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REVIEW

Progress and Prospect of Flood Monitoring with Fengyun Meteorological Satellite

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ABSTRACT

With the intensification of global climate change, flood disasters have become increasingly frequent, and satellite remote sensing has become a core technical means for flood monitoring. The Fengyun meteorological satellites, independently developed by China, hold irreplaceable application value in the timely and efficient monitoring of flood disasters. As a systematic review, this study aims to address the lack of systematic regarding the evolutionary trajectory and application status of Fengyun satellites in flood monitoring. By integrating relevant domestic and international research, it systematically reviws the FengYun-1 to FengYun-4 satellite series in flood monitoring and their application practices on a global scale, and clarifies the complete evolutionary of water body identification technologies—from the early visual interpretation method and the threshold method that dominated in the 1980s–1990s, to the machine learning method emerged in the 1990s, and further to the mixed-pixel decomposition technology pursuing sub-pixel-level accuracy. This study identifies the applicable scenarios and limitations of various water body identification technologies, analyzes the key issues in current applications, summarizes the core advantages of Fengyun meteorological satellites and technical bottlenecks that need to be overcome,

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and provides an outlook on future development directions in flood monitoring. Finally, it offers systematic theoretical references and practical guidance for the technological upgrading and operational application of flood monitoring based on China's independent satellite remote sensing.

Keywords: Fengyun Meteorological Satellite; Flood Water Body; Remote Sensing Monitoring; Principles and Methods

1. Introduction

Flooding is a natural disaster that occurs frequently and devastatingly on a global scale, causing great losses to human society and the ecological environment [1]. As global climate change continues to intensify, the frequency and destructiveness of floods are showing an increasing trend, and it has become imperative to adopt more effective monitoring and early-warning measures to meet this challenge. Field measurements can accurately monitor real-time information on the extent of surface water; however, they are constrained by high time consumption and labor-intensive costs, thus limiting their application to local areas only. By contrast, satellite remote sensing technology possesses characteristics of wide coverage, short data acquisition cycles, and rich information content—enabling it to monitor flood disasters more quickly, objectively, and comprehensively [2]. As such, it has emerged as an important supplement for observing the dynamic changes of surface water.

The Fengyun meteorological satellites, independently developed by China, are advanced remote sensing satellite systems that hold irreplaceable significance in the field of water body and flood monitoring. Since their operation, these satellites have enabled real-time capture of changes in surface water bodies through their equipped high-precision sensors, providing strong data support for the early identification of flood disasters and emergency response. They also play a crucial role in water body monitoring, flood prevention and control, as well as disaster prevention and mitigation efforts. In recent years, with the launch of a new generation of meteorological satellites and the continuous progress of remote sensing technology and data processing capability, the application of Fengyun meteorological satellites in water body flood monitoring has made remarkable progress. Researchers have developed a variety of methods for water body flood monitoring based on Fengyun Meteosat data, and these methods have made breakthroughs in improving monitoring accuracy and shortening response time.

This study is a systematic review focusing on flood monitoring using Fengyun meteorological satellites, aiming to address the gap in the systematic collation of the technological evolution and application status of Fengyun meteorological satellites in flood monitoring. This paper systematically reviews the overall research progress of Fengyun meteorological satellites in flood water monitoring, with a focus on clarifying the complete development trajectory of water body identification technologies. It deeply analyzes the core challenges faced in current technological applications and operational implementation, summarizes the application advantages of Fengyun satellites in flood monitoring and the technical bottlenecks that urgently need to be broken through, and provides an outlook on future development directions.

2. A Brief Review of Fengyun Meteorological Satellites in Flood Monitoring Applications

Since the launch of the meteorological satellite development program in 1970, China has successfully independently developed and launched the Fengyun-1, Fengyun-2, Fengyun-3, and Fengyun-4 series of meteorological satellites (**Tables 1** and **2**, Data source: Fengyun Satellite Remote Sensing Data Service Network (https://data.nsmc.org.cn/)), and has established operational systems for geostationary and polar-orbiting meteorological satellites in stable operation [3]. With the continuous innovation of satellite remote sensing processing technology, the monitoring capability of Fengyun meteorological satellites has been significantly improved. Especially in the globalized and refined integrated detection of the atmosphere and the Earth's multi-circle system, Fengyun meteorological satellites provide strong data support for meteorological forecasting, disaster prevention and mitigation, and ecological environment monitoring. At present, Fengyun meteorological satellites have also demonstrated their significant advantages in the monitoring of the surface ecological environment, and have been successfully applied in a number of fields, such as the monitoring of flooded water bodies, the monitoring and early warning of forest and grassland fires, and the assessment of the state of vegetation cover, thus improving the ability to monitor the dynamics of the surface ecological environment, and providing important data support for the relevant management and decision-making departments.

Table 1. List of Fengyun series polar-orbiting meteorological satellites.

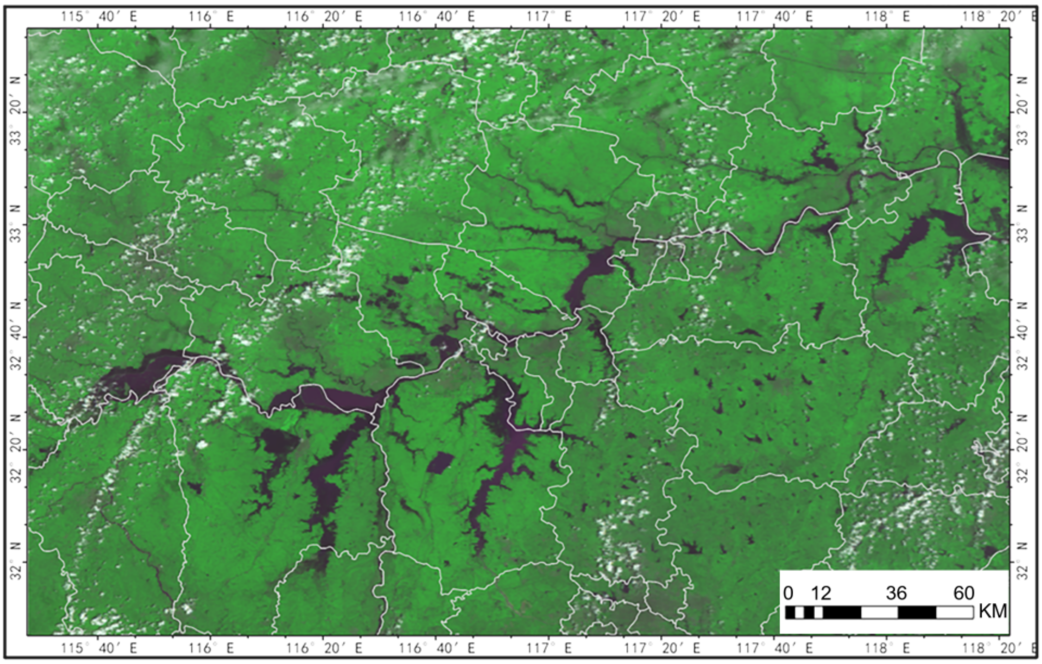
Satellite Type	Business Type	Main Instruments for Water Monitoring	Spatial Resolution	Coverage/Period	Number of Bands
FY-1A	polar orbit	MVISR	1.1 km	Global coverage/day, 2 times/day	12
FY-1B	polar orbit	MVISR	1.1 km	Global coverage/day, 2 times/day	12
FY-1C	polar orbit	MVISR	1.1 km	Global coverage/day, 2 times/day	12
FY-1D	polar orbit	MVISR	1.1 km	Global coverage/day, 2 times/day	12
FY-3A	polar orbit	MERSI-I	250 m/1 km	Global coverage/day, 2 times/day	20
FY-3B	polar orbit	MERSI-I	250 m/1 km	Global coverage/day, 2 times/day	20
FY-3C	polar orbit	MERSI-I	250 m/1 km	Global coverage/day, 2 times/day	20
FY-3D	polar orbit	MERSI-II	250 m/1 km	Global coverage/day, 2 times/day	25
FY-3E	polar orbit	MERSI-LL	250 m/1 km	Global coverage/day, 2 times/day	7
FY-3G	polar orbit	MERSI-RM	500 m	Global coverage/day, 2 times/day	8
FY-3F	polar orbit	MERSI-III	250 m/1 km	Global coverage/day, 2 times/day	25
FY-3H	polar orbit	MERSI-III	250 m/1 km	Global coverage/day, 2 times/day	25

Table 2. List of Fengyun series geostationary meteorological satellites.

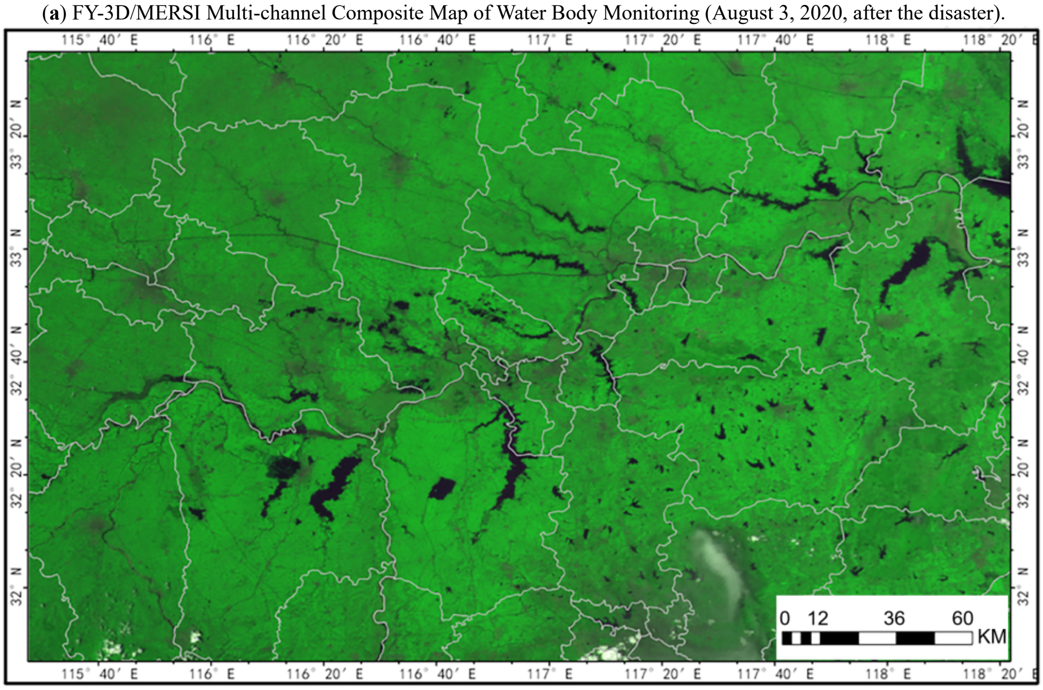
Satellite Type	Business Type	Main Instruments for Water Monitoring	Spatial Resolution	Coverage/Period	Number of Bands
FY-2A	geostationary satellite	VISSR-I	1.25 km/5 km	Full disc 30 min	3
FY-2B	geostationary satellite	VISSR-I	1.25 km/5 km	Full disc 30 min	3
FY-2C	geostationary satellite	VISSR-II	1.25 km/5 km	Full disc 30 min	5
FY-2D	geostationary satellite	VISSR-II	1.25 km/5 km	Full disc 30 min	5
FY-2E	geostationary satellite	VISSR-II	1.25 km/5 km	Full disc 30 min	5
FY-2F	geostationary satellite	VISSR-II	1.25 km/5 km	Full disc 30 min	5
FY-2G	geostationary satellite	VISSR-II	1.25 km/5 km	Full disc 30 min	5
FY-2H	geostationary satellite	VISSR-II	1.25 km/5 km	Full disc 30 min	5
FY-4A	geostationary satellite	AGRI	500 m/1 km/2 km/4 km	Full disc 15 min	14
FY-4B	geostationary satellite	AGRI/GHI	AGRI: 500 m/1 km/2 km/4 km, GHI: 250 m/500 m/2 km	Full disc 15 min, Region 1 min	15, 7

The application history of Fengyun meteorological satellites in the field of flood water monitoring epitomizes China's continuous progress and innovation in the field of meteorological satellite technology. Since 1988, when China successfully launched the first Fengyun series of meteorological satellites, with the continuous updating of sensor technology and the gradual improvement of the ground application system, the Fengyun satellite system has evolved into a complex network consisting of multiple satellites by carrying more advanced sensors and equipped with a perfect ground application system [4]. Advanced sensors have greatly improved the accuracy and effectiveness of Fengyun satellite data, providing a more reliable data source for flood water monitoring. High-precision datasets allow us to assess the potential risks and affected scopes of floods more rapidly and accurately, thereby furnishing more robust technical support for flood control decision-making. At the same time, the improvement of the ground application system has also significantly enhanced the ability of real-time monitoring and rapid response.

Fengyun satellite has played an important role in China's flood monitoring field since the 1991 Jianghuai flood event. Through the correction and enhancement of satellite data, researchers were able to accurately distinguish between water bodies and non-water bodies in the Jianghuai floods, define the land and water boundaries, and calculate the area and duration of floods, which provided scientific support for decision-making in flood control. In 1998, remote sensing technology was first applied on a large scale in severe floods across the Yangtze River Basin and other river basins, achieving remarkable outcomes. In 1999, FY-1C satellite data were employed in flood prevention and disaster mitigation efforts in the Yangtze River Basin, providing timely and accurate monitoring services for disaster information reporting [5]. In the 21st century, with the launch of a new generation of meteorological satellites, the temporal and spatial resolution of remote sensing data has been significantly improved. The SMART system (Satellite Monitoring Analysis and Remote Sensing Application System) developed by the National Satellite Meteorological Center integrates various disaster monitoring functions such as flood monitoring, and realizes technological breakthroughs in data processing and product generation, which greatly improves the accuracy and efficiency of flood monitoring. In recent years, the SMART system has provided key information in the monitoring of major floods, especially in the monitoring of floods in the Songnen Basin in 2013 and the Huaihe River Basin in 2020 (**Figure 1**), which demonstrated its important value in disaster early warning and assessment.



(**a**) FY-3D/MERSI Multi-channel Composite Map of Water Body Monitoring (August 3, 2020, after the disaster).



(**b**) FY-3B/MERSI Multi-channel Composite Map of Water Body Monitoring (July 24, 2017, after the disaster).

Figure 1. Monitoring map of 2020 Huaihe River basin flood disasters by Fengyun meteorological satellite.

The international application of Fengyun meteorological satellite data demonstrates its key role in the global Earth observation network. Through international cooperation and data sharing, Fengyun meteorological satellites have provided timely monitoring services to users around the world. During the floods in Myanmar in 2015, Fengyun satellite data provided important information for disaster assessment and response. In 2019, Fengyun satellite monitoring services again proved its value in the global monitoring of the severe floods in Mozambique and other countries triggered by Tropical Cyclone Idai. In the severe floods in Mozambique and other countries triggered by Tropical Cyclone Idai in 2019, Fengyun's monitoring services once again proved its value in global disaster prevention and mitigation. The international sharing of data from Fengyun meteorological satellites not only promotes the improvement of global Earth observation capability, but also provides strong support for international cooperation in disaster prevention and mitigation. Its application on a global scale demonstrates China's active contribution and responsibility in the field of international disaster prevention and mitigation. Through the monitoring services of Fengyun meteorological satellites, the international community is able to respond more effectively to natural disasters, reduce the losses caused by disasters and protect people's lives and property.

3. Progress in Monitoring Flooded Water Bodies by Fengyun Meteorological Satellites

Flood monitoring by Fengyun meteorological satellites is an important component of satellite remote sensing of surface disasters. Remote sensing data are applied throughout the three critical periods of flooding, before, during and after the disaster. Before the disaster, remote sensing is used for daily monitoring to capture the characteristics of water bodies in a steady state. During the disaster, remote sensing imagery is used for real-time monitoring of water body changes during the disaster. After the disaster, remote sensing data record the flood recession process and provide information support for disaster recovery. Comparative analysis of water body information during and before the disaster, combined with land use and topographic data, can accurately assess the inundation range and depth of flooding and provide a scientific basis for disaster damage assessment. The monitoring of post-disaster water body information, on the other hand, helps to assess the long-term impact and recovery from floods.

The observation frequency, band range and spatial resolution of the new generation of Fengyun meteorological satellites have been significantly improved, providing a rich data source for flood monitoring. Its features include: rich spectral information that enhances the identification of water bodies and other land surfaces; high-frequency observation that realizes the rapid dynamic monitoring capability of flood disasters; large-range observation capability with global coverage; multi-satellite network observation that enhances the accuracy and efficiency of monitoring; and multi-source data fusion technology that enriches the content of disaster monitoring information.

The key to accurately determining flood disasters lies in the precise identification of water body information in remote sensing images. Scientific and technological personnel have conducted long-term and systematic research on the water body identification technology of Fengyun meteorological satellites, and have made remarkable progress. Meanwhile, the monitoring methods of foreign satellites such as MODIS have also been successfully applied to Fengyun satellites, enhancing the accuracy and efficiency of flood monitoring.

3.1. Fundamentals of Optical Remote Sensing in Water Monitoring

The spectral characteristics of a feature are a direct reflection of its reflective and absorptive properties of solar radiation and provide a basis for the differentiation of feature types. Optical remote sensing satellites identify the presence of water bodies and their changes by capturing spectral information from the surface. Water bodies, due to their unique optical properties, exhibit low reflectivity and distinct absorption bands in the near-infrared band (**Figure 2**), in contrast to other feature surface characteristics, a principle that enables optical remote sensing satellites to effectively identify water bodies. The near-infrared channel is particularly sensitive to reflectance changes in flooded areas, providing an important basis for flood monitoring [6].

In the 1960s, the application potential of satellite optical sensors in monitoring land cover changes of the Earth was developed [7], and remote sensing technology was applied in hydrology in 1984[8], and in 1988, China launched the first Fengyun-1A satellite, which opened a new chapter of the Fengyun Meteorological Satellite (FMS) in the monitoring of water bodies. A new chapter in the monitoring of water bodies was opened with the launch of the first Fengyun-1A satellite in 1988. In particular, the new generation of Fengyun meteorological satellites carries multi-band optical sensors, through the visible, near-infrared, short-wave infrared observation (**Tables 3** and **4**), to obtain a wealth of spectral information, and realize the accurate differentiation of different features[9]. The application of these technologies provides high-precision judgment support for monitoring the distribution of water bodies and flood extent[10], which is of vital significance for rapid response to flood disasters, impact assessment, development of flood control plans and post-disaster reconstruction.

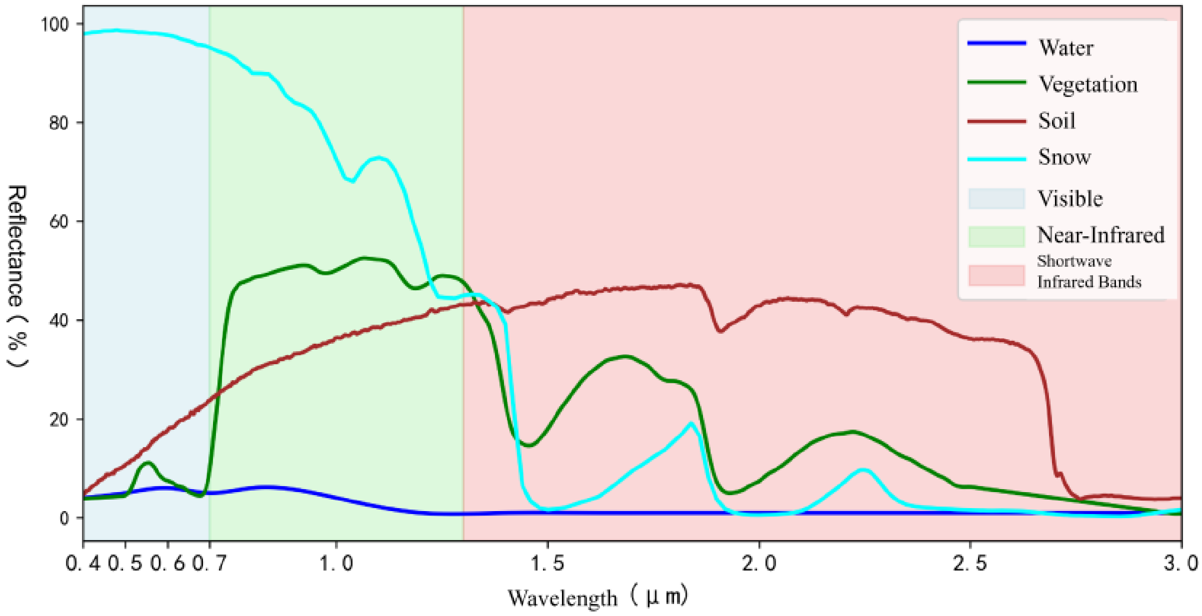


Figure 2. Spectral Characteristics of Typical Land Covers in Visible, Near-Infrared, and Shortwave Infrared Bands.

Table 3. Channel Characteristics of FY3D/MERSI-II Relevant to Water Body Identification.

Channel	Center Wavelength (μm)	Spectral Bandwidth (μm)	Substellar Point Resolution (m)
1	0.470	0.05	250
2	0.550	0.05	250
3	0.650	0.05	250
4	0.865	0.05	250
6	1.64	0.05	1000
7	2.13	0.05	1000
24	10.8	1	250
25	12	1	250

Table 4. Channel Parameters of FY-4A Geostationary Meteorological Satellite AGRI (Advanced Geostationary Radiation Imager) Relevant to Water Body Identification.

Channel	Center Wavelength (μm)	Wavelength Range (μm)	Substellar Point Resolution (m)
1	0.470	0.45–0.49	1000
2	0.650	0.55–0.75	500
3	0.825	0.75–0.90	1000
5	1.610	1.58–1.64	2000
6	2.250	2.1–2.35	2000
1	0.470	0.45–0.49	1000

3.2. Water Body Identification Method for Fengyun Meteorological Satellites

The multispectral sensors carried by the Fengyun meteorological satellites cover the key spectral bands of major features, providing an important basis for identifying information on water bodies in lakes, reservoirs, rivers and so on. Data analysis in these bands not only monitors changes in the area of water bodies, but also provides key information for flood early warning and drought assessment, thus improving the efficiency and accuracy of monitoring; long sequences of continuous remote sensing data from Fengyun Meteorological Satellites provide data support for the monitoring of changes in water bodies over long periods of time and for research on climate change. With the development of remote sensing technology, the application of Fengyun Meteorological Satellite in the monitoring of water bodies will be more extensive, providing more in-depth scientific support for water resources management and environmental protection.

Remote sensing technology of Fengyun meteorological satellite is widely used in water identification in visible blue, green and red bands, near-infrared and short-wave infrared bands, in which near-infrared bands play a key role. As China's self-developed Earth observation satellite, Fengyun Meteorological Satellite has adopted a number of key technologies in water body monitoring, demonstrating its unique advantages in water body identification and monitoring.

Accurate and rapid extraction technology of water body information is the focus of continuous research in the field of remote sensing. Early water body information recognition relied on manual visual interpretation, and with the development of computer technology, water body information recognition has gradually transformed from semi-automatic to automated. In recent years, automation technology based on deep learning has become a research hotspot [11], and the continuous evolution of technical methods has promoted the development of satellite remote sensing water body monitoring technology.

Visual Interpretation Method (1970s–1980s): the initial method of extracting water bodies from remote sensing images, which mainly relies on the direct recognition of water body features in the image by professionals, ensuring a high recognition accuracy [12]. However, the efficiency is limited by manual operation, high cost, and faces great difficulties in long time series and large scale monitoring.

Threshold Method (1980s–1990s): Also known as model classification method, this approach is primarily based on the spectral characteristics of water bodies. It involves selecting appropriate bands to construct models and setting thresholds for image segmentation. In water body extraction in complex regions, this method faces challenges related to threshold selection. Thus, a "global-local" threshold segmentation strategy is usually adopted to obtain the optimal threshold. The threshold method is divided into single-band and multi-band sub-methods, with the latter further subdivided into the inter-spectral relationship method and the index method.

(1) Single-Band Method: This is a widely used approach that leverages the spectral absorption characteristics of water bodies in both near-infrared (NIR) and short-wave infrared (SWIR) bands to identify water bodies. In 1977, Bartolucci et al. [13] discovered the strong absorption properties of water bodies within a specific wavelength range using Landsat MSS data. Yao et al. [14] utilized FY3/MERSI data and employed the single-channel threshold segmentation method for water body extraction, enabling the monitoring of water body changes in the Huaihe River Basin. While this method has been implemented in practice, it carries the risk of misclassifying shadows as water bodies, resulting in certain limitations. Despite its advantages of simplicity and user-friendliness, this method struggles to fully identify all water bodies due to the intricate nature of ground object spectral signatures, which typically restricts its extraction precision [15].

(2) Inter-Spectral Relationship Method: This method analyzes interrelationships between different bands and establishes logical judgment rules to distinguish water bodies from other land cover types. Based on remote sensing images, numerous researchers [16–18] have observed that water bodies exhibit the characteristic that the sum of reflectance in the green band and the red band is greater than that in the near-infrared band and the short-wave infrared spectral band. In 2019, Huang et al. [19] combined FY-3/MERSI and MODIS data and applied the inter-spectral relationship threshold method to monitor water bodies in the Poyang Lake region. The integration of multiple bands reduces interference from

factors such as shadows and improves the accuracy of water body extraction, particularly in areas with simple topography.

Index Method: This method constructs models based on the spectral characteristic curves of water bodies to highlight water body information. It features high band information utilization and strong anti-interference capabilities, making it the most widely used approach for water body identification. In 1996, McFeeters[20] proposed the Normalized Difference Water Index (NDWI), which is calculated using the ratio of green and NIR bands. This index effectively distinguishes water bodies while suppressing background interference; owing to its simplicity and ease of implementation, it is frequently used in water body identification. However, its sensitivity to complex terrain and highly reflective surfaces limits its generalizability[21]. To address this issue, researchers have developed various improved water body index models based on the spectral properties of water bodies, including Modified Normalized Difference Water Index (MNDWI)[22], Enhanced Water Index (EWI)[23], Novel Water Index (NWI)[24], Revised Normalized Difference Water Index (RNDWI)[25], Automatic Waterbody Extraction Index (AWEIsh)[26], False Normalized Difference Waterbody Index (FNDWI)[27], Shadow Waterbody Index (SWI)[28], and Augmented Normalized Difference water index(ANDWI)[29]. These models have been applied in practice, especially in flood monitoring using Fengyun meteorological satellites. In 2015, Ma et al.[30] used FY3/MERSI data and compared multiple indices to monitor snowmelt floods in the alpine regions of Xinjiang. Chen et al.[31] utilized FY3A/MERSI data, comparing multiple methods to conduct a study on water body extraction in Bosten Lake, Xinjiang. Jiali Shao et al.[32] used FY4A imagery, combining NDWI with the maximum between-class variance algorithm (OTSU) to automatically extract floodwater in South Asia, obtaining relatively accurate information on flooded water bodies. **Table 5** lists the index methods commonly used in Fengyun satellite data processing.

Table 5. Commonly Used Index Methods in Fengyun Satellite Data Processing.

Model	Equation
Normalized Difference Waterbody Index (NDWI)	NDWI = (G − NIR)/(G + NIR)
Enhanced Waterbody Index (EWI)	EWI = (G − NIR − SWIR)/(G + NIR + SWIR)
Revised Normalized Difference Waterbody Index (RNDWI)	RNDWI = (SWIR − R)/(SWIR + R)
Shaded Waterbody Index (SWI)	SWI = B + G − NIR

Note: G, R, NIR and SWIR correspond to the pixel values of the green band, red band, near-infrared band, and short-wave infrared band, respectively.

Machine Learning Methods (1990s): Significant progress has been made in remote sensing water body identification. Traditional methods are limited by factors such as water body turbidity, topography, surrounding feature types, and observation time, while machine learning methods utilize spectral, spatial, and textural information of images to improve the accuracy and adaptability of water body extraction. (1) Supervised classification: by selecting a sufficient number of water body training samples and extracting features, the classification algorithms are trained in combination with category labels. Common algorithms include minimum distance classification, maximum likelihood classification, support vector machine (SVM), etc. The SVM method[33], performs particularly well when the number of labeled samples is limited, and Paul et al.[34] verified the result. (2) Unsupervised classification: with little or no initial parameters, the algorithm automatically matches the image element features and performs clustering to realize automatic extraction of water bodies. Common algorithms include K-means clustering, ISODATA, and hierarchical clustering, etc. Kloiber[35] et al. realized water body assessment during 1973–1998 by using unsupervised classification. (3) Decision tree method: a classification method based on spatial data mining and knowledge discovery[36]. It focuses on the selection of attributes of different categories of objects and includes versions ID3, C4.5 and C5.0[37]. (4) Random Forest: constructs multiple decision trees and will combine the prediction results to improve the accuracy and robustness of classification. Rao et al.[38] based on MODIS data of Dongting Lake water body identification research, random forest method of water body accuracy is better than logistic regression and SVM method. (5) Deep learning: simulate neural network structure to learn the data pattern, through the deep neural network structure to automatically extract features learning and other advantages to achieve water body information recognition[39]. Common methods include convolutional neural network (CNN), semantic segmentation model, attention mechanism, and deep full convolutional network. Deep learning is undergoing continuous development in water body identification. It is anticipated that with advances in algorithms and computational power, more innovative approaches will emerge to drive the advancement of remote sensing-based water body monitoring.

Hybrid Image Element Decomposition: It is crucial to improve the accuracy of water body information recognition in wind and cloud meteorological satellite images. The reflectance spectrum of a water body is essentially a hybrid spectrum formed by the combined effect of multiple water quality parameters. This technique solves the mixed image element problem faced by the traditional image element-based water body extraction methods by analyzing at the sub-image element level. Liu et al.[40] and others quoted the linear mixed image element method to extract water bodies based on MODIS data, and Gong et al.[41] incorporated the mixed pixel method to improve the extraction accuracy of mountain river water body boundaries from medium and low-resolution remote sensing images. In addition, the accuracy of water body area estimation by hybrid image element is especially critical for the estimation of the impact area of flooded water bodies, especially for small-scale flooded water bodies.

With the development of remote sensing technology, water body information recognition technology is also evolving. Currently, water body recognition technology is moving towards advanced fields such as deep learning. Deep learning has significant advantages in automated water body extraction, but it still needs to be further optimized in terms of the versatility and flexibility of the algorithms to meet the needs of remote sensing water body monitoring in different geographical areas.

3.3. Current Status and Shortcomings of Fengyun Meteorological Satellites in Flood Monitoring

Fengyun meteorological satellites have realized continuous technological development in flood monitoring. The launch of the Fengyun-1C satellite marked the launch of the nationwide flood monitoring operations of the Fengyun series of satellites, whose 1-km spatial resolution provides effective data for monitoring larger bodies of flooded water. With the launch of the new generation of meteorological satellites, its spatial and temporal resolution and observation channels have been significantly improved, bringing highly efficient and accurate data sources for flood monitoring. The 250-m resolution channel of the Fengyun-3D star, as well as the high-frequency observation data of Fengyun-4, have significantly enhanced the monitoring accuracy and dynamic monitoring capability of flooded water bodies.

With the successful launch of a new generation of meteorological satellites, the National Satellite Meteorological Center has launched the SMART system, which integrates a variety of disaster monitoring functions, such as flood monitoring, and can use Fengyun-3 polar-orbiting meteorological satellite data to generate a variety of satellite-based flood monitoring products, including the identification of bodies of water, the monitoring of floods and the analysis of dynamic changes, the estimation of area and duration, and the degree of impact on vegetation. In recent years, the National Satellite Meteorological Center and provincial remote sensing centers have made use of new-generation meteorological satellite data and the SMART system to carry out operational monitoring of the country's seven major river basins and major flood events, which has effectively supported decision-making in flood relief. At the same time, the application efficiency and service level of satellite remote sensing flood monitoring have been enhanced through the establishment of joint monitoring mechanisms at the national and provincial levels.

Although Fengyun meteorological satellites have made remarkable progress in the field of flood monitoring. (1) Data source, the development of the Fengyun satellite series has provided diversified data for flood monitoring. The sensors carried by Fengyun-1 to Fengyun-4 satellites are capable of capturing key parameters of the Earth's surface and atmosphere, such as temperature, humidity and wind speed, providing comprehensive information for monitoring. (2) Monitoring accuracy. The technological advances of the new generation of Fengyun meteorological satellites have significantly improved the resolution and accuracy of the data, and their high-resolution imaging technology has made it possible to clearly show the details of the flooded areas, including submerged farmland, towns and cities, etc. The multi-spectral and multi-parameter observation technology has further enhanced the accuracy of the data. Multispectral and multi-parameter observation technology further enhances the monitoring accuracy and reliability of parameters such as water body area and duration. (3) Monitoring system, the development of Fengyun meteorological satellites has brought about a more efficient and improved data processing system. The enhancement of real-time data transmission and rapid response capability ensures that images of flooded areas can be rapidly acquired and transmitted, providing support for disaster response and rescue plan development. The application of data fusion technology further improves the precision and timeliness of monitoring by integrating Fengyun satellite data with other remote sensing data sources. In summary, Fengyun meteorological satellites have made important breakthroughs in flood monitoring in terms of data sources, monitoring accuracy and system refinement.

Although Fengyun meteorological satellites have achieved significant breakthroughs in data sources, monitoring accuracy improvement, and system construction for flood monitoring, they still have the following key shortcomings in practical applications due to limitations in technical principles, equipment performance bottlenecks, and the complexity of application scenarios: (1) Optical observation is prone to restrictions from adverse weather. Currently, Fengyun satellites rely primarily on optical sensors (e.g., FY-3/MERSI, FY-4/AGRI) for flood monitoring. However, flood disasters are often accompanied by adverse weather such as thick clouds and heavy rain—thick clouds cause severe obstruction of optical signals, making it difficult for optical observation to achieve all-weather and continuous monitoring of flood waters. (2) Insufficient spatiotemporal matching of high-resolution data. There exists a trade-off between "spatial resolution and observation frequency": the 250-m high-resolution data from Fengyun polar-orbiting meteorological satellites (e.g., FY-3H) only pass over the target area 1–2 times per day due to orbital characteristics, making it difficult to track the rapid evolution of sudden floods such as urban waterlogging in real time; in contrast, the 15-min high-frequency observation data from Fengyun geostationary meteorological satellites (e.g., FY-4) have a resolution of only 500 m, which cannot accurately monitor the boundaries of small-scale water bodies such as rivers and fails to meet the needs of refined disaster assessment (e.g., farmland plot-level assessment). (3) Insufficient adaptability of water body identification models to complex underlying surfaces. To meet the needs of monitoring water bodies on complex underlying surfaces in different regions, existing water body identification algorithms perform stably in open plain waters but are susceptible to interference in special scenarios. For instance, in urban-rural transition zones. The spectral characteristics of cloud shadows and topographic shadows are highly similar to those of water bodies, which easily leads to false positive extraction of water bodies. These issues make it difficult to accurately quantify the scope of flood inundation.

4. Conclusions

With the increasing frequency of extreme weather events, flood prevention and mitigation are facing unprecedented challenges. Fengyun meteorological satellites, as an important monitoring tool, have made significant progress in the monitoring and assessment of floods, but there are still technical bottlenecks that need to be broken through, and the following is an outlook for future flood monitoring applications:

(1) Improve monitoring accuracy and real-time: Rapid response to floods requires that monitoring data must have high accuracy and real-time. Fengyun meteorological satellites need to further improve the temporal and spatial resolution of the sensors to realize refined and instantaneous data collection. In addition, the integration of advanced data processing algorithms, such as time series analysis and machine learning models, can quickly and accurately identify and assess flooding situations, enhancing the response speed and accuracy of monitoring.

(2) Enhancement of all-weather high-precision observation capability: All-weather high-precision observation is crucial for continuous monitoring of flooding under severe weather conditions. At present, the optical instrument data of Fengyun Meteorological Satellite is limited in its ability to recognize water body information under thick cloud conditions, which affects its all-weather monitoring capability. Therefore, Fengyun Meteorological Satellite needs to carry high-precision active microwave sensors to realize the ability of all-weather flood monitoring without the restriction of cloud cover and other weather conditions, and having

this ability will significantly improve the continuity and reliability of flood monitoring.

(3) Efficient processing of remote sensing datasets: with the increase in the amount of remote sensing data, Fengyun Meteorological Satellite data need to be processed by means of efficient data processing, such as cloud computing, big data technology and parallel computing, in order to accelerate the processing and analysis of data. In addition, the development of intelligent data management and analysis tools will help to extract thematic monitoring information, such as water bodies, from huge long time series datasets and improve monitoring efficiency.

(4) Realize the effective combination of Fengyun satellite data and ground monitoring: Data fusion technologies such as geographic information systems (GIS) and multi-source data integration algorithms can combine Fengyun satellite data with ground monitoring data to realize the complementary advantages of macro and microscopic data. This fusion technology not only improves monitoring accuracy, but also enhances the ability to monitor flooding in complex terrain and under special conditions.

Fengyun meteorological satellites play an irreplaceable role in flood monitoring in China's vast territory and frequent flood conditions. In the future, through technological innovation and application practice, Fengyun meteorological satellites will play an even more critical role in the field of flood monitoring, providing solid scientific and technological support for flood prevention and disaster reduction in China.

Author Contributions

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

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Data Availability Statement

This study did not generate any new data. All data analyzed during the research are publicly available from official repositories, and the relevant sources have been clearly cited in the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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