and improve mechanisms for incorporating monitoring data into policy-making. The overarching goal is to achieve scientific decision-making, precise supervision, and improved ecological public services.

Five years after the launch of the *Overall Program for Ecological and Environmental Big Data Construction*, China has made notable progress in integrating and sharing ecological and environmental data resources. Environmental protection departments at multiple administrative levels have increasingly standardized operational data in key areas, including air, water, soil, nuclear and radiation safety, environmental impact assessments for construction projects, ecology, law enforcement, monitoring, and emergency response. At the national level, data exchange specifications and a unified system of data resource catalogs have been introduced. Within the big data framework, the application of China's ecological environment monitoring system is most prominent in three areas:

1) Pollution control and emission reduction;
2) Prediction and early warning of environmental incidents;
3) Provision of public ecological and environmental services.

II. B. 1) Ecological Pollution Control and Abatement

Intelligent ecological environment monitoring serves as a cornerstone for evaluating pollution control and emission reduction outcomes. On one hand, it enhances real-time, comprehensive, and precise tracking of environmental conditions. This capability is evident in the online monitoring of pollution sources, real-time tracking of key energy-consuming units, and mobile management of hazardous waste [15]. Notably, China has transferred authority for 2,050 national surface water monitoring sections, fully implemented the separation of "collection and testing," and achieved nationwide interconnection and sharing of surface water monitoring data.

On the other hand, intelligent monitoring advances the integration, precision, and grid-based management of environmental law enforcement. According to environmental monitoring and law enforcement cases released by the Ministry of Ecology and Environment between January 1, 2020, and May 1, 2021, authorities have actively explored the "Internet+ Supervision" model. This approach combines drones, remote sensing, real-time data streams, and other technologies to investigate and address environmental violations. These measures have strengthened the procedural linkage between administrative law enforcement and criminal prosecution of environmental crimes, ensuring a more cohesive and effective enforcement process.

Table 1: Environmental Monitoring Enforcement Cases Issued by the Ministry of Ecology and Environment

Sr #	Name of Case	Main Plot	Consequences of Penalties
1	Falsification of environmental monitoring data by a third-party monitoring organization in Chongqing Municipality.	Commissioned by the Water Affairs Bureau to monitor wastewater from 26 sewage treatment plants, the organization falsified monitoring times and manipulated data, issuing two false reports, in violation of environmental monitoring laws.	Administrative penalty of 150,000 yuan on the company and 30,000 yuan on its principal person in charge; reported to the market supervision department for qualification review.
2	Cardboard factory in Xichang, Sichuan Province, altered and falsified monitoring data.	In March 2019, video surveillance indicated illegal nighttime discharge of high-concentration wastewater and falsification of automated monitoring data.	Fine of 800,000 yuan imposed; case transferred to public security.
3	Zhejiang Rui'an Daneng Environmental Protection Technology Company tampering with automatic monitoring data.	Between March 24 and April 9, 2020, workers tampered with nitrogen oxide monitoring instruments over 100 times to create the appearance of standard emissions.	Four individuals criminally detained for environmental pollution.
4	Shandong Jining Huaying Medical Packaging Material Co., Ltd. interfering with online monitoring facilities.	In March 2020, the company disconnected monitoring pipelines; manual checks revealed sulfur dioxide and nitrogen oxides exceeded standards by 4.79 and 12.26 times, respectively.	Criminal case opened; company excluded from positive supervision list due to violation and breach of trust.
5	Hubei Yichang illegal tampering with automatic monitoring data.	Between August 15 and September 11, 2020, the company tampered with exhaust data to evade regulation.	Two individuals convicted of damaging computer systems; sentenced to seven months' imprisonment and six months' detention.
6	Hangzhou environmental crime detected through "Environmental Protection Code."	On March 3, 2021, intelligent analysis revealed collusion to manipulate monitoring probes, concealing excessive emissions.	Case transferred to public security; main suspects under coercive measures.
7	Illegal air pollutant emission by Northwest Lead-Zinc Smelter, Gansu Baiyin Nonferrous Group Co.	On March 30, 2020, abnormal sulfur dioxide detected; investigation used drones and microstations to trace source.	Ordered to correct violations; fine of 122,000 yuan imposed using Gansu Penalty Decision System.
8	Sichuan Province case of excessive emissions and falsified monitoring data.	On March 30, 2021, night discharges of black sewage detected, but monitoring data showed no exceedances.	Case referred to public security for suspected violations.
9	Wenzhou case of hidden sewage discharge detected via "automatic monitoring + drone."	In January 2021, drones located a private concealed pipe used by a printing and dyeing company for illegal discharge.	Administrative detention of responsible parties; 350,000 yuan fine; facilities seized for 15 days.
10	Hubei Huangshi third-party monitoring in law enforcement.	From February 10–13, 2021, sulfur dioxide and particulate matter exceeded daily limits; third-party monitoring confirmed violations.	Case filed by Municipal Bureau of Ecology and Environment; processing ongoing.

II. B. 2) Environmental event prediction and early warning

Predictive analysis of the ecological environment is crucial for effective ecological and environmental governance. It has proven highly effective in areas such as global climate change prediction, ecological network observation and simulation, regional air pollution management, and environmental risk management. For example, the National Air Quality Forecast Information Release System of the Ministry of Ecology and Environment provides forecast data based on results from participating cities, provincial (autonomous region) environmental monitoring units, regional forecasting centers, and relevant environmental protection forecasting departments. These forecasts are derived from pollutant source monitoring, real-time ambient air quality monitoring, air pollution process simulation and analysis, and forecast results from member meetings. However, the data released by the platform are used solely to offer health guidance to the public and are not directly employed for assessing air quality compliance. Most provinces and cities rely on national control points to evaluate air quality compliance.

Furthermore, intelligent ecological and environmental monitoring has enhanced environmental early warning and emergency management. Through a unified monitoring and information management platform, regulatory authorities can link environmental prediction and early warning with emergency response capabilities. In the event of an environmental incident, the intelligent management platform facilitates rapid response, enabling the integration and analysis of information from various departments, real-time reporting, and comprehensive monitoring of the incident's progression. It also helps in allocating emergency resources and agencies effectively, thereby enhancing the government's emergency response capabilities.

II. B. 3) Provision of ecological public services

With the intelligent development of ecological and environmental monitoring, the level of environmental information disclosure in China has steadily improved. The public can now access critical environmental data, such as water quality, air quality, and solid waste discharge permits, through unified government data resource or disclosure platforms. As of May 1, 2021, the Beijing Municipal Government Data Resource Network had disclosed 92 pieces of environmental and resource protection information. The departments involved were the Beijing Municipal Water Bureau, the Bureau of Landscape Architecture and Greening, and the Bureau of Ecology and Environment, among others. Similarly, Shanghai's public data open platform revealed 102 pieces of information related to resources and the environment, with contributors such as the Shanghai Municipal Environmental Protection Bureau, the Commerce Commission, and the Water Bureau.

While most of this public information is available unconditionally, allowing easy access to vital environmental data, there is still a need for improvement in the channels for public participation and feedback on environmental information.

III. Problems of China's ecological environment monitoring system in the context of big data

Unlike public services such as education and healthcare, pollution control involves significant cross-border and even intergenerational spillover effects, making it difficult for decentralized regulatory systems to fully internalize the benefits of regulation [16]. This often leads to "free-riding," where local governments take advantage of the spillover benefits without fully contributing to pollution control efforts. Effective environmental governance requires a systematic approach, where the use of science and technology plays a crucial role. Big data is instrumental in implementing comprehensive environmental regulation by enabling the collection, storage, standardized processing, and circulation of vast amounts of data. This facilitates the communication and coordination between ecological management departments, allowing for remote monitoring of environmental supervision.

Additionally, the decentralized nature of blockchain technology can help prevent forgery and manipulation of monitoring data, ensuring the integrity of the governance process. This integration of technology brings environmental supervision closer to a systematic and reliable public service model.

The United States, as a leader in environmental big data system construction and project promotion, launched the *Big Data Research and Development Program* in 2012 under the Obama administration. Under this strategy, the US Environmental Protection Agency (EPA) accelerated the development of environmental big data. The US experience highlights how environmental regulation has become more functional in the era of big data, leading to more targeted legal rules, accurate monitoring and reporting systems, and significantly improved transparency of environmental information [17]. Key aspects of environmental big data practices in the US include:

1) **Establishment of specialized environmental data agencies.** These agencies provide support for the comprehensive management of environmental data, encompassing "collection–processing–disclosure–technical support." At the federal level, the EPA is the primary authority for environmental information and has prioritized data collection, use, and dissemination. The EPA's Office of Environmental Information (OEI), led by the Chief Information Officer (CIO), oversees the entire data management process. The OEI is divided into four branches: the Information Collection Office, the Office of Technical Operations and Planning, the Office of Information Analysis and Acquisition, and the Office of Program Management. At the state level, regional and state environmental protection departments have environmental information offices or commissioners responsible for collecting, maintaining, and releasing environmental information. This institutional setup ensures a smooth flow of environmental information from the source to the recipient.
2) **Creation of a data monitoring network for integration and sharing.** The EPA developed the Facility Registration System (FRS) to integrate data. FRS registers facilities with sewage disposal rights, including enterprises, sewage treatment plants, civil facilities, and mining operations. Each facility receives a unique Facility Identification Code (FIC), which clarifies the relation between data from different business systems and enables cross-system and cross-database searches. The EPA's Office of Environmental Informatization centrally manages and maintains the sewage FRS. Envirofacts, an EPA environmental data query system, is publicly accessible for queries related to air, water, waste, toxics, radiation, soil, and maps. Additionally, the EPA uses the Central Data Exchange (CDX) for secure and efficient transmission and sharing of environmental data, aiming to create a fast and reliable real-time data exchange network that connects the federal government, local governments, businesses, and EPA branches.

Table 2: Typical cases of US environmental big data in environmental pollution control management innovation [18]

Form	Case (law)	General situation
	Government Database and Open Access Initiatives (GDB&Open Access Initiatives)	Pursuant to the Presidential Executive Order on Achieving Development and Machine Readability of Government Information, initiated by the Office of Management and Budget, a phased approach was implemented to make government data open and machine-readable by default, with the aim of improving data openness, accessibility, and utility. The Data.gov database hosts approximately 70,000 databases, including 32,000 are from the National Oceanic and Atmospheric Administration (NOAA). These datasets range from Caribbean coastal habitat data to image archives spanning from the early 20th century to the present.
	National Geographic Information System Scientific Data Sharing Platform (GeoPlatform)	Initiated by the Department of the Interior, the platform integrates map-based tools and geospatial data collection, services, and applications from federal agencies, state, territorial, local, and tribal governments, as well as nongovernmental contributors. It operates on a shared infrastructure designed to provide one-stop data delivery.
Open Data	Online Enforcement and Compliance History Program Enforcement and Compliance History Online ECHO	The US Environmental Protection Agency has been implementing the program since 2002. Commitments and government enforcement for approximately 800,000 regulated facilities have been uploaded into the system. ECHO includes facilities regulated as stationary sources under the Clean Air Act, as well as facilities regulated as direct dischargers under the provisions of the Clean Water Act, and generators/disposers of hazardous wastes under the Resource Conservation and Recovery Act. 29. It provides information about permits, inspection dates and findings for the past three years, violations, enforcement actions, and penalties. Data are obtained from EPA staff, state, local, and tribal agencies, and regulatory facilities.
	Compliance 2.0 Next Generation Compliance	An action plan, initiated by EPA, to enhance and promote enforcement and compliance with environmental regulations.
	Earth observation system GEOSS	The system connects and integrates Earth and terrestrial monitoring systems to help the international community respond to forest fires, climate change, and natural resource management.
Data sharing	Environmental Response Management ApplicationEnvironmental Response Management Application	The system makes sensitive data available to authorized users and general data available to the public, presenting information from environmentally sensitive index maps, ship positions, and weather and ocean currents to generate integrated data products.
	Computational Toxicology Research Program CompTox	The US EPA created the Computational Toxicology Research Program (CompTox) to address the severe lack of health and environmental data on thousands of chemicals. The data collected are integrated and analyzed through a sophisticated computer system to generate risk-based rankings. This new data collection has led to decision-support tools, such as Toxicity Predictor (ToxCast), which can quickly, efficiently, and cost-effectively screen a large number of chemicals for toxicity risk.
Public engagement	Air quality monitoring Air Quality Monitor	The US Environmental Protection Agency's Office of Research and Development is currently working with the commercial sensor industry and others to develop personal air quality monitoring systems to support local communities. EPA is developing the use of portable air testing equipment in this program to monitor motor vehicle air pollution, among other aspects.

3) **Development of a public-facing platform for environmental big data.** Following the implementation of the Emergency Planning and Community Right-to-Know Act, the EPA published a list of hazardous substances, requiring regulated entities to report emissions. Entities that withhold, omit, or inaccurately report data may face substantial fines. The EPA can update the list of toxic chemicals as needed, and any person or state governor may recommend changes to the list.

Compared with the United States' environmental big data infrastructure and China's ecological environmental governance requirements for an environmental monitoring system, China's development level in environmental monitoring intelligence is still inadequate. Despite the issuance of numerous reform documents, China's ecological and environmental monitoring system, in the context of big data, faces several challenges. These include relatively decentralized ecological and environmental monitoring legislation, an inadequate data-sharing mechanism among various agencies, an underdeveloped environmental information platform, and insufficient management of socialized environmental monitoring agencies.

III. A. Ecological monitoring legislation is fragmented

For a long time, China's ecological environment monitoring has lacked specific laws or administrative regulations, instead being dispersed across various environmental protection laws. The system mainly focuses on (1) establishing monitoring systems for different environmental elements, (2) defining the monitoring functions and responsibilities of environmental protection departments, enterprises, and key pollution disposal units, (3) prohibiting the fabrication and tampering of monitoring data, and (4) strengthening legal accountability for violations of monitoring obligations.

In 2014, amendments to the Environmental Protection Law, Water Pollution Prevention and Control Law, and the Soil Pollution Prevention and Control Law emphasized: (1) unifying the ecological environmental monitoring functions of various departments, (2) improving the construction of monitoring data platforms and enhancing data sharing and disclosure, (3) strengthening social and environmental protection systems, and (4) enhancing public participation in environmental monitoring. In March 2018, the Ministry of Ecology and Environment resumed drafting the *Regulations on Ecological Environment Monitoring*, resulting in the preliminary formation of the *Regulations on Ecological Environment Monitoring (Draft)*.

Table 3: Provisions on ecological monitoring systems in specialized legislations on environmental protection

Name of the document	Timing	Stake a claim	Additional
Environmental Protection Act	Adopted with amendments on April 24, 2014	Article 17: The State shall establish and improve environmental monitoring systems. Article 42: The key emissions unit shall, in accordance with the relevant provisions of the State and monitoring standards for the installation and use of monitoring equipment, save the original monitoring records to ensure the normal operation of monitoring equipment. Tampering with or falsifying the monitoring data or evading supervision by improper operation of pollution prevention and control facilities and other means of discharging pollutants in violation of the law are strictly prohibited.	Article 39 (new): The State establishes and improves the system of environment and health monitoring, investigation, and risk assessment. Article 32 (new): The State shall strengthen the protection of the atmosphere, water, and soil. It shall establish and improve corresponding systems of investigation, monitoring, assessment, and restoration. Article 63 (new): Administrative penalties for forgery and falsification of environmental monitoring data. Article 65 (new): Environmental monitoring organizations and related equipment operating organizations shall be jointly and severally liable for any impact caused by falsification. Article 54 (new): The competent department for environmental protection under the State Council uniformly publishes information on the quality of the national environment, monitoring of key sources of pollution, and other significant environmental information. The competent department for environmental protection of the people's government at or above the provincial level regularly issues bulletins on the state of the environment.
Act on Exploration and Exploitation of Resources in the Seabed Area for Exploration and Exploitation	Revised and adopted on February 26, 2016	Article 13: Contractor must establish and implement an environmental monitoring program. Article 20: The Contractor shall periodically report to the competent marine affairs department of the State Council on the following matters relating to the performance of the contract for exploration and exploitation: (ii)Environmental monitoring.	
Air Pollution Prevention and Control Act	Revised and adopted on October 26, 2018	Articles 23 to 26: Powers and duties of ecological and environmental authorities, enterprises and institutions, and key emission units in monitoring air pollution. Article 91: Atmospheric Pollution Monitoring Sharing and Information Disclosure System. Article 100: Legal responsibility for the violation of monitoring obligations.	
Water Pollution Control Act	Adopted with amendments on June 27, 2017	Article 23: Under the implementation of sewage licensing management, enterprises, institutions, and other producers and operators are required by law to conduct self-monitoring. Article 25: The State shall establish a system for monitoring the quality of water environment and the discharge of water pollutants. Article 39: Prohibition of falsification of monitoring data. Article 40: Groundwater monitoring. Article 82: Administrative penalties for failure to monitor in accordance with the law. Article 100: In disputes over the liability for damages and the amount of compensation caused by water pollution, the parties may entrust the environmental monitoring organization to provide monitoring data. The environmental monitoring organization shall accept the commission and truthfully provide the relevant monitoring data.	Article 24 (new): Under the implementation of emissions licensing management, enterprises, institutions, and other producers and operators shall be responsible for the authenticity and accuracy of the monitoring data. Article 28 (new): The competent department for environmental protection under the State Council shall, in conjunction with the water administration department under the State Council and the people's governments of the relevant provinces, autonomous regions, and municipalities directly under the Central Government, shall establish a joint coordination mechanism for the protection of the water environment in the watersheds of important rivers and lakes. This mechanism includes the implementation of unified planning, unified standards, unified monitoring, and unified preventive and control measures. Article 32 (new): Monitoring of toxic water pollution lists Article 45 (new): Monitoring equipment for industrial agglomerations. Article 72 (New): Relevant departments at or above the county level must monitor and publicize the use of water for drinking purposes.
Marine Environment Protection Act	Revised and adopted on November 4, 2017	Article 14: The competent department of marine administration under the State Council shall assume the obligation to monitor the marine environment. Article 15: The relevant departments of the State Council shall provide the environmental protection to the administrative department under the State Council with the marine environmental monitoring information. This information is essential for the preparation of the national environmental quality bulletin. Article 16: The competent department of ocean administration under the State Council is responsible for the management of the comprehensive ocean information system.	
Law on Weights and Measures	Revised and adopted on October 26, 2018	Article 9: The administrative departments of measurement under the people's governments at or above the country level should conduct the mandatory verification of environmental monitoring instruments included in the mandatory verification catalog.	
Soil Pollution Prevention and Control Act	Adopted on August 31, 2018	Article 15: The State shall implement a system for monitoring the soil environment. Article 16: Priority monitoring requirements for agricultural land. Article 17: Priority monitoring requirements for construction sites. Article 21: Self-monitoring requirements for Key Regulatory Units of Soil Pollution. Article 82: Census reports on soil pollution conditions, along with monitoring data, investigation reports, soil pollution risk assessment reports, risk control effect assessment reports, and remediation effect assessment reports shall be uploaded to the national soil environment information platforms in a timely manner. Article 86: Legal responsibility for failure to monitor in accordance with the law	
Environmental Impact Assessment Act	Revised and Adopted on December 29, 2018	Article 17: The environmental impact statement of a construction project shall include the following: (vi) Recommendations on the implementation of environmental monitoring for construction projects;	

III. B. Inadequate mechanisms for sharing environmental monitoring data from multiple sources: an example of an information-sharing mechanism for the soil environment

Article 8 of the Soil Pollution Prevention and Control Law mandates the establishment of a national soil environment information-sharing mechanism. The State Council's ecological environment department, in collaboration with departments responsible for agriculture, natural resources, housing and urban–rural development, water resources, health and sanitation, and forestry and grasslands, is tasked with building a comprehensive platform for soil environment information. This platform must enable dynamic data updates and ensure information sharing across relevant sectors.

On April 13, 2020, the Shanghai Municipal Bureau of Ecology and Environment, together with other departments, issued the "Program for the Implementation of the Soil Pollution Prevention and Control Law to Address Outstanding Soil Pollution Issues." This program specifically emphasizes creating a soil information-sharing mechanism to integrate environmental data resources, including census data on soil pollution, detailed investigations, and monitoring data. Additionally, the program seeks to strengthen data sharing between various municipal departments, such as the Bureau of Ecology and Environment, the Bureau of Planning and Resources, and the Agricultural and Rural Commission.

The initiative focuses on sharing data on contaminated land parcels, risk control and remediation assessments, lists of construction land under remediation, agricultural land classification, safe-use programs for contaminated arable land, areas prohibited from producing specific agricultural products, and land parcels repurposed for residential, public administration, and public services.

The Circular on Further Strengthening the Soil Environment Linkage Supervision of Construction Land, issued by the Guangdong Provincial Department of Ecology and Environment and other departments on March 15, 2021, designates natural resource authorities as the lead body and requires them to: (1) **Inquire about Soil Pollution Status**: During the preparation of detailed control planning, land development and utilization (including the acquisition and resumption of land-use rights, land supply, etc.), and the issuance of planning permits, authorities must inquire about the soil pollution status of land parcels. (2) **Incorporate Soil Pollution Information**: Authorities must integrate information on soil pollution status, including survey-listed land parcels and spatial data on polluted land parcels provided by the competent ecological and environmental authorities, into the management of the "one map" of national land spatial planning. (3) **Regular Information Sharing**: Information on changes in land-use rights, especially for residential, public administration, public service, or commercial land use, must be regularly shared with the competent ecological and environmental authorities.

However, the implementation of the soil environment information-sharing system across regions has been limited. Most areas have only achieved the integration and sharing of environmental data—such as atmospheric, water, and soil data—within different levels of the competent ecological and environmental authorities. The construction of the national soil environment information platform remains incomplete, and its openness for sharing is still limited. Moreover, dynamic updating and information sharing between the competent ecological and environmental authorities and those in charge of agriculture, natural resources, housing and urban–rural construction, water conservancy, health and sanitation, and forestry are not yet fully established.

The dynamic updating of data and information sharing between competent authorities remains insufficient, making it difficult to meet the requirements of Article 8 and Article 59 under the Soil Pollution Prevention and Control Law. These articles stipulate that soil pollution status investigation, risk assessment, risk control, and remediation must precede any change in land-use rights or land use. The current lack of effective soil environmental information-sharing mechanisms and platform construction can be attributed to the following reasons: First, **Administrative Compartmentalization** has created information barriers. In practice, compartmentalization between departments has hindered data sharing. Problems arise from decentralization and the "departmental privatization" of information. Institutional setup, division of functions, budget management, business process design, administrative culture, appraisal methods, and confidentiality have made many departments "unwilling" or "inconvenient" to share and disclose data. Furthermore, data sharing between levels often remains top–down, with grassroots departments obliged to upload data but having limited access rights. Second, strong departmental coordination for overall planning and implementation is lacking. Although some provinces have included information-sharing systems in their implementation programs for the Soil Pollution Prevention and Control Law, only a few, such as Guangdong Province, have designated the natural resources department as the main coordinating body. Most provinces still have fragmented implementation, with responsibilities spread across departments for ecological environment, agriculture and rural areas, natural resources, and housing and construction. The issue of compartmentalization persists, with separate authorities managing different aspects of soil environment information. Third, although the Environmental Protection Law, the Soil Pollution Prevention and Control Law, and other relevant regulations mandate environmental data-sharing mechanisms, environmental protection departments and bureaus at all levels lack dedicated departments and systems for data collection and processing. The role of environmental information centers is confined to management planning and technical support, which hinders meeting the requirements for integrated environmental data collection, processing, disclosure, and technical support.

In contrast, the US EPA, responsible for environmental information in the United States, incorporates the collection, use, and dissemination of data and information into its core functions. As an early leader in environmental information systems,

the EPA established an OEI to manage the entire lifecycle of environmental information, including collection, analysis, and distribution. This office, with over 400 employees, includes branches for Access, Information Technology, and Planning. At the state level, environmental information offices or commissioners in regional offices and state environmental protection departments handle information collection, uploading, maintenance, and distribution. This structured system ensures efficient transmission of environmental information from the original source to its recipients.

IV. Countermeasures for the development of China's ecological environment monitoring system in the context of big data

A good natural environment is essential for human survival, and natural resources such as water, air, and soil are fundamental to healthy living and societal harmony. As such, the environment has become a crucial public good in society. However, China's rapid economic development has led to significant environmental pollution, making environmental issues a critical priority for the government and strategic development.

In response, the central government has made substantial decisions regarding ecological civilization construction, establishing a "five-in-one" development framework. This approach highlights the need for comprehensive and systematic advancements in the era of big data. To effectively build an ecological and environmental monitoring system, several steps need to be taken, which can be summarized as follows:

IV. A. Legislation and Data Sharing

Enhance legal frameworks governing environmental monitoring and data sharing, ensuring robust and cohesive regulations.

Currently, China lacks specialized legislation specifically addressing ecological environment monitoring, which necessitates unified regulations on legislative objectives, basic principles, systems, quality assurance, and legal responsibilities. Additionally, the qualifications, capabilities, and management mechanisms for ecological environment monitoring institutions require legislative clarification. The existing chaotic management structure hampers the effective execution of social and ecological environmental monitoring activities and undermines data quality assurance. To address these issues, the following measures are recommended.

(1) Legislation for Environmental Data: Enforce specialized laws to safeguard environmental data security and privacy protection, thus refining the existing legal framework. Given that environmental data management involves various departments such as the Ministry of Ecology and Environment, the Ministry of Agriculture and Rural Development, and the Ministry of Natural Resources, inconsistencies in statistical standards, cycles, costs, and requirements across these departments complicate the data integration and sharing processes. Furthermore, the lack of overarching data-sharing regulations or unified coordination by the State Council makes inter-departmental data collaboration difficult. For instance, within the Ministry of Agriculture alone, 12 departments and 9 deployed institutions manage monitoring and statistical work, leading to the problem of data duplication and integration difficulties, among other issues [19].

(2) Local Government Framework: At the local government level, establish targeted regulations regarding environmental data openness, reuse, and security within the existing legal framework. These regulations should clarify the rights and obligations of the public in acquiring, storing, and reusing environmental data. Additionally, develop a comprehensive plan for environmental data openness to facilitate and promote the data-sharing process [**?**].

IV. B. Improving the legal regime for data sharing

The dynamic nature of environmental pollution, often crossing administrative and basin boundaries, poses significant challenges for effective management and governance. The difficulty in distinguishing between locally generated pollution and that transferred from other regions necessitates robust cross-sectoral and cross-regional cooperation. Currently, China's environmental data sharing suffers from insufficient legislation on government data sharing and low data standardization, hampering effective cross-sectoral collaboration. Article 8 of the Soil Pollution Prevention and Control Law emphasizes the establishment of a mechanism for sharing soil environmental information, a basic database for the soil environment, and a national platform for soil environmental information, with dynamic data updating and sharing.

To enhance the government data-sharing mechanism: the State Council issued the Interim Measures for the Administration of Information Resources Sharing in Government Affairs on September 5, 2016, to promote the interconnection of government information systems and facilitate public data sharing. On March 27, 2017, the Zhejiang Provincial People's Government issued the Measures for the Management of Public Data and E-Government in Zhejiang Province, which stipulates that (1) people's governments at or above the county level shall establish public data platforms; (2) public management and service agencies at all levels must aggregate data into these public data platforms; and (3) without a legal basis, public management and service agencies must not refuse sharing requests from other institutions [20]. The Shanghai Municipal People's Government's Measures for the Management of Public Data and One-Web Office, issued on September 30, 2018, reflect the concept of full life cycle management of public data. Regarding data sharing: (1) Article 26 establishes that sharing is the default principle, and non-sharing is an exception; (2) Article 27 introduces a categorized sharing system, dividing public data into three categories:

unconditional sharing, authorized sharing, and non-sharing. Public management and service organizations requiring data from the unconditional sharing category for their duties must be granted access; and (3) Article 28 provides for an "application scenario authorization" system, allowing public management and service agencies to obtain direct authorization for using shared data if their application needs align with specific scenarios.

In terms of international experience, the United States has advanced government data sharing through initiatives like the Presidential Executive Order on Achieving Government Information Development and Machine Readability. This initiative, led by the Office of Management and Budget, aims to make government data open and machine-readable by default in phases, thus improving data openness, accessibility, and usefulness. Currently, China lacks specialized legislation for environmental data sharing, leading to inadequate sharing of ecological and environmental protection data with other relevant sectors, such as rural agriculture, natural resources, and housing construction and planning. To establish an effective environment information-sharing mechanism, China should focus on enhancing environmental data sharing legislation and management mechanisms. This should include the following aspects: (1) scope of environmental data and sharing information catalog; (2) principle of sharing; (3) environmental data management organization; (4) environmental data collection, processing, and transmission, (5) procedures and requirements for environmental data collection, processing, transmission, and sharing; (6) provision and use of shared information; (7) infrastructure construction of environmental data databases, data sharing platforms, and data exchange platforms; (7) establishment of inter-ministerial joint meetings and coordination systems led by the Ministry of Ecology and Environment; and (8) supervision and safeguards for information-sharing work.

IV. C. Environmental Information Platform

Strengthen the development and functionality of environmental information platforms to support data integration and accessibility.

To achieve the integration and sharing of environmental data, the US EPA has developed the FRS. This system registers facilities with sewage disposal rights—including enterprises, sewage treatment plants, civil facilities, and mining operations—by assigning each of them a unique "FIC." This allows for the clarification of relationships between data from different business systems and facilitates cross-business system and cross-database searches. To establish a fast, effective, secure, and accurate real-time data exchange network, the EPA utilizes the CDX, which connects the federal government, local governments, businesses, and various branches of the EPA.

Globally, differences in data formats, business requirements, and service targets have led to varied digital platforms for data collection, sorting, and storage, creating "technical barriers" to data sharing [21]. China has begun building a national soil information management system for contaminated sites (see Figure 8), primarily for inputting, uploading, and auditing information on soil risk control and remediation. However, this system still falls short of the requirements set by the Soil Pollution Prevention and Control Law.

The construction of a soil information-sharing platform should focus on integrating natural, economic, social, and other aspects of soil environment information. This involves establishing a unified cloud platform for soil environmental data management across national, provincial, municipal, and county levels of government. It requires coordination among local governments and relevant functional departments to formulate a unified platform framework, tasks, data standards, and operation and management mechanisms. Additionally, the platform should clarify data format standards and exchange protocols, as well as establish an interconnected and synergistic environmental informatization regulatory system spanning levels, regions, departments, and systems. This approach can help realize the transition from top–down control regulation to a synergistic regulation that combines top–down and bottom–up efforts, thereby overcoming the challenges of data sharing and coordination.

IV. D. Management System

Improve the management and oversight of socialized environmental monitoring institutions to ensure effective and reliable monitoring.

The qualification system is a key component for market-entry approvals, serving as a prerequisite for institutions to enter the market. Qualifications in administrative law reflect in the certifications issued by administrative bodies to attest to specific skills [22]. For instance, Articles 12–14 of the Construction Law specify that construction units and individuals must have legal qualifications, with different qualification levels determined by factors such as registered capital, professional and technical personnel, and performance. These units are permitted to engage only in construction activities within the scope of their qualification levels.

The legislative goal of the qualification system is to safeguard public security and public interests. Article 12(a) of the Administrative License Law states that administrative licenses can be issued for "specific activities directly related to national security, public security, economic macro-control, ecological environmental protection, and the direct relationship between personal health, life, and property safety."

However, in practice, some qualification systems related to market access have not achieved their legislative goals and have instead contributed to industry monopolies, illegal affiliations, and unauthorized subcontracting or borrowing of qualifications. Therefore, the reform of socialized environmental monitoring agencies should focus on strengthening supervision both during and after the event. It should also establish a management model that emphasizes credit evaluation and the disclosure of practice-related information.

First, in the access management, the monitoring organization's qualification management of the relevant laws and regulations must be improved. Creating red and black lists of environmental monitoring organizations is essential. Furthermore, market competition mechanisms must be established to enhance the level of relevant professional organizations. At the same time, promoting local excellent practical experiences nationwide is crucial; for example, Article 35 of the Regulations on Soil Pollution Prevention and Control in Shandong Province, which stipulates that the same unit shall not be entrusted to engage in activities such as investigation of soil pollution status and risk assessment, risk control, and remediation.

Second, in the supervision during and after the incident, the role of the filing system must be strengthened. For example, according to Articles 57 and 65 of the Soil Pollution Prevention and Control Law, the filing system applies to the preparation of the risk control program for construction land, as well as the preparation of the risk control and remediation effect assessment report and many other links. Accordingly, more emphasis must be placed on the formal review and ex post facto supervision of the filing system, clarifying the filing procedural requirements and review methods and ensuring that it covers the whole process of contaminated soils from investigation, assessment, preparation of the risk control program, implementation of the risk control process, and acceptance. The filing implementation organization needs to further clarify the filing procedures, deadlines, document catalogs, and examples of filed documents.

Third, the legal responsibility of socialized environmental monitoring institutions must be strengthened. Determining the causal relationship of environmental pollution and proving crimes are often heavily dependent on the monitoring report and data provided by the environmental protection administrative organs. The introduction of ecological environment monitoring data fraud regulations or methods in various provinces and cities highlights the importance of environmental monitoring data and the harm caused by fraudulent behavior. In formulating the Regulations on Ecological Environment Monitoring, the following recommendations are proposed:

(1) Clearly enumerate the illegal incidents of tampering with, falsifying, and interfering with the monitoring data by social and ecological environment monitoring organizations, and impose corresponding administrative or criminal penalties on the direct person in charge of these illegal situations.

(2) Set legal responsibilities for social and ecological environmental monitoring institutions for violations of monitoring activities, violations of regulations on the practice of monitoring, and the use of defective facilities for monitoring; institutions violating the regulations must be imposed penalties by the corresponding competent authorities.

(3) Establish a blacklist system for monitoring personnel, operation and maintenance personnel, and legal representatives of social ecological environment monitoring organizations, as well as restrict or prohibit their participation in any activities related to ecological environment monitoring.

(4) Stipulate laws mandating that social ecological environment monitoring organizations shall be held jointly and severally liable for the environmental pollution or ecological damage caused by their fraudulent behavior in relevant monitoring activities.

(5) Clarify the legal responsibility for data falsification when applying for qualification recognition.

Funding

This work is supported by the The National Social Science Fund of China (No, 17BFX130).

References

[1] Fang, Y.; Xu, P. Research on China's environmental rule of law issues in the era of big data. J. China Univ. Geosci. Soc. Sci. Ed. 2016, 16, 74-75, doi:10.16493/j.cnki.42-1627/c.2016.01.007.
[2] Wu, J.; Chen, C.; Jiang, R.; Hu, T.; Yu, Y. Effectiveness and prospects of China's ecological environment monitoring network construction. Environ. Monit. China 2021, 37, 1-7, doi:10.19316/j.issn.1002-6002.2021.02.01.
[3] Cox, M.; Ellsworth, D. Application-controlled demand paging for out-of-core visualization. In Proceedings of the Proceedings. Visualization'97 (Cat. No. 97CB36155), 1997; pp. 235-244.
[4] Ahalt, S.; Bedard, D.; Carsey, T.; Crabtree, J.; Green, K.; Jeffries, C.; Knowles, D.; Kum, H.; Lander, H.; Nassar, N. Establishing a national consortium for data science; Renaissance Computing Institute, University of North Carolina at Chapel Hill: Chapel Hill, NC, USA, 2012.
[5] General Office of the Ministry of Environmental Protection. Circular on the issuance of the overall program for the construction of ecological environment big data. Available online: https://www.mee.gov.cn/gkml/hbb/bgt/201603/t20160311_332712.htm (accessed on September 1,2024).
[6] Guan, T.; Xue, L.; Zhao, J. Technology enabled governance innovation: A case study in China's environmental field. Chin. Public Admin. 2019, 58-65, doi:10.19735/j.issn.1006-0863.2019.04.07.
[7] Schönberg, V.; Cukier, K. The age of big data: The great transformation of life, work and thinking; Zhejiang People's Publishing House: Hangzhou, 2013.
[8] Yu, K. Governance and good governance; Social Science Literature Press: 2000.
[9] He, Y. Rationalizing relationships and the shaping of national governance structures. Soc. Sci. China 2018, 26-47.
[10] Zhang, Z.; Zhou, R. The current status and prospect of China's collaborative governance theory research. Soc. Gov. Rev. 2016, 50-51.
[11] Beck, U. The Risk Society; Yilin Publishing House, 2004.
[12] Breyer, S. Breaking the vicious cycle: How governments can effectively regulate; Law Press: 2009.

[13] Testimony of John P. Wargo Professor of Risk Analysis and Environmental Policy Yale University Before the Subcommittee on Investigations and Oversight House Committee on Science and Technology U.S. House of Representatives. 2010.
[14] Lv, Z. The transformation of China's environmental law - from consequence control to risk prevention. China Environ. Superv. 2019, 37-39.
[15] Ministry of Ecology and Environment. 2017 China Ecological Environment Status Bulletin. Available online: https://www.mee.gov.cn/hjzl/sthjzk/zghjzkgb/201805/P020180531534645032372.pdf (accessed on February 20, 2024).
[16] Maben. Economic Competition, Benefit Spillovers and Local Government Environmental Regulatory Failure - An Assessment of the Effects Based on a Higher-Order Spatial Econometric Model for Prefecture-Level Cities. World Econ. Lett. 2018, 6, 44.
[17] Next generation compliance and big data. In Proceedings of the Environmental Law Institute Big Data Conference, October 22, 2013.Xu, Y., Li, W., Tai, J., & Zhang, C. (2022). A Bibliometric-Based Analytical Framework for the Study of Smart City Lifeforms in China. International journal of environmental research and public health, 19(22), 14762.
[18] Breggin, L. Big data and environmental protection: an initial survey of public and private initiatives; Environmental Law Institute: 2014.
[19] Wang, D.; Li, Z.; Zhang, J.; Xu, S. Current situation and countermeasures of agricultural data sharing. J. Agr. Sci. Technol. 2016, 1-6, doi:10.13304/j.nykjdb.2015.564.
[20] Measures for the Administration of public data and e-government of Zhejiang Province. Available online: https://ditm.zjdex.com/home(accessed on February 20, 2024).
[21] Xu, X.; Feng, L.; Liao, J. Research on standardization path of government data sharing in China. Stand. Sci. 2021, 85-90, doi:10.3969/j.issn.1674-5698.2021.01.016.
[22] Wang, K. On the categorization reform of administrative approval and the construction of alternative systems. China Legal Sci. 2015, 24.