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ARTICLE

Monitoring and Early Warning Index System for Mountain, Water, Forest, Field, Lake, Grassland, and Sand: A Case Study Approach in China

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ABSTRACT

Against the backdrop of China's escalating ecological challenges driven by urbanization, industrialization, and climate change, this study addresses the critical need for a unified, nationwide ecological monitoring and early warning system. Focused on China's seven core ecosystems—mountains, waters, forests, fields, lakes, grasslands, and deserts—it analyzes existing fragmented monitoring frameworks and proposes an integrated index system to enhance ecological risk prediction and management. By synthesizing secondary data, including satellite imagery, government reports, and case studies of the Loess Plateau, Poyang Lake, Dongting Lake, and Bayanbulak Grassland, the research evaluates current monitoring efficacy and identifies implementation gaps. It develops a conceptual framework encompassing three key pillars: selection of ecosystem-specific indicators, integration of multi-source data via GIS and remote sensing technologies, and predictive modeling using statistical analysis and machine learning to forecast risks like desertification, flooding, and water pollution. The proposed system demonstrates strong predictive capabilities across diverse ecosystems, accurately identifying high-risk areas and enabling timely interventions. However, challenges persist, including data quality inconsistencies, limitations

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in short-term extreme event forecasting, and the need to integrate socio-economic factors such as land-use changes and population dynamics. Policy implications emphasize the establishment of a national-level monitoring system, intersectoral collaboration, and enhanced local data collection infrastructure. By refining predictive models and fostering community engagement, the system can significantly strengthen China's ecological resilience, supporting sustainable development goals and ensuring the long-term health of its natural resources. This research provides a foundational framework for scalable, adaptive ecological management in a rapidly changing environment.

Keywords: Ecological Monitoring; Early Warning System; Remote Sensing; China Ecosystems; Environmental Risk Management

1. Introduction

Sustainable development (interdependence of natural resources, biodiversity, and human activities) is defined by the ability to live in harmony with nature. In the China report, it is a country with such a rich geographical and ecological diversity; it is only through environmental protection through mountains, water bodies, forests and fields, lakes, grasslands and deserts that the environmental sustainability of China is assured, not to mention its socio-economic life. These are the seven large ecosystems and may also be referred to as the seven pillars that China depends on in terms of climate, biodiversity, agricultural practices and provision of water and the livelihood of the rural people. which is the outcome of the excessive degree of urbanization and industrialization, and the change of climate assumed the expression of a tremendous deterioration of the ecology, and therefore an alarming difficulty for the ecology and for the conservation of the existing resources [1]. One of the most urgent questions facing China is the increased vulnerability of these ecosystems in China and particularly in the vast rural and semi-arid regions in China due to the fact that the impacts thereof can be catastrophic and can be categorised in terms of their adverse environmental effect as desertification, flood, loss of biodiversity and agricultural productivity. An effective, timely and efficient monitoring and early warning system is then necessary to detect, assess and mitigate the risks that are associated with ecological imbalances. Value-added is that identifying the environmental stressors and their potential impacts through modern tools at the earliest possible time can prevent the occurrence of interlinked ecological losses of significant scale, improve the quality of policy response and assist with the focused conservation measures [2–4].

An ecology monitoring and warning system (EWS), means constant gathering of data, and then analysis, possibly leading to warning and focus on ecological risks that might occur in the future. With such systems, good decisions are made, which may prevent or minimize environmental disasters. They rely on a set of carefully chosen ecological indicators, e.g., the health of vegetation, the quality of water, the moisture of soils, and the degree of biodiversity that can be used to signal the beginning of environmental deterioration or natural risk. Early warning systems are therefore tools that can be employed early enough so that agencies and individuals can then respond effectively in time before the situation gets out of hand [5].

The multiple ecosystems of China that include the mountainous regions of the Loess Plateau and the arid deserts of Xinjiang necessitate that there be region-specific monitoring systems whose functionality will be subjected to the peculiarities of the specific ecosystem. A universalized early warning index, which is used in all types of ecosystems, might not be effective in capturing the ecological processes or threats that exist in each of them. Therefore, there is an increasing demand for an all-purpose monitoring and early warning index system that unites special environmental features of other landscapes all over the nation. Such a system must be able to pick up a warning of an ecosystem collapse, whether climatic, human, or natural disturbance caused [6,7].

In this project, the research seeks to design such a monitoring and early warning system of index in China with respect to the seven main types of ecosystems of China, including mountain, water, forest, field, lake, grassland, and sand ecosystems. This research paper will carefully examine secondary data and case studies of different regions in the country with the intention of analyzing the efficacy of the current monitoring systems and identifying the gap in their implementation, as well as suggesting an integrated monitoring system of ecological risks. This study will use secondary information, such as satellite images, environmental reporting, and government publications, to give a detailed insight into the use of these systems deployed and their success, along with lessons learnt in their implementation [8].

China is already making huge strides towards the development of environmental monitoring systems, but they are too localized or divided. The central concept of the presented study is to unite the findings of various case studies and identify the indexation system that may be implemented on a broader level. Additionally, assist China in overcoming numerous complex issues that the process of ecological degradation may just indicate. This comprehensive approach would not only strengthen the monitoring of individual ecosystems, but also contribute to the formation of a more comprehensive, balanced, and coherent management of the natural resources of the state [9].

Specifically, the case studies provided in the research will be based in the Loess Plateau, Poyang Lake, Dongting Lake and the Bayanbulak Grassland as these four areas symbolize three different ecological zones in China. These examples will demonstrate how local monitoring networks have been developed, data gathered and how these systems have been used to improve the health of their local ecosystems as well as make policy. The study will assess the results of such endeavours and propose possible developments of creating a national-level index, which can be implemented in any region [10,11].

The importance of the study is that it has the potential to support the overall environmental targets in China, as well as its 13th Five-Year Plan on Ecological and Environmental Protection and its United Nations Sustainable Development Goals, which have a biodiversity and climate change target. This study will not only represent an in-depth understanding of the Chinese environmental governance policy but will also present a new model to other countries also struggling with similar environmental issues through advancing the formulation of a mammoth monitoring and early warning index [12].

2. Literature Review and Conceptual Framework

The literature review/conceptual framework section is very important in any research because it sets the stage ready through reviewing previous knowledge and outlines the theoretical grounding on why the study is needed. In this section, existing literature on the subject of ecological monitoring and EWS will be reviewed, and some of the related background frameworks and procedures will be identified to develop a conceptual core for the development of an integrated monitoring system that fits the unique Chinese ecosystems. This part will be subdivided into some subparts, each covering one of the specific concerns of the research topic [13].

2.1. Ecological Monitoring and Early Warning Systems

The ecological monitoring process involves observations and quantifications of environmental indicators that give information on the health and integrity of ecosystems. Such monitoring is used to identify the emergence of environmental stress at an early stage and provides a scientific basis for the decision-making process based on the maintenance of natural ecosystems. Conversely, the EWS aims to forecast and anticipate the possible environmental risks, including floods, droughts, wildfires, and the collapse of the ecosystem. The major objective of EWS is to give early warnings in order to avert threats before they can inflict much harm.

EWS cannot be overemphasized in a changing ecosystem, particularly when such changes are quite rapid. Such systems help the government officials and other stakeholders to be proactive in anticipating and responding to threats in the environment. The EWS has been applied effectively in managing disasters, climate change and biodiversity conservation in the world. In recent years, an increasing awareness has surfaced regarding the necessity to incorporate EWS into the wider environmental management systems that would help ecosystems to recover and adapt better [14].

China is focusing a lot on the evolutionary development of an integrated EWS that will oversee multiple ecosystems at the same time. Such systems not only monitor the major indicators of ecosystem health like vegetation cover, water quality, and biodiversity, but also are able to predict threats such as desertification, soil erosion, and habitat fragmentation, which are widespread in most parts of China. Overreliance on remote sensing, field-based research, and government data collection activities has been identified as a major issue in ecological monitoring throughout China, which is highly region and ecosystem-dependent [15].

2.2. Ecological Indicators and Index Development

Effective ecological monitoring and risk assessment require the design and development of ecological indicators and indices. Ecological indicators refer to any quantitative measurements that are employed to evaluate the health of an ecosystem, such as soil quality, water chemistry, vegetation health, as well as biodiversity. These pointers are essential in identifying ecological imbalances and also in assessing the efficacy of conservation and control interventions [16].

Several steps are used in developing ecological indices, including the selection of indicators, weighting of the indicators based on their importance in the formulation of a general assessment of the ecosystem health, and compilation of the indicators into composite indices. To illustrate, the indicators that can be used to define an index of forest health can be examples of tree cover, soil quality, and biodiversity. Equally, water quality indicators such as pH levels, nutrient levels, and aquatic life diversity can be used as an index to measure water quality [17].

In China, many region-specific indices have been created that track specific ecosystems. As an example, vegetation cover and land degradation on the Loess Plateau are monitored by the use of the Vegetation Index, and Lake ecological status of lakes such as Poyang and Dongting is monitored by the Lake Ecological Health Index. Even though these indices have been valuable in determining local ecological threats, there is an increasing demand to have more holistic and nationwide types of indices that take into consideration the interrelationships that exist among various ecosystems and give a wider view of ecological threats [18].

The fact that Dongting Lake has been included in this study portrays the significance of creating composite indices, which will combine both land and water indicators. As an example, a combination of information about soil erosion, vegetation health (using Normalized Difference

Vegetation Index (NDVI), water quality (turbidity, pH, nutrition levels, etc.), and biodiversity can provide an all-encompassing look at the state of the ecosystem. This combined method aids in the realisation of the interrelationship between the land systems and aquatic systems, which is paramount in effective management of the ecosystem and prediction of the risk early [19,20].

One of the main problems of ecological indices development is their standardization and applicability of the indices to different ecosystems and areas. This entails the consideration of the international approaches to the development of indices, and the restrictions and difficulties of utilizing indices under various settings within the environment [21].

2.3. Integrated Ecosystem Management

Integrated ecosystem management (IEM) is a dynamic way of approaching natural resource management that acknowledges interdependence within ecosystems and how multi-faceted interventions should be managed in unison. IEM considers the ecological, social, economic and cultural aspects of resource administration, and seeks a balance between the interests claiming the various ecosystem facilities and the efforts of preserving and protecting natural resources. Within the context of the varied ecological systems in China, IEM stresses the collaborative needs of sectoral coordination between the government agencies, the residents on the ground, the researchers and other entities concerned. As an example, the health of a river basin cannot be addressed through only one of these factors (water quality and land use practices in the catchment area) but must be assessed in an integrated manner. In a similar effort, conservation of biodiversity and sustainable grazing policies are both required in the management of grassland ecosystems [22].

Ecological monitoring and EWS play a major role in IEM because they will provide the data and predictive ability that will be used to inform decision-making and shape adaptive management. As an example, in the Loess Plateau case, there has been an improvement in integrated management initiatives by providing monitoring mechanisms to observe soil erosion and vegetative status, which helps in taking specific steps to recover the damaged lands. As an example, in a desert land like Bayanbulak Grassland, monitoring prints within which to measure the vegetation cover and moisture of the soil is crucial in the prevention of desertification, as well as in facilitating sustainable land management activities [23].

Dongting Lake plays a vital role in the hydrological system of the Yangtze River Basin and acts as a natural buffer against flooding. However, the lake's ecosystem is increasingly threatened by changes in water levels due to upstream dam constructions, land-use changes, and water pollution. A key element of integrated ecosystem management in the Dongting Lake Basin is balancing flood control and conservation efforts, while ensuring that the surrounding wetlands and biodiversity are protected. Effective management requires continuous monitoring of hydrological data (water levels, river flows), water quality, vegetation health, and biodiversity. This is where early warning systems, like the one proposed in this study, can help by providing integrated data and predictions to guide decision-making and mitigate risks [24,25].

Nevertheless, in China, there is a problem that many monitoring systems are segmented or limited to a specific region with limited integration across ecosystems or sectors. There is a necessity for a more holistic strategy which integrates these interrelationships between mountains, water bodies, forests, fields, lakes, grassland and deserts. The purpose of this research is to help develop an integrated monitoring and early warning system that would meet these challenges and make ecosystem management more effective at the national scale [16,26].

2.4. Case Studies in China

Numerous case studies have been carried out to investigate the concerns regarding ecological surveillance and early warning frameworks in China that provide rich insights regarding implementation and impacts. These case studies are often confined to specific locations, scenery or even types of environmental threats and hazards, such as soil erosion, desertification, floods or water pollution.

The other case is the research conducted at the Loess Plateau, where it has been observed that soil erosion and vegetation restoration must be observed when implementing integrated land management. The Poyang Lake basin, too, has been subject to water quality surveillance and flood prediction research, and significant progress has been recorded in the past decade in terms of flood forecasting and early warning facilities. They have established monitoring systems to oversee the changes in the vegetation cover, the surrounding soil status and the intensity of grazing activities in grasslands such as the Bayanbulak Grassland to address the issue of desertification and to maintain sustainable pastoral activities [27,28]. As a significant freshwater lake, Dongting Lake has been exposed to land- and water-based pressures (agriculture, urbanization, pollution, flood control). The monitoring activities at Dongting Lake consist of water quality monitoring, hydrological monitoring, and species monitoring; however, combining these monitoring activities with terrestrial monitoring indicators (soil moisture, vegetation cover and land use) may provide a more comprehensive picture of the ecological situation. In this regard, Dongting Lake represents a valuable example of creating a nationwide monitoring system that will incorporate both land-based and aquatic ecosystem indicators [29–31].

The given case studies provide much information applicable to the practical issues of the realisation of ecological monitoring systems in China. Their teachings about the way to develop a nationwide-level monitoring and early warning index system can also apply to other ecosystems and regional scenarios. And these examples will contribute to informing the research by assisting in identifying best practices, lapses in the current monitoring frameworks currently in use, and what the research subject deems to be a unified way to manage the ecosystem [32].

2.5. Conceptual Framework

In accordance with the literature review, this paper suggests a common conceptual structure for the development of a unified surveillance and early warning index system of the diverse ecosystems of China. Its framework will have three very important elements:

1. **Selection of Ecological Indicators:** The most relevant indicators are denominated on each of the 7 ecosystems (mountain, water, forest, field, lake, grassland and sand). These indicators will be chosen depending on their capability to show the course of the ecosystem and forecast possible dangers.
2. **Data Integration:** Designing a platform to integrate data sets sourced by remote sensing, field observations and government data sources to give a more complete picture of ecosystem health. It will include the utilisation of Geographic information systems (GIS) technologies, satellite photos and any other sources of information.
3. **Predictive Modelling:** To apply the method of predictive modelling and create the ability of early warning when it is possible to predict ecological risks on the basis of the chosen indicators. This will be done using analyses and mathematical models, machine learning software and other pieces of analytics to see trends,

and forecast possible risks to ecosystem well-being.

The framework is designed to be comprehensive, scalable, and flexible, and is aimed at the development and application of monitoring and early warning of outbreaks to the diverse conditions that prevail in China [33,34].

Such a conceptual framework is ultimately implemented by using dedicated software platforms. Such software successfully merges the major features of data updating, extraction, analysis, and predictive modelling in one environment, as visualized in **Figure 1**. These platforms are used to provide access to real-time data, storage of analysis results and to present critical information to experts, as well as decision makers, in a dedicated management website. This underlines the feasibility of the framework to transform ecological indicators into clear, useful early warnings [35]. This transition to integrated and software-based platforms has already been reflected in the current architectures of the multi-hazard early warning. The application of this principle using the modular structure of such platforms as Xenios, an illustration of which is presented in **Figure 2**, makes it possible to operationalize the aforementioned idea. They are built into their own architecture of pluggable forecasting components of a certain type of threat (e.g., fire, flood), integration of monitoring real-time data of multiple sources (e.g., sensors, UAVs), and dedicated frontends to distribute information to managers and the general population [36]. This is representative of the agile and flexible methodology to be used in China, whose ecosystem needs are diversified, with each region experiencing a different mix of ecological pressures.

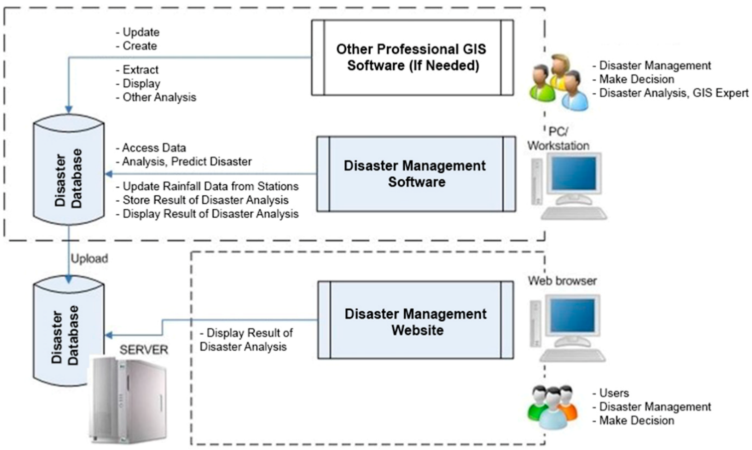


Figure 1. Generalized model and key features of a disaster management and early warning software platform, illustrating the integrated workflow from data input to decision support [36].

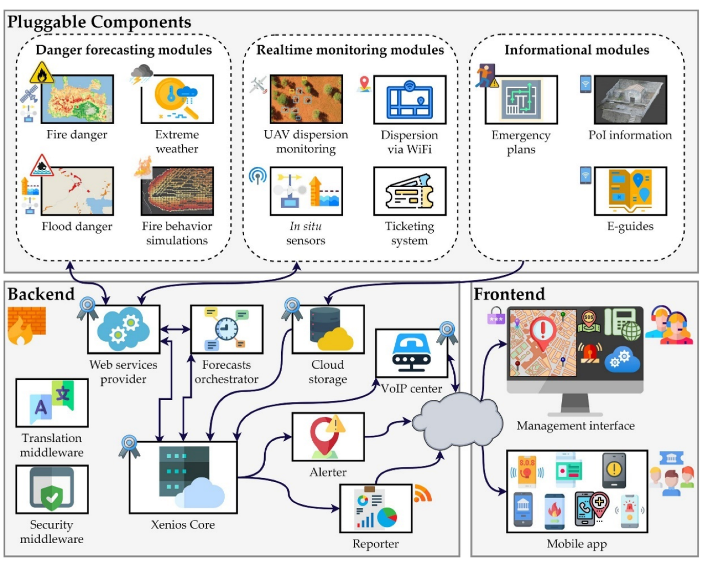


Figure 2. Modular architecture of the Xenios platform, showcasing pluggable forecasting, monitoring, and informational modules supported by a centralized backend and frontend interfaces [37].

3. Methodology (Based on Secondary Data)

The following section presents the methodology followed to come up with a detailed monitoring and early warning index system of the environment of China, using secondary data. The research combines various existing data sets, remote sensing data, government publications, and case studies to examine the condition of ecological health in various and distinct ecosystems in China. Based on these secondary sources of data, the objective is to come up with a reliable index system that can be utilized to track and monitor any environmental changes and give an early warning on the possibility of an ecological threat. This methodology consists of four steps, which are the collection of data, selection of case studies, data analysis methods and formulation of a monitoring and early warning index system [37].

3.1. Data Collection

The research has primarily relied on secondary research information that has been acquired via satellite images, environmental monitoring publications, government publications and academic research. The study area is extensive and hence quite varied; therefore, to carry out effective research, secondary data shall be taken into account as it encompasses a vast gamut of different ecosystems of the study area without necessarily relying on primary data collection activities, which can be very hectic.

The acquired data have been employed to ascertain the variation in vegetation health and land use and water bodies using Satellite information in Moderate Resolution Imaging Spectroradiometer (MODIS) and Landsat. In one example, MODIS images have provided it with coherent information on vegetation cover in the Loess plateau over the years. The evolution of vegetation vitality during the years was measured with the help of the NDVI, and explained a little of what happened according to the soil erosion and unstable climate. The NDVI is a critical indicator of the health of the system, as the density of vegetation is assessed, and a decrease in the vegetation density is likely to be noted over the years, particularly in areas with soil that is very vulnerable to erosion.

In addition to satellite data, we have also used two types of government reports, the Ministry of Ecology and Environment (MEE) and the National Bureau of Statistics of China to provide us with important indicators in such environmental factors as water quality, biodiversity, and water degradation. One of them is made to check the water quality in the largest freshwater lake in China, Poyang Lake, with the help of the data delivered by the MEE. These data sets would also include parameters such as turbidity, nutrient concentration, and pH, etc., which have been critical in establishing the ecological status of the lake. In the same vein, in the case of Dongting Lake, MODIS and Landsat satellite remote sensing data were acquired to track land cover, water quality, and surface area variation of the lake over time. Spatial and temporal patterns (concerned with the quality of water, seasonal variations, and land-use effects surrounding the lake) can be analyzed using these satellite data. Historical data showed that the level of pollutants in the lake had increased over time, and particularly during rainy seasons, and this encouraged the inclusion of water quality monitoring in the index system [38].

Certain details on the numerous problems affecting most of the ecosystems in the area have also been provided in case studies and research papers by academic institutions such as the Chinese Academy of Sciences. The soil moisture and vegetation coverage have been found to be crucial parameters in the example of the Bayanbulak Grassland in Xinjiang, which has been experiencing desertification. Field surveys, along with the analysis of these studies, have been useful in developing a detailed ecological picture of the stressors on the grasslands [39].

3.2. Software Architecture for System Implementation

The combination of assimilating the various secondary data sources identified above requires a well-designed, secure, and scalable infrastructure software design. The efficient functioning of an early warning system is not only determined by the level of data it has but also the platform that guarantees its upgrade, processing and safety. Contemporary design patterns, e.g., onion architecture with platforms (like Xenios), introduce a methodological solution to this problem. The architecture provides middleware to key functions such as authentication and authorization to control access to sensitive data and information of the ecological models, and user access to this sensitive information [37,40,41]. This architectural methodology forms the foundation for transforming raw data into actionable early warnings (**Figure 3**).

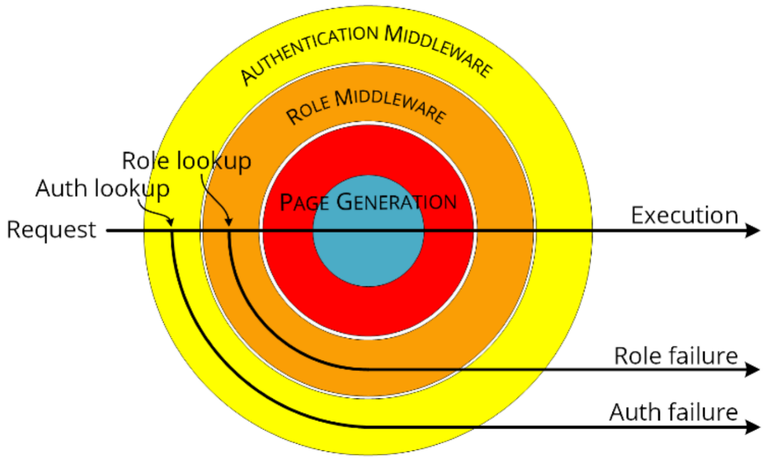


Figure 3. Architectural workflow for secure access control in an early warning system platform, illustrating the sequential authentication and role-based authorization middleware layers [37].

3.3. Selection of Case Studies

The study concentrates on four different ecosystems of China, namely the Loess Plateau, Poyang Lake, Dongting Lake and Bayanbulak Grassland. The selected ecosystems are based on their geographical and ecological diversity, and can be characterized by the availability of detailed long-term data sets as a result of past monitoring initiatives. All these ecosystems offer special environmental challenges that will offer useful insights into the development of a proposed index-based early warning system and monitoring system [42–44].

The Loess Plateau is a northern part of China that is among the most impoverished areas in China, with soil erosion and desertification. The region has undergone numerous ecological restoration processes, and different surveillance systems have been implemented in monitoring soil erosion, vegetal cover, and deterioration of the land. Ministry of Agriculture and Rural Affairs data on historical vegetation cover in the Loess Plateau over the last decade have indicated that there has been variability, with areas showing huge decreases in vegetation cover even through massive deforestation activities. Since this area is part of the research, the researchers will be able to evaluate the efficiency of any monitoring system of the area presently in use with regard to curbing further deterioration of the ecology and design a better indexing system capable of predicting the dangers of soil erosion with a high degree of accuracy [45].

Another important case study is Poyang Lake, which is a major freshwater resource. Since the lake is affected by pollution as well as water level, and land usage changes, its ecological balance has been subject to serious stress. The abundance of information generated by the government reports and satellite data on the lake's hydrological status, and the reports of water quality monitoring, has made the information rich. As an example, water quality samples being taken by local water monitoring stations have indicated increasing levels of water pollutants nitrogen and phosphorus, especially when there is increased rainfall. Such trends point to the necessity of an early warning system that would help to predict possible degradation in the quality of water and anticipate the occurrence of flooding events [46].

Dongting Lake has been subjected to significant ecological pressures, including land reclamation, water quality degradation from agricultural and industrial pollution, and changes in water levels due to upstream dam projects. Therefore, monitoring the ecological health of Dongting Lake is vital for maintaining regional biodiversity and water security [24].

Bayanbulak Grassland in the arid area of Xinjiang faces different kinds of problems, i.e., overgrazing and desertification. Local environmental monitoring station data have followed the changes in vegetation cover and soil wetness, and the recent reports are frightening, showing desertification in some areas of the grassland. Together with field observations and remote sensing data, these data allow for establishing a clear vision of ecological pressures on this area. The inclusion of the Bayanbulak Grassland in the case study selection will also help the research to underline the need to monitor indicators in arid ecosystems (i.e., soil moisture and vegetation health)[47].

3.4. Data Analysis Techniques

After the acquisition of the pertinent data, the data are to be analyzed to draw tendencies and relations between ecological indicators. The analysis of data used in this study uses a relative mix of geospatial and statistical methods to estimate the functioning of the ecosystems and early warning signs of at-risk conditions.

Geographic information systems applied to geospatial analysis of the geographical distribution of ecological indicators is one of the most important approaches. GIS has been employed to determine variation in land cover and vegetation cover in all the study areas. As an example, the use of GIS based on MODIS satellite imagery from the Loess plateau has demonstrated that there was an overall change in land cover, especially in areas that have experienced soil erosion. Integrating the satellite findings and the ground-level findings with the help of GIS tools, the erosion-prone areas have been visualized, and it has been enabled to pinpoint the areas where immediate action is to be taken. The given spatial analysis will be critical to the derivation of the overall ecological dynamics in each case study, as well as influential to the formulation of the early warning system[47].

Statistical analysis methodology has also been applied to analyze the relation between various ecological indicators through correlation and regression analysis. As an example in the Poyang Lake case study, water quality parameters (nutrient concentrations) were cross-compared with hydrological data to determine the possible cause of the relationship between rain patterns and water quality degradation. For Dongting Lake, the focus was on analyzing water quality and hydrological data. Time-series analysis of water turbidity, pH, and nutrient levels was carried out to identify pollution trends and predict periods of water quality degradation. Spatial analysis using GIS data provided the changes in the lake's surface area and surrounding land cover over time, helping to visualize the impacts of land-use changes on water quality[48].

For water quality and flood event data, regression models were developed to quantify the association between the two measures and help predict at what point in the future water quality may become dangerous. To trace the long-term changes in these aspects, time series analysis of NDVI data is undertaken on the Loess Plateau to give a clear picture of where the region is headed. Besides the geospatial and statistical analysis, the processing of remote sensing data has been utilized to extract the related ecological data. This has been done by processing Landsat and the MODIS satellite data to show the movement of vegetation cover, water bodies, and land use change over time. As such, vegetation health has been measured with the NDVI in all three ecosystems and has assisted in gaining precious knowledge on the effects of land degradation/pollution and global warming. The processed data is subsequently utilized in developing patterns and trends, which are used as the foundation for coming up with the monitoring and early warning index. The multi-faceted nature of the methodology of the suite of data analysis techniques that are used in this study allows the study to conduct a multi-faceted assessment of the risk and health of an ecosystem. All techniques have a distinctive ability, such as the depiction of spatial trends and the measurement of temporal dynamics and the identification of relevant ecological indicators. Combining these approaches is the key to establishing an effective early warning index, since it is possible to cross-check outcomes and get a better idea of the complicated interactions within the environment[49,50]. A summary of these techniques, their functions, and their applications is provided in **Table 1**.

Table 1. Overview of the core data analysis techniques, their purpose, and their application within the methodology.

Analysis Technique	Primary Function	Application Example	Data Sources Used
Geospatial Analysis (GIS)	Analyze spatial distribution and changes over area.	Mapping erosion-prone areas on the Loess Plateau by visualizing land cover change.	MODIS imagery, ground-level observations
Statistical Analysis	Examine relationships between variables and quantify trends.	Using regression models to link rainfall patterns to water quality deterioration in Poyang Lake.	Water quality data, hydrological data, NDVI time-series
Remote Sensing Data Processing	Extract and quantify ecological parameters from imagery.	Calculating NDVI to track vegetation health across all three case study ecosystems.	Landsat and MODIS images

3.5. Development of the Monitoring and Early Warning Index System

The last practice in the methodology is the creation of an index system of monitoring and early warnings. The described system will allow integrating the most significant ecological indicators highlighted during the data analysis process and provide a composite index per ecosystem. The idea is to develop an index that is easily comprehendible and that encompasses the health of the ecosystem as a whole, and can give prior signs of risks to occur.

Work on the index system starts with the choice of the most pertinent ecological indicators that characterize each of the ecosystems and is directly dependent on the results of the analysis of the existing data. As an instance, in the case of the Loess Plateau, factors like erosion rate of soil and vegetational cover will be prioritized, and in the case of the Poyang Lake, water quality factors like turbidity, level of nutrients, and dissolved oxygen will be used as indicators. The weight of each indicator will be given with reference to how significant the indicator is in predicting ecological risks. These weights are calculated with the analytical tools, like the Analytical Hierarchy Process, considering the relative significance of each indicator in the given ecosystem. After the indicators are used and the weighting is done, they are compiled into a single composite index for each ecosystem. The composite index was selected to receive an overall indicator of ecosystem health, and thus to be used to qualify the degradation risk and to forecast the possible ecological disasters. Early warning thresholds will be set already in the past data, and the index will provide warnings when a certain indicator reaches precarious levels. To give a scenario, when the NDVI of the Loess Plateau falls below a certain limit, or the amount of nitrogen in Poyang Lake rises above certain levels, the system will warn interested parties to take a preventive action beforehand [51].

Validity of the final monitoring and early warning index system will be determined relative to the historical data in the case history to give an idea of the accuracy of the index system and its capabilities in terms of anticipation. In order to promote consistency in prevention and productive reflection of the ecological risk at its early stages, the research will compare the outcomes of the index with the history of the ecological crisis in every named ecosystem.

4. Case Studies (4 from China)

In part 3, we discuss three individual case studies in China, which demonstrate how monitoring systems and early warning indicators can be applied to different ecosystems. Pictures of how systems that are already present and installed in operation are met, and whether efficient or not in forecasting and coping with ecological hazards is brought about through the present case studies. Each of the case studies is dedicated to another type of ecological issue and gives hints to the methods used and data processed with the help of which it is possible to define the condition of the ecosystem or trace its development, to give a warning of a potential ecological catastrophe.

These case studies include the Loess Plateau, Poyang Lake, Dongting Lake and Bayanbulak Grassland. The case studies are used to assess the effectiveness of the monitoring and early warning systems, identify key ecological indicators, and learn from the successes and limitations of existing systems [52].

These selected ecosystems are the different settings of the environment in China, which are diverse in issues encountered and how they have responded using monitoring and early warning systems. Looking at such cases, we can note best practices, find out limitations, and envisage the development of the unified monitoring system that could be implemented in various ecosystems within the country.

4.1. Case Study 1: Loess Plateau (Mountain and Field Ecosystems)

The fact that the Loess Plateau, situated in the north of China, is one of the most ecologically unstable regions of this country, which has a long history of soil erosion and degradation, proves this vulnerability. Overgrazing, deforestation, and poor farming practices have been attributed to land degradation in the area, which has been a plague of concern for many years. These have led to soil erosion, desertification, and a significant loss of biodiversity that places the region at risk of climate change.

The Chinese government has reacted to such efforts by carrying out large-scale ecological restorative projects like the Grain to Green program, under which they revert their agricultural land to forest and grassland. Surveillance on the extent of soil erosion, the vegetation cover, and land use has been introduced. These efforts have been directed at remote sensing data, in particular the MODIS and Landsat images. NDVI is a fashionable index, which has been employed in the past 10 years in the monitoring of vegetation cover changes. The measure of the effectiveness of the restoration plans can thus be taken through providing information on how far vegetation has regained its lost ground that was originally lost through erosion [53].

Complementary to the satellite information, the local government agencies and the research organizations have managed to collect data on the moisture of the soil and rainfall, among other climatic properties that have been identified to affect the rates of erosion. Such kind of data, along with field surveys, have been largely used in the formulation of predictive models that would help determine the likely regions that would be washed away in the future. These models have been used with the framework of early warning, whereby the local government and the people are notified of the dangers of soil erosion and desertification.

Although most of the restoration schemes have met with success, there are still limits to the proper forecast of troublesome soil erosion hazards. As another example, in certain areas of the plateau, the rate of vegetation loss remains high even after interventions, making the monitoring system in those areas still insufficient with regard to predictive capabilities. As illustrated in the case study of the Loess Plateau, areas that can be efficiently monitored through the use of satellite should be combined with nearby data to help in the provision of more successful early warning techniques of land degradation [54].

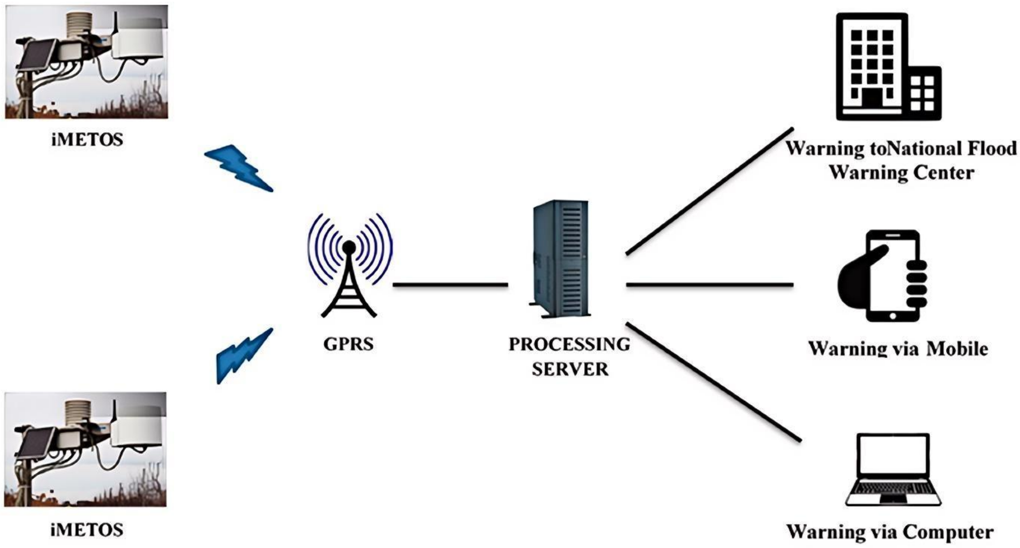
4.2. Case Study 2: Poyang Lake Basin (Water and Lake Ecosystems)

Poyang Lake (Jiangxi Province, China) is the largest freshwater lake in China and also plays a very important role in flood control, water supply, and ecological conservation of biodiversity. The lake, however, has had grave environmental pressures in the recent past few decades. Alterations in land cover, the rise in the levels of pollution occasioned by industries, and the undulating level of water as a result of climate change have endangered the health of the lake ecosystem. The reduction of water quality and distortion of seasonal flood patterns have caused a decrease in biodiversity and the distortion of ecosystem services.

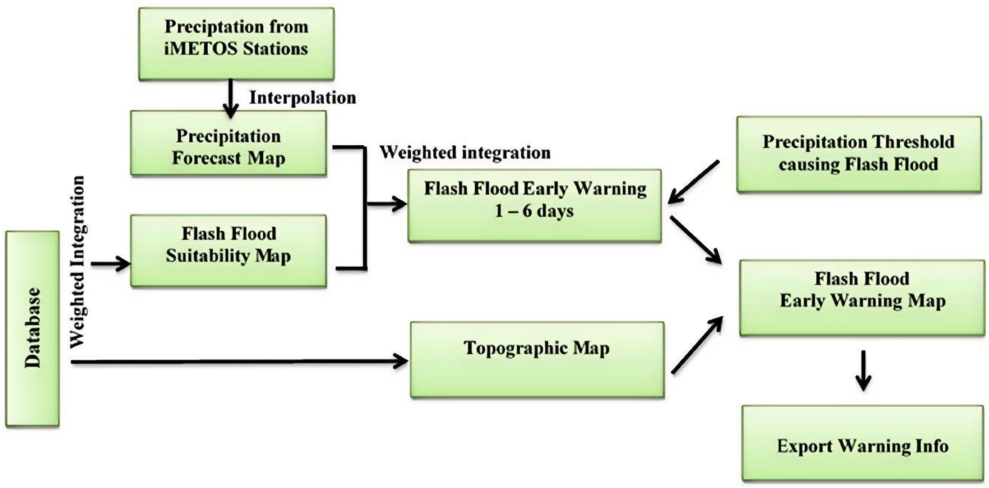
The Poyang Lake monitoring system is concentrated to a great degree on the parameters that can measure the water quality, i.e., the turbidity, the dissolved oxygen levels, pH, and the nutrient concentrations. The parameters are continuously monitored by the local environmental agencies both in situ through a range of water quality monitoring stations, as well as through remote-sensing data. Remote sensing instruments have also played a pivotal role in monitoring the alterations of water surface area and plant coverage along the lakes edge that are central measurements of lake well-being. Satellite images, especially within the Landsat program, have been utilized to check how the land cover around the lake has changed, which includes encroachment of the urban environment and expansion of agriculture, which impacts water quality and regulation of water flooding. Besides water quality monitoring, hydrological models have been employed in following the seasonal works of the Poyang Lake. These models can simulate water flow, rain patterns, flood risks, and can help simulate when the lake may overflow, and the water levels will fall to dangerous levels. Models like these have been used to develop early warning systems where a signal is specifically broadcast, and local authorities immediately issue a flood warning in time to save the community [55].

The presence of real-time integration is essential to any early warning. An example of such a system, commonly employed in the field of hydrology monitoring, is shown in **Figure 4**. This model shows how data (such as precipitation data collected by monitoring stations) can flow through processing (interpolation, integration with lip-topographical and suitability maps) to the ultimate output, a flash flood early-warming map, and the transmission of warnings to designated people and the populace via mobile and computer networks.

Although these monitoring activities have paid off in enhancing the early warning systems of local authorities, some problems are still present. As an example, the degradation of water quality is often difficult to predict due to a variety of factors that may be affecting it, such as industrial discharge, agricultural run-off, and natural cycles in hydrology processes. The case study of Poyang Lake lends credence to the importance of a multi-dimensional approach in monitoring by combining water quality, hydrological data, and land-use patterns as a means of increasing the efficiency of early warning systems [36].



(**a**)



(**b**)

Figure 4. Workflow of an integrated flash flood early warning system: (**a**) Model of information processing and data integration; (**b**) Workflow of the processing server for generating and disseminating warnings.

Source: Adapted from iMETOS-based systems [36].

4.3. Case Study 3: Bayanbulak Grassland (Grassland and Desert Ecosystems)

The Bayanbulak Grassland is feeling the pressure of desertification and overgrazing in the dry region of Xinjiang in China. This vast grassland is fertile with wild animals and plants, but it is slowly losing its vegetation cover to humans and the weather. Over-grazing by livestock and prolonged drought have also led to a high level of depreciation of the land and productivity of the grasslands. Desertification is already becoming one of the most significant environmental problems, and the destruction of dunes is threatening not only the livelihood of people but also biodiversity.

In the Bayanbulak Grassland, the control system tracks various crucial indicators of ecology that address the degree of the wellness of vegetation, the state of soil moisture, and species variety. The change in vegetation cover and regions at risk of desertification have been observed using remote satellites, in this case, MODIS and Landsat satellites. Remarkable amounts of NDVI data have been capitalized on by following the changes of the land cover over several years, trying to diagnose the state of health of the vegetation according to a long-term aspect. Also, the local management-funded monitoring stations ensured that soil moisture and grazing pressure have 24/7 data capture with a real-time monitoring system that follows the satellite-derived data [56].

The complexity of desertification processes could be considered one of the most significant issues in the context of its monitoring on the Bayanbulak Grassland. The process of desertification is slow, and it will thus be difficult to detect when degradation has started unless it is closely monitored. This is the reason why early warning systems are ready to monitor such significant parameters as the level of soil moisture and the plant health condition. To illustrate this, once soil moisture drops to a certain level, the alarm can be sounded as a measure to signal the possibility of a drought event and subsequent desertification. The purpose of using these warnings is to alert the local authorities and pastoral communities to ensure that some kind of mitigation activity is taken, like the reduction of livestock pressure, or the communities can be encouraged to take some action that will help them conserve the soil.

Although a great success, monitoring systems still have gaps regarding predicting desertification rate as well as its overall impacts on the ecosystem. The effectiveness of early warning systems heavily hinges on continuous quality and flow of information, and community access to act on the warnings. As demonstrated in the case study of Bayanbulak Grassland, remote sensing data must be supplemented by local field data to alert early to the pending desertification of areas that lack sufficient water [57].

The three case studies give us the chance to learn the real problems and achievements of ecological monitoring and early warning systems in China. All of the examples point to the necessity of introducing individual approaches to monitoring that consider the peculiarities of different ecosystems. Incorporation of remote sensing data and in situ observations is another commonality to these case studies because institutions have found using a combination of technologies and local knowledge to be useful in managing their ecosystems better.

4.4. Case Study 4: Dongting Lake (Water and Wetland Ecosystems)

Dongting Lake is the second-largest freshwater lake in China and is dominant in flood control, water supply, and biodiversity conservation in the northeastern region of Hunan Province. The lake is enclosed by huge wetlands and functions as a key ecological buffer in the Yangtze River Basin. Nevertheless, Dongting Lake has encountered severe environmental stresses over the last few decades, such as the deterioration of the quality of water, intrusion of harmful species, and variations in water levels as a result of dam construction upstream and land reclamation.

The Dongting Lake monitoring system is more concerned with water quality parameters of turbidity, nitrogen, phosphorus levels, and dissolved oxygen. Changes in water surface area, vegetation cover in wetlands, and land-use patterns surrounding wetlands have been tracked using satellite imagery data, such as Landsat and MODIS. Local environmental monitoring stations can give real-time data that can provide more information about water quality and hydrology, and can predict possible floods or droughts that can affect the lake and the ecology around it.

An important characteristic of the Dongting Lake monitoring system is its incorporation of hydrological information (e.g., river flow rate, water level) with the data on water quality and vegetation health. This integration allows detection of the risk of eutrophication in time, which is especially valuable in preserving biodiversity in the wetlands of the lake. When the water quality parameters, such as turbidity cross preset limits, warnings are transmitted to ensure the local authorities can take remedial action, e.g., reduce agricultural run-off or increase the nutrient treatment of the wastewater [58].

The incorporation of Dongting Lake into a case study adds value to the monitoring of the freshwater ecosystem in China. It raises awareness of the problems of aquatic systems that deliver essential ecosystem functions, including flood management, water resources, and biodiversity. The inclusion of Dongting Lake shows that to capture the intricate interplay between water quality, land-use modifications, and hydrological interactions, it is important that both terrestrial and aquatic information is included in the early warning system. Another focus of the case study is the need to integrate multi-dimensional data to provide a comprehensive assessment of the health of the ecosystem and project future environmental hazards, such as water quality decline and flooding.

Given the critical role of hydrological, water quality, and vegetation health information in the efforts to get a more holistic picture of the health of an ecosystem, the monitoring system of Dongting Lake presents an important example. With the inclusion of Dongting Lake into the larger index system, the research is being used to formulate a single way of managing freshwater and terrestrial ecosystems in China [59].

4.5. Comparison of Similarities and Differences across Ecosystems

The case studies of the Loess Plateau, Poyang Lake, Bayanbulak Grassland, and Dongting Lake provide efficient information about the ecological problems of various ecosystems in China and the different success rates of the monitoring and early warning systems. Among the lessons learned during these case studies is the fact that individualized monitoring strategies need to be considered based on the peculiarities of the ecological conditions and issues of a particular area. As an example, the Loess Plateau and Bayanbulak Grassland are subjected to various types of degradation, soil erosion, and desertification, respectively, and each subject requires different monitoring indicators and predictive models [53,56]. In a similar vein, the examples of Poyang Lake and Dongting Lake show that aquatic ecosystems require a complex type of monitoring that incorporates all the parameters of water quality, hydrological conditions, and land-use patterns to reflect the entire range of environmental hazards [55,58].

Another critical takeaway is the importance of integrating multi-source data, including remote sensing data such as MODIS and Landsat, with in-situ observations and local knowledge. This combination enhances the efficiency and accuracy of monitoring systems, allowing for more timely and precise assessments of ecosystem health. For example, in the Poyang Lake case study, combining water quality monitoring with hydrological data and land-use changes has proven essential for improving the early warning system's reliability. In the case of Dongting Lake, the integration of hydrological, water quality, and vegetation data allows for better detection of eutrophication risks, ensuring that preventive actions can be taken to protect biodiversity [58].

Predictive models and early warning systems have been fundamental in managing ecological risks. However, challenges remain in fully realizing their potential. While early warning systems in Poyang Lake have successfully helped prevent flood damage, issues like forecasting desertification or water quality degradation are more complex and require more sophisticated models. For instance, in the Loess Plateau, soil erosion and vegetation loss continue to be a significant concern, even after the implementation of restoration programs, which highlights the limits of current predictive models. Enhancing these systems to provide real-time, actionable data to communities is a key challenge that remains unresolved in many regions. The need for continuous data flow, real-time integration, and predictive forecasting underscores the importance of building more robust monitoring systems that can predict and mitigate a wider range of ecological hazards [36,57].

Engagement with local communities is another crucial factor that has emerged across these case studies. In the Bayanbulak Grassland, for instance, early warnings about impending droughts and desertification risks must be communicated effectively to pastoral communities to enable them to take preventive actions, such as reducing livestock pressure [56]. Similarly, the authorities in Dongting Lake rely on early warnings to manage potential floods and water quality declines, emphasizing the importance of timely and accurate information for effective decision-making. Successful early warning systems are therefore a function not only of the technology and data on which they are based but also of the effectiveness of local stakeholder response to and action upon the warnings given.

Taken together, these case studies demonstrate the possibility of developing a national unified monitoring and early warning system. Drawing from these lessons learned across diverse ecosystems, China could develop a more integrated system capable of adaptation in the various ecological contexts found within the country. This would involve data collection and reporting standardization, enhancement of data integration tools, and the development of region-specific predictive models to enhance the effectiveness of the system as a whole. By refining the approach to data integration, forecasting, and community involvement, a more resilient and unified monitoring system could be developed, better safeguarding China's diverse and ecologically significant landscapes.

Substantial progress has been made in monitoring and early warning systems in different ecosystems, but scaling, improving predictive capability, and community engagement remain the ongoing challenges. However, the experiences from these case studies all provide the foundation to take forward a national system that can effectively address ecological risk and enhance resilience throughout China [52,59].

5. Results and Discussion

Here, the results of the data analysis, the case studies, and the development of the system of monitoring and early warning indexes are summarized and explained. The major objective is to examine the efficacy of the proposed monitoring system and its potential to enhance ecological management and risk prediction over the various ecosystems in China. The findings would also be compared to what is currently in place through monitoring systems, and the present study would undertake to improve on the proposed approach by reviewing lessons learnt in studying the case scenarios. The topics of interest covered in this section are: synthesis of findings of the case studies, the usefulness of monitoring and early warning index system, regional variation and challenges, policy implications, limitations, and areas to improve [60].

5.1. Synthesis of Findings from the Case Studies

The three case studies (Loess Plateau, Poyang Lake, Dongting Lake, and Bayanbulak Grassland) brought about concrete impressions of the process of monitoring systems being customized to suit the distinct ecosystems and the problems encountered per location. The results of such case studies played a vital role in the final monitoring and early warning index system.

Soil erosion has been significantly lowered in the Loess Plateau in areas where ecological restoration work has been undertaken and in areas where other sites have recorded a high percentage of vegetation loss. The patches of low vegetation cover areas were not eroded in the NDVI analysis and remained vulnerable to erosion. The predictor models, named by soil erosion and vegetation health indicator, were found to be useful to reveal future locations that would result in additional erosion. However, one evident thing is that these models still had to be revised. The relevance of integrating the soil moisture with the vegetation cover and erosion information system into a single information system to provide early alerts to the occurrence of instances in the region was informed by the case study [61].

As is evident in the Poyang Lake case-study, a multifaceted issue involved the interaction between water quality, the change of land use, and the hydrological processes. The water quality parameters that included turbidity and the level of nutrients were followed to derive that the level of pollution was escalating, particularly when the irrigation runoffs were so immense, in addition to periods when the rainfall was abundant as well. By hydrological monitoring and water quality parameter prediction, early warning of floods and pollution is possible via predictive models. However, a few challenges still remained in forecasting the degradation of water quality as the models were unable to take into consideration the multi-dimensional aspects contributing to the quality of water. Multi-layered data integration, as noted in the case study, is a must, particularly a combination of hydrological, land-use, and water quality data to enhance early warning of lakes and other water bodies [62].

The case study of Bayanbulak Grassland showed how important vegetation health and soil moisture are in signifying desertification. Remote observation data and ground-truth records indicated that desertification was taking place incredibly in the grassland, with vegetation cover deteriorating as a result of overgrazing and insufficient rainfall. Soil moisture level and the percentage of vegetation cover are valid early warning thresholds for the occurrence of desertification. Yet, the case study made it clear that desertification is a particularly tough process to predict in areas where the rainfall is infrequent, and grazing patterns are too variable. The study implies that the local level of research can be a more detailed type of monitoring of desertification processes in arid territories.

As a large flood control system and water source in the Yangtze River Basin, Dongting Lake presents its own challenges of erratic water levels, agricultural runoff, and invasive species. The Dongting Lake DSS pilot integrated both the water quality indicators (e.g., turbidity, nitrogen, phosphorus) and hydrological indicators (e.g., water levels, river flow rates) with data on the health of the vegetation (NDVI) to provide a holistic view of the lake's ecological health. This system was successfully shown to have provided early alerts of increased pollution and forecasted the occurrence of flooding, but it is difficult to accurately predict the occurrence of eutrophication events during high nutrient loading times. Integrating land-based and water-based information, however, proved essential to the understanding of the complex relationship between land use and water quality as well as ecosystem health [63,64].

5.2. Effectiveness of the Monitoring and Early Warning Index System

The proposed monitoring and early warning index system, based on findings made during the case studies and secondary data analysis, has proven potential towards enhancing ecological risk management in China. The combination of several ecological indicators, e.g., soil erosion, vegetation health, water quality, and biodiversity, allows the index system to offer a comprehensive picture of the ecosystem health, helping to identify ecological stressors as soon as possible before getting out of control.

The system showed an excellent potential in predicting regions prone to degradation in all three of the ecosystems. An example is in the Loess Plateau, where the capability of the model to identify any risks of erosion in soil due to data recorded on the number of vegetation cover and rainfall demonstrated a high level of accuracy. Similarly, in Poyang Lake, the combination of the water quality and the hydrological data allowed the system to predict with high accuracy the high-pollution risks and flood periods. In the Bayanbulak Grassland, the soil moisture and vegetation predictors were successful, and desertification hazards were anticipated, which resulted in early warnings, even before the desertification hazards occurred, and actions were taken to curb such movement. For Dongting Lake, the system accurately predicted rising water pollution and potential flooding events by integrating water quality and hydrological data. However, while the system excelled at predicting long-term trends, it faced limitations in accurately forecasting short-term, extreme events, such as sudden rainfall surges in Poyang Lake or unexpected fluctuations in water quality in Dongting Lake [65].

The degree to which the system could provide early warnings of potentially upcoming ecological disasters was verified by data comparison of prior cases. The alerts provided by the system were converted into reality with regard to the activities in nature, including the flooding in Poyang Lake or the escalation of desertification in Bayanbulak. This implies that the system of indices can be useful in predicting the ecological risks as well as ensuring that the local government establishes enough lead time to implement preventive or corrective measures. It was, however, recorded that the system could not capture fast, short-term changes in the environment, especially where there were highly varying climatic factors or activities of man [66]. Dongting Lake's early warning system helped predict water quality degradation, allowing local authorities to take action to reduce agricultural runoff. However, some delays in response time were observed, particularly in areas with inconsistent or delayed data inputs.

The efficiency of the proposed index system is confirmed by the high predictive capacity and the practical value of the system applicable to three sufficiently different case studies, implying unique ecological situations. The main strength of the system is the incorporation of important region-specific indicators as the sources of timely warnings that have been confirmed to be correct by examining the history of comparisons. Its performance is, however, also limited by the characteristics of the data quality and environmental variability. The detailed output of both ecosystems is presented in **Table 2**, reflecting the custom indicators applied, the demonstrated functionality of the system and the situational issues that had to be addressed [67].

Table 2. Demonstrated Effectiveness of the Proposed Monitoring and Early Warning Index System.

Ecosystem	Loess Plateau	Poyang Lake	Bayanbulak Grassland	Dongting Lake
Key Indicators Monitored	Soil erosion rate, Vegetation cover (NDVI), Soil moisture	Water quality (Turbidity, pH, Nitrogen, Phosphorus), Vegetation health (NDVI), Flood risk	Soil moisture, Vegetation cover (NDVI), Species diversity, Grazing pressure	Water quality (Turbidity, Nitrogen, Phosphorus), Hydrological data (Water levels, River flow), Vegetation health (NDVI)
Data Sources	MODIS, Landsat, Field data, Local government reports	MODIS, Landsat, Local monitoring stations, Water quality reports	MODIS, Landsat, Field data, Government reports, Local monitoring stations	MODIS, Landsat, Field monitoring stations, Local environmental reports, Hydrological data

Table 3. *Cont.*

Ecosystem	Loess Plateau	Poyang Lake	Bayanbulak Grassland	Dongting Lake
Key Findings	Significant decrease in soil erosion in restoration areas, Vegetation health improving, but localized vegetation loss persists.	Rising pollution levels, particularly nitrogen and phosphorus, Increased flood risk during monsoon seasons, Vegetation health declining in some areas.	Desertification risk detected through declining NDVI, Early warnings of soil moisture stress preventing severe desertification, Vegetation recovery in controlled grazing areas.	Successful early warnings for pollution spikes, Flood risk predictions, Hydrological data integration enhanced water management, Vegetation health and wetland monitoring helped predict eutrophication risks.
Effectiveness of Early Warning	Effective in predicting areas at risk of soil erosion, Alerts triggered restoration programs in high-risk areas.	Accurate in predicting flood risks, Water quality degradation predictions helped mitigate pollution during high runoff events.	Effective early warnings for desertification, Alerts allowed grazing restrictions and restoration efforts, Reductions in desertification rates.	Predicted water quality degradation and flooding risks, allowed early intervention to manage agricultural runoff, Mitigated pollution impacts.
Challenges Encountered	Unpredictability in rainfall patterns, Difficulty in accurately forecasting short-term erosion events.	Challenges in predicting localized pollution events, Difficulty in accounting for rapid flood changes due to extreme weather events.	Unpredictable rainfall and grazing patterns, Difficulty in preventing desertification in remote areas with irregular rainfall.	Challenges in accurately forecasting eutrophication, Difficulty in predicting nutrient loading during high agricultural runoff seasons.

The system has already displayed flexibility in adjusting to varying ecological regions, which present a great advantage to large and diversified nations like China. The index system can be expanded to cover other areas beyond the case study areas by the use of remote sensing information, field data and predictive models. However, the success in other regions will be determined by local availability and the correctness of local data, so there is a need to continue to invest in monitoring infrastructure and data collection [68].

5.3. Regional Variations and Challenges

Results from this study underline large regional differences in ecosystem vulnerability, data availability, and efficiency of early warning. These differences stem not only from the intrinsic ecological differences among regions but also from technological and logistical challenges related to monitoring and prediction.

For instance, the Loess Plateau has long faced the problem of land degradation, which demands continuous monitoring and long-term intervention strategies. In contrast, the primary ecological concerns in Poyang Lake deal with fluctuations in water level and quality, controlled by rainfall and hydrological dynamics during different seasons and from upstream areas. On the other hand, the Bayanbulak Grassland is specifically susceptible to desertification and overgrazing, greatly linked with local environments and climatic conditions. Challenges associated with these regions are further exacerbated by limitations in acquiring high-quality data at the local level, which was one of the major constraints in the case studies. Satellite-based remote sensing makes a valuable contribution in terms of large-scale monitoring, while local data, including but not limited to soil moisture, grazing intensity, and real-time water quality indicators, are often inconsistent or unavailable. The latter represents a very important discrepancy that further underlines the need for enhancing local data acquisition systems with an integrated approach, including ground-based measurements and satellite data [69–71].

Data integration has been one of the prevailing technological challenges faced in this study. The ecosystem monitoring and early warning index system relies heavily on integrating varied datasets from multiple sources, such as satellite imagery, local sensors, and socio-economic data. However, the integration of these datasets remains a big challenge today. For example, satellite-based data can provide broad-scale coverage, which provides critical information regarding land cover changes, vegetation health, and major hydrological changes. These data are mostly coarse in terms of temporal resolution, especially when there is a rapid change. On the other hand, most ground-based information, like soil moisture and water quality, is very fragmented, inconsistent, or difficult to access in real time, impeding predictive accuracy. Challenges with data integration are exacerbated by the intrinsic limitations of current predictive modelling techniques. Predictive modelling generally depends on historical data for the forecast of future trends. These models may perform weakly under climatic uncertainties, especially in regions sensitive to unpredictable weather events. For example, the Poyang Lake and Bayanbulak Grassland ecosystems are highly sensitive to climatic shifts in sudden rainfalls and/or extreme temperature events. Such factors can transform the area's ecological state within a short period, but existing models fail to capture these extreme events with good accuracy. Therefore, the monitoring system can be more reliable for long-term predictions rather than forecasting short-term climate extremes. This discrepancy points out the need for more advanced modelling skills, such as ensemble modelling or machine learning algorithms, that are capable of handling climate variability and predicting the occurrence of extreme events with greater precision [72–74].

The regime shifts in water level caused by upstream dam operation and further influenced by climate have compounded the difficulties in the flood and nutrient loading models. The various steady-state models do not reproduce the nonlinear water quality dynamics observed during high loading events. Therefore, this amounts to additional support for the demand for more adaptive models that can consider the effects of climate change and anthropogenic implications, such as dam building or agricultural runoff. Hydrological models based on modern approaches and including methods for integrating data are required to enhance prediction capabilities in this system (e.g., at Dongting Lake, where water-level fluctuations are rapid) [70,75].

Human activities continue to be a predominant cause of ecosystem deterioration; the Bayanbulak Grassland is being overgrazed, and Poyang Lake has been impacted by agricultural runoff. Although this monitoring system functions well to provide information on large-scale patterns of ecological change, it is inadequate for attempts to quantify and predict the effects of anthropogenic activities attributable to land-use change, urbanization, and industrialization. Such events may be spasmodic and difficult to model, especially if they take place in a very small area or in a highly urbanised setting. For example, agricultural runoff and urbanization have a significant negative effect on water quality in Dongting Lake, but this is generally not well reflected by the monitoring system due to the spatial heterogeneity of such impacts. The lack of socio-economic information, such as land-use patterns, population density, and industrial development, poses a limitation in predicting cascading effects of human activities on ecological well-being. In this respect, integration of socio-economic information into the monitoring system appears to be a prerequisite for addressing the whole suite of pressures to which ecosystems are subjected [76,77].

Furthermore, such alterations in land use, including deforestation and the extension of intensive farming, may also be contributing to environmental degradation, but their impacts are likewise infrequently captured in monitoring systems. The observation of Dongting Lake revealed that finer-scale information on human activities and land-use patterns is necessary to identify the causes of environmental degradation. Inclusion of socio-economic indicators would provide a better insight into the solar energy of ecosystem degradation [78,79]. The Dongting Lake case study demonstrated that agricultural overland flow, urbanization, and invasion by alien species had all resulted in serious impacts on water quality and primary/secondary ecosystem health. However, although the observation system observed its spread quite well, it was not able to illustrate adequately the full extent and scope of the anthropogenic changes, particularly in regions that had undergone rapid industrial growth or urbanization. This indicates the importance of incorporating socio-economic variables, including population growth, land-use change, and industrial activities, into the monitoring system to better understand the driving forces that result in ecosystem degradation.

Briefly, the monitoring and early warning index system proposed herein seems to work well; however, it should still be further developed by taking into account some technological and environmental issues, as we pointed out. These include data integration issues, predictive modeling under climatic uncertainty, and the impact of human impacts on ecosystems. All these things are going to require more research and innovation. Similarly, improvements in predicting longer term trends and short-term extremes could be achieved by even more focused efforts on: improving data acquisition; integrating socio-economic factors; and refinement of predictive models to improve the capacity of the system for forecasting long-term as well as short-term trends. And only once we do so, can we be sure that these systems will deliver to us the 'right' information at the 'right time' for management and conservation of ecosystems.

5.4. Policy Implications

The meaning of the discovery of this study lies in the field of policy emphasis on environmental control in China. Firstly, we can establish a monitoring and early warning index system at the national level to enable harmonized activities among government agencies, environmental organizations, and local people. The system can provide policy implications, i.e., land-use planning, conservation plans, and/or disaster risk management by providing real-time information and early warnings. You could also have an opportunity to monitor the system, and the policymakers would therefore be able to make quality decisions concerning the distribution of resources, and a priority that must be satisfied first when it comes to the degradation of resources. One such area is highlighting the regions with the greatest potential towards desertification and subsequently focusing on the most at-risk regions with an emphasis on promoting ecological restoration efforts or the introduction of land management strategies that limit over-grazing and other forms of unsustainable land-use strategies [80].

The paper highlights the need for intersectoral collaboration when addressing the ecological risk. Surveillance and early warning in the form of a management tool must include the collaboration of environmental agencies, local authorities, agricultural departments, and scientific institutions. Data gathering in sectors such as water quality measurement, land use practices and biodiversity measurements can be pooled together to represent a more comprehensive concept of the health of our ecosystem.

5.5. Limitations and Areas for Improvement

Although there is potential in the monitoring and early warning index system, there are a few limitations and areas that can be improved. Among the principal constraints, one should note the inconsistencies in the quality and availability of information in the region. Local data collection efforts in certain regions were uneven or incomplete, and this had an impact on the accuracy of the system. Enhancing local data collection processes, i.e., creating additional ground-based monitoring stations and promoting community engagement in the system, is a necessary measure to improve the quality of the system [81].

The vagaries of climate change, especially extreme weather, present a complication of short-term ecological risk forecasting. Research in the future requires trying to enhance the capacity of the system to take into consideration the uncertainties in the climatic conditions using new modelling estimations and the incorporation of information on climate forecasts. Also, placing socio-economic conditions, e.g., land-use changes and heat changes in population, into the monitoring framework would facilitate the provision of a more cross-dimensional environment understanding of risk on the ecosystem and would increase the predictive capability of the index system. Regardless of these obstacles, there are valuable ways in which the offered system will improve the ecological risk control in China. By investing more in data trapping efforts, enhancing the predictive modelling process, and integrating its information across sectors, the monitoring and early warning program can be pursued further and extended to meet the increasing environmental challenges weakening a variety of ecological systems in China [82].

6. Conclusion

This paper has discussed how to develop a holistic monitoring and early warning index system to measure the health of different ecosystems of China, such as the Loess Plateau, Poyang Lake, Bayanbulak Grassland, and Dongting Lake. The proposed system is a systemic intervention to monitor and predict when risks are affecting the ecosystem by integrating multiple ecological warning signs, such as soil erosion, vegetation health, water quality, and biodiversity.

The case studies reveal that the monitoring system can be used to record the initial indicators of ecological degradation and issue timely warning signals to counter the situation. The erosion and health of vegetation information was found to be effective in the Loess Plateau in predicting the areas at risk of land degradation with targeted conservation actions. In the same way, flood risk predictions and early warning of pollution events could be made in Poyang Lake by integrating water quality and hydrological data. The case study of Bayanbulak Grassland demonstrated that the functions of monitoring soil moisture and vegetation covers is highly vital in forecasting desertification, and the early warning system is essential in averting the further disappearance of grass and land.

It is noted that the incorporation of Dongting Lake in this study has greatly contributed to freshwater ecosystem monitoring. Dongting Lake is the second-largest freshwater lake in China and is considered a crucial flood control, water supply, and biodiversity conservation tool in the region. To provide a holistic perspective of the ecological health of the lake, Dongting Lake integrated its monitoring system with water quality parameters, hydrological parameters, and vegetation health parameters. The good thing about the system was that it anticipated all degradation of water quality and floods, but it did not predict with any degree of accuracy on the occurrence of eutrophication and pollution events on high nutrient loading days. The case study identifies the issues associated with the management of freshwater ecosystems that are prone to changes in water levels, agricultural runoff pollution, and upstream dam construction effects.

Although the monitoring and early warning index system has shown excellent predictability and early warning skills, issues connected to the data availability, climate variability, and complexity of the interactions between humans and the environment still exist. As the case studies reveal, the information gained through satellite-based data can be very useful in understanding the large-scale changes, but the accuracy of the system is largely determined by the accessibility of the local, real-time data. There is also the challenge of climate variability, especially with regard to unpredictable rainfall and temperature patterns, which makes it more difficult to predict risk in the short term, particularly in ecosystems such as Dongting Lake, where water levels rise and fall on a short-term basis.

The second cycle in the system needs to be established to support its predictive capability and scalability through strengthening the data collection processes, introducing socio-economic aspects, and revising the predictive models to take into account climate uncertainty. This shall be supplemented by recommendations to address the socio-economic statistics of land utilization, as well as population density and industrial activity, to derive an improved understanding of the causal implications of the ecological degeneration and overall systemic efficiency.

In order to ensure the monitoring system's long-term performance and sustainability, certain significant policy recommendations are included. Interagency collaboration and well-informed decision-making will be made easier by bolstering national and regional data-sharing systems. The timely data required for early warning measures will be provided by increased investment in real-time monitoring systems, particularly in rural or susceptible locations. Regulations about ecosystem-specific issues, such as preserving sustainable farming methods around Dongting Lake and regulating grazing in Bayanbulak Grassland, may also be implemented. Involving local populations in the monitoring and management process will improve system implementation and foster a feeling of shared accountability at the ecosystem health level.

Finally, this research would help build on the growth of a sound monitoring and early warning index mechanism applicable to a broad scope of ecosystems in China. The earth and the freshwater ecosystem, with the Dongting Lake as a whole system of environmental risk management, is bound to add value to the policymakers and likewise to the environmental managers. As the pressure on the environment increases, it will be crucial that the ecological risk is predicted and the system is timely intervened to protect the natural resources in China and the sustainable development.

Author Contributions

Conceptualization, Y.W. and S.Q.; methodology, S.Q.; software, J.Z. and J.W.; validation, S.X., Y.Z. and L.L.; investigation, S.Q., Y.Z. and L.L.; data curation, S.Q., Y.Z. and L.L.; writing—original draft preparation, S.Q.; writing—review and editing, Y.W.; supervision, Y.W.; project administration, Y.W.; funding acquisition, Y.W. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no competing interests.

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