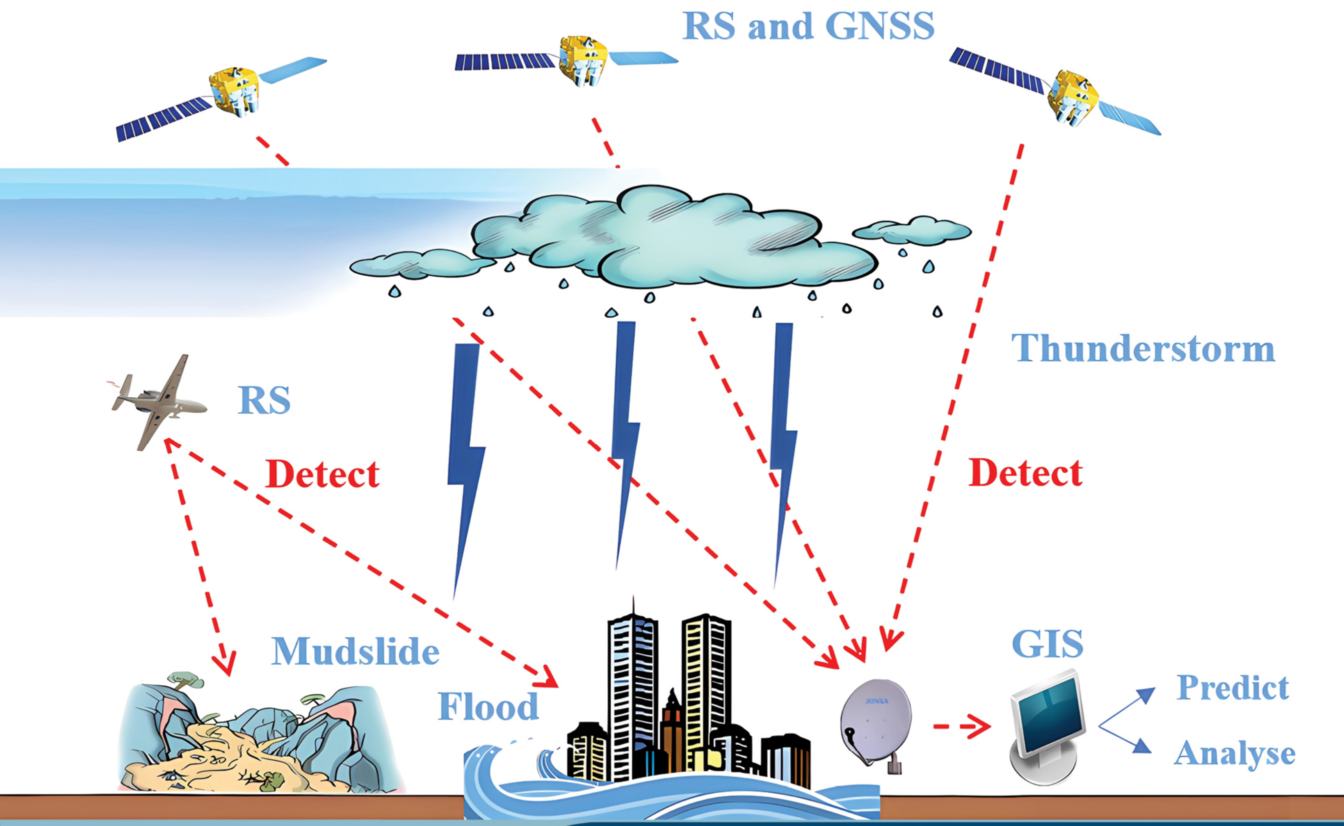

3S Technology Applications in Meteorology

Observations, Methods, and Modelling

Edited by
Shuanggen Jin

CRC Press
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3S Technology Applications in Meteorology

Spatial information technology and its integration, such as remote sensing, geographic information systems (GIS), and global navigation satellite systems (GNSS), known as 3S technology, have been extensively utilized in managing and monitoring natural disasters. This book illustrates the 3S integrated applications in the field of meteorology and promotes the role of 3S in developing precise and intelligent meteorology. It presents the principles of 3S technology and the methods for monitoring different meteorological disasters and hazards as well as their application progress. The case studies from the United States, Japan, China, and Europe were conducted to help all countries understand the 3S technology functions in handling and monitoring severe meteorological hazards.

FEATURES

- Presents integral observations from GNSS, GIS, and remote sensing in estimating and understanding meteorological changes
- Explains how to monitor and retrieve atmospheric parameter changes using GNSS and remote sensing
- Shows three-dimensional modeling and evaluations of meteorological variation processing based on GIS
- Helps meteorologists develop and use space-air-ground integrated observations for meteorological applications
- Illustrates the practices in monitoring meteorological hazards using space information techniques and case studies

This book is intended for academics, researchers, and postgraduate students who specialize in geomatics, atmospheric science, and meteorology, as well as scientists who work in remote sensing and meteorology, and professionals who deal with meteorological hazards.

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Contents

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1 A Review of 3S Technology and Its Applications in Meteorology

Haiyong Ding and Shuanggen Jin

1.1 BACKGROUND

Meteorological disaster is the direct or indirect damages caused by the atmosphere to human life, economy, and national defense construction, which usually includes climate disasters and derived disasters (Guan et al., 2015; Ye, 2022). Climate disasters are directly caused by severe weather such as typhoons, rainstorms, blizzards, thunderstorms, hail, high temperatures, drought and other meteorological factors (Allan et al., 2006). The derived meteorological disasters are caused by meteorological factors. According to statistics, nearly 90% of natural disasters were related to the bad weather (United Nations, 2015). The derived meteorological disasters mainly include forest fires, debris flow and landslides. Traditional meteorological disaster monitoring mainly uses quantitative observation instruments. For example, anemometers, rain gauges and temperature measuring instruments are used to monitor high wind hazards, urban rainstorms and high temperatures, respectively. Traditional meteorological disaster monitoring methods have various deficiencies. For instance, mechanical rain gauges such as siphon type gauges are mainly used to monitor rainstorms (Li et al., 2010), while such instruments are cumbersome in operation and lack self-adjustment and self-adaptation ability. In addition, the monitoring of meteorological hazards requires not only a conventional meteorological observation network, but also a focus on the structural changes in the atmospheric boundary layer that affect human activities and the human habitat, as well as the impact of changes in the subsurface on meteorological conditions (Wang et al., 2009). However, such detection is difficult to achieve, only relying on traditional ground-based observation instruments.

3S technology specifically refers to the Global Navigation Satellite System (GNSS), Remote Sensing (RS), and Geographic Information System (GIS) (Zhang, 2020; Li, 2003). 3S technology, as the core technology of spatial informatics, can provide a full range of resource and environmental data and quickly obtain multi-platform, multi-temporal, multi-band, high-precision and high-resolution massive space-time information (Li, 2003; Li et al., 1998). The combination of 3S technology observations in meteorology can overcome the shortcomings of traditional meteorological instruments such as low accuracy and poor self-adaptive capability for observing certain meteorological parameters. For example, images acquired from satellite remote sensing can draw a map of water distribution in the atmosphere and rainfall distribution through light recognition equipment and infrared sensors, which can effectively improve the observation ability of rainfall in heavy rainstorms. GNSS Radio Occultation (GNSS RO) can achieve high vertical resolution and spatial coverage of the atmospheric parameter profiles, which can effectively solve the problems of poor stability and low vertical resolution of traditional observation means such as radar and reanalysis data and effectively improve the monitoring ability of meteorological disasters. 3S technology can not only enrich the means of meteorological observations and improve the ability of meteorological observations, but also collect, store and analyze meteorological data by GIS. For example, GIS can carry out statistical analysis of meteorological disaster data, assess meteorological disasters risks and improve the ability to defend against meteorological disasters. GIS can also evaluate the disaster

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situation of meteorological disasters through the integration and analysis of information. Therefore, 3S technology has become an important means of meteorological observation, processing and analysis, and can improve the comprehensive management and assessment of meteorological disasters (Li, 2003; Li, 1998). With the development of 3S, more closely combined meteorological parameter observation and disaster monitoring and forecast will be constantly improved.

1.2 3S TECHNOLOGY AND DEVELOPMENT

1.2.1 Basic Concepts

The "3S" is the general name of Global Navigation Satellite System (GNSS), Geographic Information System (GIS), and Remote Sensing (RS), which is the integration of space technology, satellite navigation and positioning technology, computer technology, sensor technology and other disciplines (Li, 2003). The 3S technology system is used to quickly acquire spatial data using RS and GNSS and use GIS as the basic platform to store, manage and analyze spatial information.

The GNSS is a satellite-based radio timing and navigation system that provides high precision time and spatial location data for users in aviation, space, land and sea, online or offline (Lechner, 2000; Dow, 2009; Norman, 2012). The GIS refers to the representation of geospatial objects' nature, characteristics and motion state and all relevant and useful knowledge. GIS is a computer system that collects, stores, manages, analyzes, displays and applies geographic information (Goodchild, 2009). In a broad sense, RS refers to remote sensing technology for objects or natural phenomena without direct touch (Campbell & Wynne, 2011). In a narrow sense, RS is a modern technical science that uses various sensors (such as cameras and radars) to acquire surface information on various platforms at high altitudes and in outer space, and studies the shape, size, position and nature of ground objects and their relationship with the environment through data transmission and processing. GNSS and RS are respectively used to acquire point and surface spatial information or monitor its changes, while GIS is employed to store, analyze and process spatial data. Due to the obvious complementarity of the 3S technologies, one gradually realizes in practice that when 3S techniques are integrated in a unified platform, their respective advantages can be fully played.

Since the 1990s, 3S integration has attracted increasing attention and gradually developed into a new interdisciplinary discipline: geomatics (Gomarasca, 2009). But before that, the three went through independent and parallel development. RS obtains real-time, rapid geometric and physical qualitative or quantitative data on large areas of the landscape and environment. GNSS provides real-time or quasi-real-time target positioning information. GIS is a platform for storing, managing, analyzing and applying data from various sources. These three technologies have different characteristics. The 3S technology integrates the relevant parts of the three separated technologies to form a powerful and integrated system. It can provide users with accurate data and map information and realize the collection, processing and update of various spatial and environmental information quickly, accurately and reliably. As shown in Figure 1.1, the relationship of 3S technology is more like "one brain and two eyes".

The comprehensive application of 3S technology is one of the hot topics in current informatization applications. It is also a comprehensive informatization means to realize dynamic acquisition, editing and processing, storage management, analysis and mining of spatial information. The GNSS, RS and GIS are independent and complementary, which are widely used in many fields, such as meteorological disaster monitoring, intelligent transportation, flood monitoring, drought prevention and control, land management, landslide warning and ecological and environmental protection. The application of 3S technology in these fields can make good use of its advantages, enrich observation data, improve observation capacity, and achieve information integration, processing, analysis, prediction and display through GIS with improving the observation and governance level. The different needs of each application area have also contributed to and improved the continuous development of 3S technology.

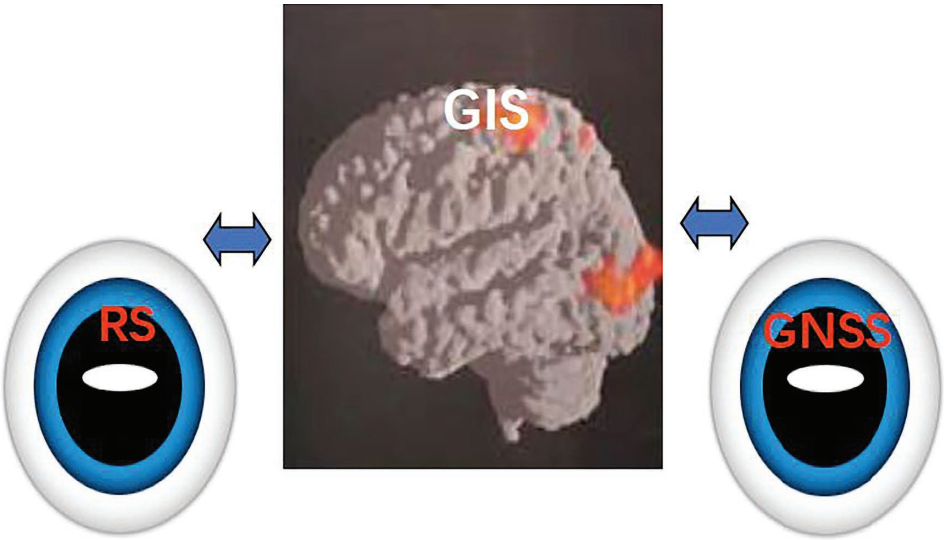

FIGURE 1.1 The relationship between GIS, RS and GNSS.

1.2.2 3S Technology Development

1.2.2.1 GNSS

Global Navigation Satellite System (GNSS) is a space-based radio navigation and positioning system that can provide users with all-weather three-dimensional coordinates, speed and time information at any place on the Earth's surface or near-Earth space (Wang, 2005; Jin, 2012). GNSS mainly includes four global navigation satellite systems, namely, China's BeiDou Navigation Satellite System (BDS), the United States' Global Positioning System (GPS), Russia's GLONASS satellite navigation system (GLONASS) and the European Union's GALILEO satellite navigation system (GALILEO).

GPS is the first global positioning system established and applied to navigation and positioning in the world. The US Department of Defense began to build GPS in 1973 and launched the first test satellite in 1978, and the entire GPS was completed in March 1994. The construction of GPS is divided into three stages. The first stage is the project demonstration and preliminary design stage. From 1973 to 1979, 4 experimental satellites were launched, and the ground receiver and tracking network were developed. The second stage is the comprehensive development and test stage as well as the networking stage, and the positioning accuracy of GPS was verified. The third stage is the practical networking stage, which began with the successful launch of the first GPS operational satellite in 1989 and ended with the complete completion of the GPS in 1994. The GPS satellite constellation is a combination of satellites in space, distributed in six orbits covering the entire Earth. The GPS has an orbital altitude of 20,200 km, an orbital inclination of 55 degrees, and an operating cycle of 11 hours and 58 minutes. GPS is one of the most significant achievements of space technology in the twentieth century. The emergence of GPS has expanded mapping and positioning technology from land and offshore to the entire ocean and outer space, from static to dynamic, from post-processing to real-time (quasi-real-time) with absolute and relative accuracy. The absolute and relative accuracy of GPS reaches the level of meter, centimeter and even sub-millimeter, which greatly broadens its application range and role in all walks of life.

The GPS consists of three main components: the space satellite component, the ground monitoring component and the user equipment. The ground monitoring part is composed of several tracking stations distributed all over the world. It is divided into master control station, monitoring stations, and ground antennas (Jin, 2012). The master control station is located at Falcon Air Force Base, Colorado. Its function is to calculate the correction parameters of satellite ephemeris and satellite clocks according to the GPS observation data of each monitoring station and send these data into the satellite through the ground antennas. At the same time, it also controls the satellite, issues instructions to the satellite and dispatches the standby satellite to replace the failed operational satellite. The master control station also performs a monitoring station. There are five monitoring stations. In addition to the main station, the other four are in Hawaii, the Ascension Islands, Diego Garcia and Kwajalein. The function of these stations is to receive satellite signals, monitor the working state of the satellite and provide satellite observation data for the master control station. Each of the five monitoring stations uses a GPS receiver to conduct integral Doppler observations and pseudo-distance measurements for each visible satellite and collect meteorological element data every six minutes. There are three injection stations, which are in the Ascension Islands, Diego Garcia and Kwajalein. The function of the injection station is to send the satellite ephemeris and clock corrections calculated by the master control station into the satellite. The station sends the ephemeris of 14 days three times a day each time. It also automatically sends signals to the master control station to report its operational status in minutes.

GLONASS is a satellite positioning system similar to the GPS, which was built by the Soviet Union in 1976. It went through several twists and turns, experienced the collapse of the Soviet Union, and is now managed by the Russian Space Agency. From 1982 to 1985, the Soviet Union successfully launched 3 simulated and 18 prototype satellites for testing. Due to the limited technology at that time, the average time of these satellites in orbit was only 14 months. In 1985, the GLONASS navigation system was officially under construction, and in 1985–1986, 6 real GLONASS satellites were launched. These satellites had improved frequency accuracy over the prototype, but the satellite life was still poor with an average of only 16 months. Since then, the Soviet Union has launched another 12 satellites with an average life span of 2 years. By 1987, GLONASS had launched a total of 30 satellites and realized 9 operational satellites in orbit. From 1988 to 2000, GLONASS launched 54 satellites and further improved the service life of the satellites. In 1996, the GLONASS space constellation was completed, and the system entered the phase of full operation and daily updates and maintenance.

The GLONASS also consists of three parts: satellite constellation, ground monitoring control station and user equipment (Hofmann-Wellenhof et al., 2007). The GLONASS satellite constellation consists of 24 satellites and one spare satellite evenly distributed in 3 nearly circular orbital planes, with 8 satellites in each orbital plane. As of 8 March 2015, GLONASS has 28 satellites with 24 satellites in operation, one in reserve, two in flight test, and one in inspection. The ground support system consists of a system control center, a central synchronizer, telemetry and remote-control stations (including laser tracking stations) and outfield navigation control equipment, all located in Russia. The system control center and central synchronization processor are located in Moscow, and the telemetry and remote-control stations are located in St. Petersburg, Ternopol, Yeniseysk and Komsomolskaya. GLONASS user equipment (receiver) can receive the navigation signal transmitted by the satellite, convert it into pseudo range and pseudo range change rate, and simultaneously extract and process the navigation message from the satellite signal. The receiver processor can process the these data and calculate the user's position, speed and time information. Unlike the GPS in the United States, GLONASS uses Frequency Division Multiple Access (FDMA) to distinguish satellites by carrier frequency (GPS is Code Division Multiple Access [CDMA], which distinguishes satellites by modulation code). The single point positioning accuracy of GLONASS is 16 m horizontally and 25 m vertically. To further improve GLONASS's positioning capability, Russia plans to spend four years updating the system, including improving ground monitoring and control station facilities and changing the frequency of the waves to further improve the positioning accuracy and system stability.

GALILEO Satellite Navigation System (GALILEO) is a global satellite navigation system developed and established by the European Union. The project was established in February 1999 and is jointly the responsibility of the European Commission and ESA. In 2011, the first two satellites of GALILEO were successfully launched. In 2012, the second batch of two satellites were successfully launched, indicating that GALILEO can initially play the function of accurate positioning on the ground. In December 2016, the GALILEO system was officially put into use. The satellite constellation component of the GALILEO system consists of three independent circular orbits, 30 GNSS Medium Earth Orbit (MEO) satellites (24 operational satellites and 6 spare satellites). Each orbital plane is evenly distributed with 10 satellites, and one serves as a spare satellite. The ground system built 3 control centers in Europe, 30–40 monitoring stations and 9 injection stations worldwide. The positioning principle is the same as GPS, and the navigation positioning accuracy is higher than other system at present, and can be combined with the existing GPS, BDS and GLONASS to achieve global navigation and positioning, so that the positioning accuracy is higher and the positioning time is faster. GALILEO provides open service, life safety, commercial, public concession, search and rescue and other basic services.

The BeiDou Navigation Satellite System (BDS) is a global navigation satellite system independently developed and operated by China. In the 1980s, China began to explore a navigation satellite system development path for its national conditions and formed a “three-step” development strategy to realize the goal of building BDS-1, BDS-2 and BDS-3 in three steps. The BDS-1 project construction was started formally in 1994. The successful launch of two navigation satellites in 2000 marked that China had established the first generation of an independent navigation satellite system, which provides China with positioning, timing, wide area difference and short message communication services. In 2004, the construction of the BDS-2 project was launched. Eight years later, the goal was achieved, and BDS began to provide services to users in Asia-Pacific. Construction of the BDS-3 began in 2009, and the basic system was completed in 2018. In 2020, the BDS-3 completed its global network and began to provide all-weather satellite navigation and positioning services, such as precise positioning, precise timing, satellite navigation and short message communication to global users.

The BDS consists of three parts: the space segment, the ground segment and the user segment. The space segment consists of several geostationary orbit satellites, inclined geosynchronous orbit satellites and medium earth orbit satellites. The ground segment includes several ground stations such as the master control station, time synchronization/injection station and monitoring station, as well as the operation and management facilities of the inter-satellite link. The user segment includes BeiDou navigation chips, modules, antennas and other terminal devices. The BDS has the following characteristics: firstly, the space segment of the BDS adopts a mixed constellation with three kinds of orbiting satellites. Compared with other global navigation satellite systems, it has more high-orbiting satellites and strong anti-occlusion capability, especially in low-latitude regions. Secondly, the BDS provides navigation signals with multiple frequency points, which can improve the service accuracy by combining multiple frequency signals. In addition, BeiDou can also integrate indoor and outdoor positioning technologies. A series of indoor and outdoor integrated navigation technologies such as BeiDou + inertial navigation system (Sun et al., 2016), BeiDou +ultra-broadband (Sun et al., 2020), BeiDou +WIFI, and BeiDou +5G are developing continuously. BeiDou’s positioning accuracy is constantly improving, and its application scenarios are increasingly wide. Thirdly, the BDS innovatively integrates navigation and communication capabilities. BDS has five functions: real-time navigation, rapid positioning, precise timing, location reporting and short message communication services.

Since the BeiDou Navigation Satellite test system was formally offered in 2003, China has made great steady progress in theoretical research, application technology development and receiver manufacturing applications. It is widely used in many fields such as transportation, marine fishery, hydrological monitoring and management, meteorology, forest fire prevention and management, power dispatching and earthquake prevention and disaster reduction. It provides convenient services and efficiency for people and produces particularly significant social and economic benefits. The rapid development of the BeiDou Navigation Satellite System is complementary to the growing economic level and the improvement of China's comprehensive national strength. China will continue to promote the construction and application of the navigation satellite system, encourage more scientists, engineers and users to join this field, and actively promote the exchange and cooperation of new navigation and positioning technologies in China and abroad.

In addition to the four global navigation satellite systems mentioned in this section, GNSS also includes regional navigation systems and navigation-related enhancement systems, such as Quasi-Zenith Satellite System (QZSS) in Japan, Indian Regional Navigational Satellite System (IRNSS) in India, WAAS (Wide Area Augmentation System) in the United States and EGNOS (European Geostationary Navigation Overlay Service) in Europe. In addition, GNSS includes other satellite navigation systems under construction and to be built in the future. In the next 20 to 30 years, the development of a global, all-weather, high-precision, continuous, real-time global satellite navigation system will be further improved. The multi-navigation equipment or sensors are combined into a combined navigation system and a comprehensive navigation system are integrated with communication, navigation, command and other functions. Navigation equipment will achieve miniaturization, digitization, automation and unattended.

1.2.2.2 Remote Sensing

The basic principle of RS is shown in Figure 1.2. Based on the characteristics of different electromagnetic waves from different objects, sensors are used to detect the reflection and emission of electromagnetic waves to extract the information of these objects and realize remote recognition of objects (Khorram et al., 2012).

Satellite remote sensing can be divided into ultraviolet, infrared, multi-band, visible light and microwave remote sensing according to the electromagnetic wave segment. According to the sensor platform, it can be divided into ground remote sensing, aerial remote sensing and space remote sensing. RS has a relatively wide visual range and relatively fast updated information. It can take advantage of different electromagnetic wave characteristics of objects to obtain specific information of each object and identify objects with relatively far distances after sorting them out. Remote sensing observation can help get a large range of spatial data in a very short time and understand the dynamic change of the Earth. It can provide a large amount of information to monitor and understand the dynamic change process of the surface. With the continuous development of RS, it will play a more important role in mineral exploration, tidal flat monitoring, weather forecast, fire warnings and other aspects.

The development of remote sensing can be divided into four stages, which are the unrecorded ground remote sensing stage, the recorded ground remote sensing stage, the aerial remote sensing

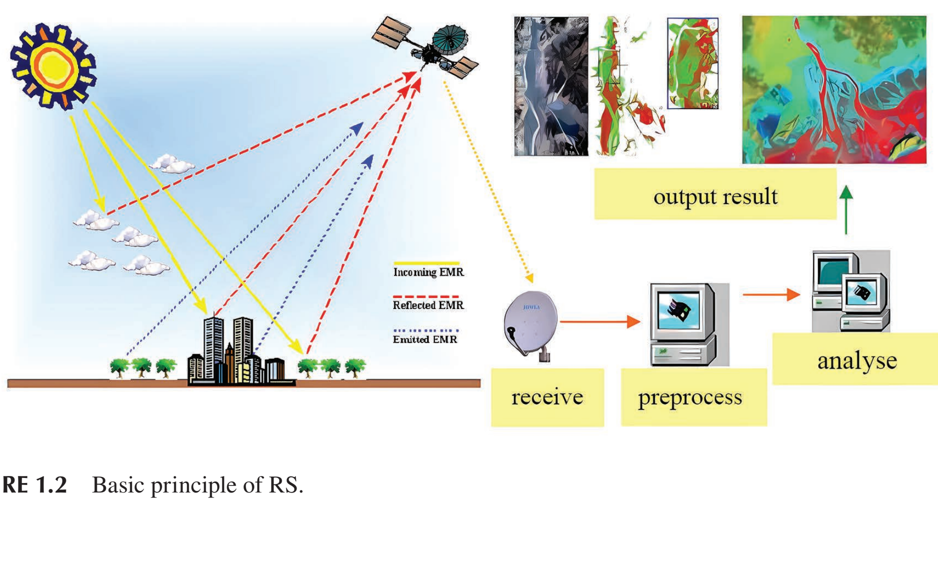

FIGURE 1.2 Basic principle of RS.

stage and the space remote sensing stage. Modern RS originated from the aerial film interpretation technology after the first photograph was obtained in 1858. With the development of technical means, especially after the successful launch of the world's first artificial satellite in 1957, RS has made a major breakthrough. Since then, the United States has launched Pioneer 2 and completed the mission to photograph the Earth's clouds. In 1960, the United States launched TIROS-1 and NOAA-1 solar synchronous satellites, which truly realized long-term exploration of the Earth from spacecraft. In 1961, the International Symposium on Remote Sensing of Environment was successfully held in the University of Michigan, USA. Since then, RS has developed rapidly as a new subject in the world. As an advanced and emerging space-based observation technology, RS has unique technical advantages when compared with traditional methods. First of all, RS has the characteristics of a large observation range, comprehensive and macroscopic, which provides favorable conditions for macroscopic study of various phenomena and their relationships. Secondly, the large amount of information in remote sensing images and the many technical means enable people to observe the Earth in a multi-faceted and all-weather capacity. In addition, remote sensing has the characteristics of fast information acquisition, short updating period and dynamic monitoring. These advantages of remote sensing prompt different countries to accelerate the development of remote sensing. In the late 1980s, France, Japan, China and India launched their remote-sensing satellites, and many countries have remote-sensing satellite programs. In the second half of 1999, the successful launch of the 1 m resolution commercial remote sensing satellite IKONOS marked the arrival of the high-resolution space remote sensing era. Then in 2000 and 2001, QuickBird with 0.61 m, OrbView-3/4 with 1 m resolution and other high-resolution commercial remote sensing satellites were launched successively, which greatly improved data selection from remote sensing images.

In recent years, with the continuous development and improvement of RS, the types of sensors carried on the remote sensing platform are constantly enriched, and the detection ability is constantly improved. The rapid development of radar interferometry, high resolution satellite remote sensing, hyperspectral remote sensing and other new technologies have promoted new applications of aerial remote sensing in many fields. At present, the RS will tend to be international cooperation, common development and common use in the world. At the same time, the spatial resolution and time resolution of the sensor will be further improved, and the multi-sensor integration will further improve the accuracy of data acquisition. In addition, the 3S integrated technology will continue to provide dynamic basic information and scientific decision-making for many industries.

1.2.2.3 GIS

Geographic Information Systems (GIS) are computer-based devices that use advanced computer technology to collect and apply data about geographic conditions on the surface of the earth. The information is further processed and analyzed to provide a more intuitive picture of the data and to provide the necessary information. With the "visualization" of GIS technology, we are able to grasp the changes in information through the feedback images. GIS is the integration of many professional disciplines, such as geospatial science and computer information technology. It is mainly composed of the computer hardware system, computer software system and spatial data. The hardware system is mainly used to collect, store and output geographic information data, and the software system is used to analyze data information. According to the content, GIS can be divided into two basic types: applied GIS and tool-type GIS. Applied GIS takes a certain profession, field or work as the main content, including thematic GIS and regional integrated GIS. Thematic GIS is the GIS with limited goals and specialty characteristics, serving a specific specialized purpose, such as forest dynamic monitoring information system and water resources management information systems. While regional information systems are mainly aimed at regional integrated research and comprehensive information services with different scales, such as national (Canada's National Geographic Information System), regional or provincial (Sweden's Stockholm Regional Information System), municipal and county level. Tool-type GIS provides the user with a package of tools, such as ArcGIS. It has spatial data input, storage, processing, analysis and other functions. According to the system structure, GIS can be divided into stand-alone GIS and network GIS. According to the data structure, it can be divided into vector data structure GIS, raster data structure GIS and mixed data structure GIS.

GIS technology was first started by Canadian researchers, who found that GIS technology needs computer processing technology to effectively improve its work efficiency and quality, and the effect of GIS technology has a significant correlation with the level of computer technology. In the early GIS technology, there were widespread problems such as insufficient functions and low speed of data information processing. In practical applications, GIS technology is closely combined with computer technology, RS and GNSS technology to realize real-time monitoring and analysis of GIS system information, providing users with possible or forthcoming situations. It also provides an important basis for users' follow-up work and decision-making. The electronic computer is developing towards miniaturization and intellectualization. It can process a large amount of data and information in a short period. At the same time, it can carry out intelligent analysis on a number of contents and reasonably predict the changes of relevant data and information in a certain stage in the future to provide decisions for the subsequent links. GIS technology has been applied in resource management, medical and health care, urban planning and design, disaster monitoring and other fields (Qin et al., 2015). In the future, it will be further developed towards the direction of intelligence, digitalization and high precision, and its application range will continue to expand.

There are four main areas of GIS technology development. The first one is the mobile GIS. In the narrow sense, mobile GIS refers to the GIS system that runs on mobile terminals and has the desktop GIS function. It does not interact with the server and is an off-line operation mode. The broad sense of mobile GIS is an integrated system which integrates GIS, GNSS, mobile communication, Internet service, multimedia technology and so on.

The second is three-dimensional GIS, which can only handle and manage two-dimensional graphics and attribute data. Three-dimensional GIS has a good advantage in replacing the traditional two-dimensional GIS, since it breaks the defects of two-dimensional GIS in the representation of spatial information and can accurately depict all parts and details of the city in the real three-dimensional space to promote the development of digitization, informatization and intelligence of the city.

The third is component GIS, which refers to the GIS provided by a group of components with some standard communication interface that allows cross-language applications based on component object platform. It can make GIS software more configurable, extensible and open, more flexible in use and more convenient in secondary development.

The last one is WebGIS. The main difference between WebGIS and GIS is that WebGIS integrates the functions of information browsing, uploading and downloading in the computer network to ensure that users can quickly query and analyze the contents of GIS data and information, further expanding the scope of information retrieval by users. Compared with the traditional GIS, the adaptability and application range of WebGIS have been further expanded with avoiding the tedious steps of information retrieval under the traditional GIS technology model. WebGIS is subdivided into two kinds: passive and active. The advantages of passive WebGIS lie in the high development rate, but its higher requirements on server performance and information retrieval time are relatively long, so the practicability is limited to a certain extent. The active technology does not use the server for information processing and retrieval. However, it sends the relevant program code to the client to achieve interaction with the customer, which is more efficient than the passive mode. Therefore, the application of active WebGIS has been increasing in recent years.

1.2.3 3S Integration

3S integration technology was proposed in the early 1990s and has been developed for more than 30 years. 3S technology integration is a new integrated technology based on RS, GIS and GNSS, which forms a whole by organically forming the relevant parts of RS, GIS and GNSS in three

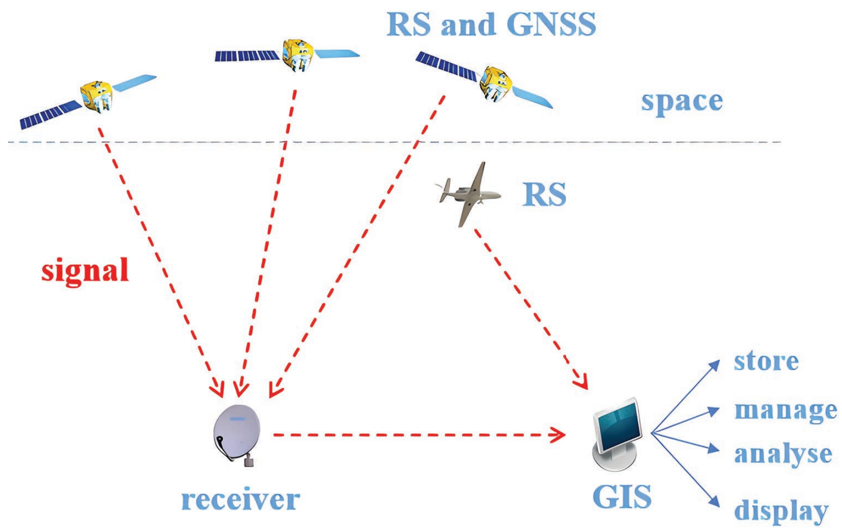

FIGURE 1.3 Brief principle of 3S technology.

independent technology fields and other high technology fields such as network technology and communication technology (Figure 1.3). 3S technology is one of the three major supporting technologies for the acquisition, storage, management, updating, analysis and application of spatial information in the current Earth observation system. It is an important technical means for the sustainable development of modern society, rational planning and utilization of resources, urban and rural planning and management, dynamic monitoring and prevention of natural disasters, etc. It is also one of the scientific methods for geological research towards quantification (Li, 1998; Li, 2003).

GNSS is mainly used to provide the spatial location of targets, including all kinds of sensors and delivery platforms such as vehicles, ships, aircraft and satellites in real time and quickly. RS is used to provide semantic or non-semantic information about targets and their environment in real time or quasi-real time and to discover various changes on the Earth's surface and update data for GIS in time. GIS, on the other hand, is a comprehensive processing, integration and dynamic access of spatial-temporal data from multiple sources management and dynamic access. As the basic platform of a new integrated system, GIS provides knowledge for intelligent data acquisition and analysis.

3S integration is the inevitable result of the development of GIS, GNSS and RS. After decades of development, 3S technology has been quite mature in terms of each technology. GNSS, GIS and RS are put forward as separate technologies, which constitute the three supporting technologies in the Earth observation system. But with the deepening of 3S technology research and application, people gradually realize that it is often difficult to meet the practical engineering application by using one of these technologies alone. Only by studying and applying the three technologies as a unified whole and making comprehensive use of the advantages of these technologies can provide comprehensive capabilities for Earth observation, information processing, analysis and simulation. GIS, RS and GNSS combine their advantages to compensate each other's shortcomings. The integrated application of 3S can be divided into the combination of GNSS and RS, the combination of RS and GIS, the combination of GNSS and RS, and the integrated application of the three techniques.

Combining RS with GNSS: Target positioning in remote sensing has always depended on ground control points. Supposed the remote sensing target positioning without ground control is to be realized in real time. In that case, the spatial position and sensor attitude of the instant acquired by remote sensing images need to be recorded synchronously by GNSS/INS. The pseudo-distance method is used for medium and low accuracy, and the phase difference method is used for high-precision positioning. GNSS dynamic phase difference has been used in aerial/aerospace photogrammetry for ground-free aerial triangulation, and is called GNSS photogrammetry. It can improve operation efficiency and save external workload. RS data volume is large and data accuracy is low, while GNSS has high data precision and low data volume, which can be organically combined to realize positioning, qualitative and quantitative earth observation.

Combining GIS with GNSS: Using the electronic map in GIS and the real-time differential positioning technology of GNSS receiver, various electronic navigation systems of GNSS + GIS can be formed, which are used in traffic, public security detection, vehicle and ship automatic driving. GNSS can be used as the data source of GIS to find the target, and GNSS data can also be used to update the GIS database, while GIS provides the technical means for GNSS to manage and analyze spatial data. At present, there are three integration methods of GIS and GNSS: one is GNSS single machine positioning + raster electronic map. The system can automatically calculate and display the best path according to the target position and the current position of vehicles and ships, guide the driver to reach the destination as soon as possible and give the driver a hint through multimedia means. The second way is GNSS single machine positioning + vector electronic map. This system is similar to the first one. The third method is GNSS differential positioning + vector/raster electronic map. The positioning accuracy can reach ± (1–3) m through the differential technology of two GNSS between fixed stations and mobile vehicles and vessels. At this time, the communication data link is needed, which can be one-way or two-way.

Combining RS with GIS: In this integrated mode, RS provides GIS with important data sources and data updating means, while GIS provides RS with technical means of spatial data management and analysis, which is used for the automatic extraction of semantic and non-semantic information. The combination of GIS and RS is the most widely used and mature technology. The key to the combination of the two lies in the software. The integration of GIS and RS can be used in global change monitoring, agricultural harvest area monitoring and yield estimation, automatic update of spatial data and so on. Remote sensing image processing and GIS are two separated systems using two separated databases, but file conversion tools are used to transfer files between different systems. Integrating remote sensing image processing and GIS into the same software system, a consistent user interface is used to process and display different types of data synchronously, but the tool library and database are separated. The same software system and database management system are used to realize the unified processing and management of remote sensing image and GIS spatial data.

The 3S integration is mainly to realize the dynamic management, analysis and application of multi-source information (multi-time, multi-scale and multi-type) in the same coordinate system. 3S integration is not a combination of equal structure, but a hierarchical organic combination. There are two main approaches: the integration approach centered on GIS (non-synchronous data processing) and the integration approach centered on GNSS/RS (synchronous data processing). The overall integration of 3S not only has the function of collecting, processing and updating data automatically and in real time, but also can analyze and apply data intelligently, provide scientific decision-making consultation for various applications and answer all kinds of complex questions that users may raise.

Due to the functional complementarity of RS, GIS and GNSS, various integration schemes were formed, which can give full play to their respective advantages and produce many new functions. The individual application of RS, GIS and GNSS can improve the accuracy, speed and efficiency of spatial data acquisition and processing, while the advantages of 3S integration are also manifested in the dynamic, flexible and automatic aspects. Dynamicity refers to the synchronization between data sources and the real world, the synchronization between different data sources, and the synchronization between data acquisition and data processing. Flexibility means that users can decide the corresponding data acquisition and data processing methods according to different application purposes and establish the connection and feedback mechanism between the two to complete the specified task most appropriately. Automation means the integrated system can automatically complete all links from data acquisition to data processing without manual intervention.

3S technology has been well applied in dynamic monitoring, crop yield estimation and other fields, thus opening new topics in the development of geography and other disciplines. Although 3S integration has been widely used, in the coming of the information age today, the development of digital Earth technology research and network information requires the combination of higher-level 3S technology and other high and new technologies, such as the combination of network technology, and distributed object technology, so as to form a multifunctional all-around integrated information system. However, there are still many problems that have not been solved, and the cooperation of more disciplines is needed.

3S integration is still a frontier in the field of spatial information science. Its development goal is “online connection, real-time processing”. In order to realize 3S integration, it is necessary to explore the theory of 3S integration, improve the technical method of 3S integration and broaden the application range of 3S integration. 3S integration should solve the problems of data storage, data processing, data transmission and data visualization. From the perspective of RS, the appearance of a variety of high-resolution satellites makes the application of RS more and more extensive. The sensor technology is used to update GIS data to combine the two “S” in 3S more closely. The remote sensing image and GNSS can be directly linked to reflect the GIS signal in real time, and the three “S” are connected. 3S technology integration is an important part of spatial information science, with the concept of the “Digital Globe”. Its importance is more and more prominent, and its application field is also expanding. In these increasing applications, higher requirements are put forward for the dynamic and real-time performance of 3S technology. To meet these demands, 3S technology integration must also be combined with communication technology and take full advantage of the current rapid development of communication technology to create a new era of geospatial information science.

1.3 CURRENT STATUS OF 3S METEOROLOGICAL APPLICATIONS

1.3.1 Flood Monitoring and Assessment

Flooding is a natural disaster with high suddenness, high frequency and serious hazards. Floods not only damage the ecological environment, but also seriously threaten the safety of human life and property and stall the process of economic development (Aja et al., 2020; Ramkar, 2021). Therefore, a quick and effective analysis of flood simulation, risk zoning and risk assessment can provide a timely and effective indication of the damage caused by floods and help the government to carry out timely relief and formulate disaster prevention and mitigation policies to reduce the impact of flood disasters.

3S technology has been widely used in flood simulation and assessment due to its fast, convenient and efficient nature. The basic principle is that RS images are used to extract information efficiently and obtain information on changes in water bodies and the spatial analysis technology of GIS is used to simulate and analyze the flooded areas well as assess the risk of the affected area with dividing it into different levels of risk zones. In addition, the combination of RS imagery and GIS technology can simulate the entire process of flooding and post-disaster assessment as a complete flood monitoring system.

1.3.1.1 Flood Extraction from Multi-Source Remote Sensing

Because satellite remote sensing has a very good current situation and wide coverage, remote sensing data are widely used for flood information extraction and flood disaster monitoring. Zhou et al. (2021) extracted the flood range of the flood in Sri Lanka on 25 May 2017 using the data obtained by GF-3 and Sentinel-1 during and after the disaster. For Sentinel-1 data, it was first processed to form

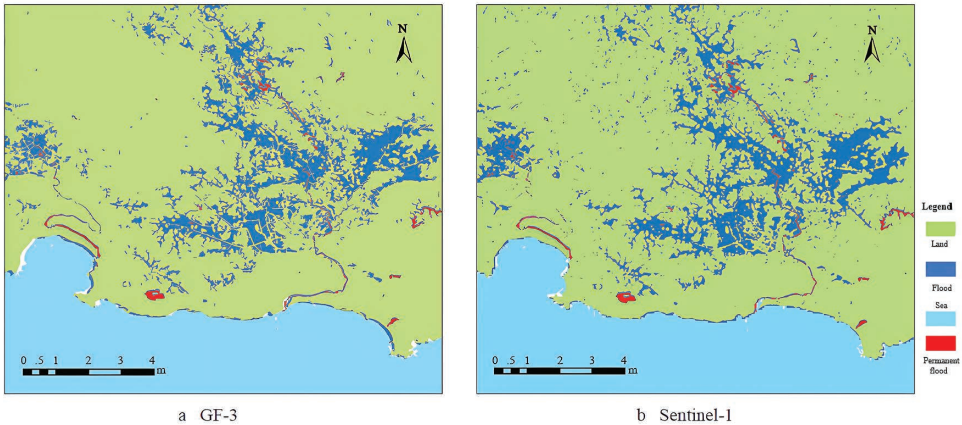

FIGURE 1.4 Flood areas extracted from GF-3 and Sentinel-1 images.

Source: Zhou et al. (2021)

a binary map, then further generated a log histogram, and finally a suitable threshold was selected for flood extent extraction. For the GF-3 data, a threshold extracted from the minimum error method is used for binary segmentation to extract the flood range. The results are shown in Figure 1.4, where the official flooded areas are compared with the GF-3 flooded areas, which are much closer to the flooded areas with high accuracy. In addition, the combination of GF-3 and Sentinel-1 with a common calibration will give more information and make the data more reliable.

Wang and Zengzeng (2022) used Sentinel-1A data to monitor the catastrophic flood disasters occurred in the Poyang Lake area since the flood season in 2020 based on supervised classification and unsupervised classification. The range of water bodies before and after the disaster is extracted to show the extent of flooding. He et al. (2022) took Guangxi's "Xijiang Flood No. 1 in 2020" as an example to study the impact of floods on various regions in Guangxi. Due to the changes in light brightness before and after the flood (the power line damage and the collapse of buildings led to a significant decrease in light brightness), the NPP-VIIRS night light remote sensing data was used for radiation normalization, and the different method was used to extract the changed and the affected areas. The affected area and the degree of post-disaster recovery show that the affected area is mainly distributed in the urban built-up area.

1.3.1.2 Analysis of Flood Inundation Based on GIS

Using GIS to conduct inundation analysis to obtain the scope of the inundated area, and then mathematical analysis to calculate the height difference between the flood level and the DEM grid, the submerged water depth can be obtained. Overlay analysis in GIS can obtain the impact of floods on the watershed, and hydrological analysis can obtain information such as river network and water flow area. Zhang et al. (2021) studied the Jinpu New District of Dalian City using the DEM data and the observation data of flood level and tide level collected for many years. Based on the spatial analysis tool of ArcGIS, the active inundation analysis and calculation were carried out using the seed spreading method, and the scope of the inundated area was obtained, as shown in Figure 1.5(a). After the difference calculation between the flood level and the DEM grid, the submerged water depth distribution map is obtained, as shown in Figure 1.5(b).

1.3.1.3 Assessment of Flood Disaster Risk Based on GIS

Using GIS technology combined with the theory and method of natural disaster risk assessment, the flood disaster risk assessment is carried out from three aspects: the hazard of the hazard, the stability of the disaster-forming environment, and the vulnerability of the disaster-affected body. Flood

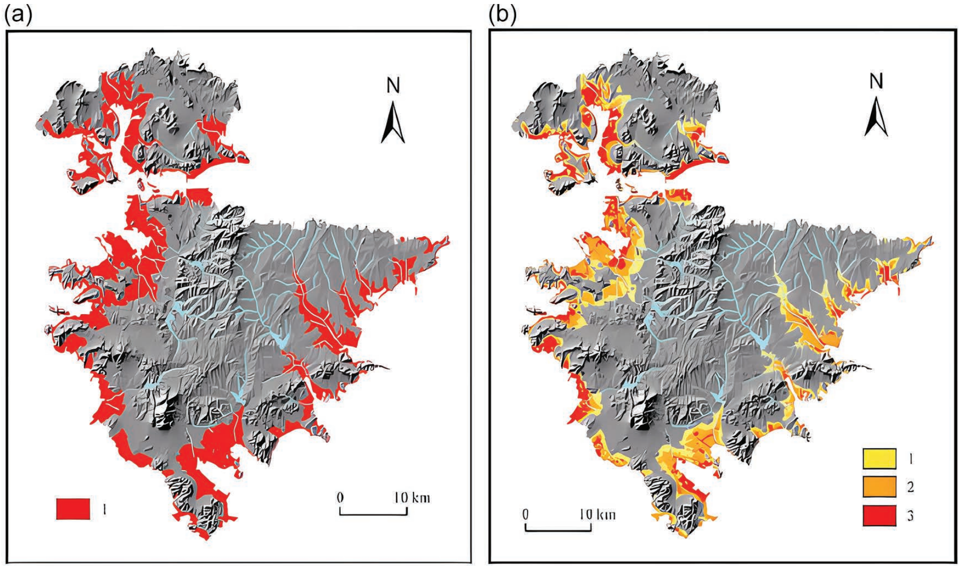

FIGURE 1.5 Maps of the flood-submerged area in Jinpu New District with flood-submerged area (a) and flood depth (b).

Source: Zhang et al. (2021)

risk assessment has two components: the flood risk impact assessment, which includes the disaster-causing factors and the disaster-forming environment factor, and the flood vulnerability impact assessment, which mainly refers to the hazard-bearing body. Sometimes the ability to prevent and mitigate disasters can also be included in the assessment of the impact degree of flood vulnerability. The Analytical Hierarchy Process (AHP) and the weighted comprehensive evaluation method are often used to evaluate the degree of influence of specific indicators in each part and then determine the weight (Ramkar, 2021; Seejata et al., 2018). Yi (2012) used GIS technology and the weighted comprehensive evaluation method for the urban area of Guilin City, Guangxi, and constructed a flood disaster risk assessment from the four aspects of disaster-causing factors, disaster-forming environment, disaster-bearing body and disaster prevention and mitigation capabilities. Then, the model was used to evaluate and analyze the flood disaster risk in the study area. Finally, the natural distance classification method was used to divide the flood disaster risk in Guilin into low-risk, medium-risk and higher-risk areas.

1.3.1.4 Flood Disaster Evaluation with Combining RS and GIS

Under the conditions of the flood submerged range with the help of high-precision DEM data, the elevation distribution of the water and land boundary (i.e., water surface) is obtained, and the water depth is calculated from the difference between the water surface elevation and the ground elevation. Dong et al. (2012) studied the flood disaster in Kouqian Town, Yongji County, Jilin Province, on 28 July 2010. Firstly, high-resolution remote sensing images were used to divide the grid according to study area's residential buildings to facilitate subsequent calculation of water depth. Then the remote sensed images were utilized to extract the normalized water index method to separate water bodies and non-water bodies. The segmentation threshold was determined by comparing with the standard false-color image, and then the submerged area of the flood was extracted. As for the water depth of the submerged area, GIS is used to process the elevation points of the flood submerged boundary first, and then the water surface elevation of each grid is obtained. Finally, the flood submerged water depth of each grid is calculated by the water depth GIS method to realize the complete evaluation of flood disasters from submerged range to water depth.

1.3.2 Drought Risk Mapping and Assessment

1.3.2.1 Drought Disaster

Meteorological disaster risk assessment requires the use of multidisciplinary theoretical knowledge such as meteorology, physical geography and disaster science, as well as certain methodologies such as analytic hierarchy process, risk index method and comprehensive weighting method. Based on GIS technology and disaster censuses, drought disaster risk analysis and assessment are made according to several elements such as the similarities and differences of the disaster-forming environment, intensity and frequency distribution of disaster-causing factors, and the vulnerability of the carrier. Among them, drought disaster refers to the social, economic and environmental conditions below a certain level caused by drought, which is the result of severe drought acting on fragile social, economic or sensitive ecological environment systems (Mishra et al., 2010). It is one of the most serious natural disasters in the world. Its frequency of occurrence, duration, the scope of influence and losses caused it to rank first among all natural disasters. With the rapid development of economy, population growth and the global climate change marked by climate warming, drought disasters tend to be further aggravated, causing incalculable damage to economic growth, social progress and ecological environment. Therefore, it is of great significance to scientifically assess the risk of drought disasters to mitigate disasters and improve economic and social benefits.

1.3.2.2 Drought Risk Assessment

Drought disaster risk assessment can characterize the form and degree of regional drought, which is the basis for formulating comprehensive disaster prevention and mitigation countermeasures. With the support of GIS software, a meteorological disaster database can be established, which includes basic geographic data, economic population data, meteorological data and disaster information. Through the comprehensive analysis of multiple factors such as the risk of hazard-causing factors, the sensitivity of the disaster-forming environment, the vulnerability of the hazard-bearing body, and the ability to prevent and mitigate disasters, several risk assessments factors such as the risk of the hazard-causing factor, the sensitivity of the disaster-forming environment, and the vulnerability of the hazard-bearing body are constructed. The evaluation model of nature, disaster prevention and resilience are established, and historical disaster data are combined to calibrate the model parameters. Finally, the disaster risk is evaluated, the division unit is determined, the disaster division level is divided, and the disaster division is carried out using the functions of GIS spatial overlay analysis, map spot merger and attribute database operation.

Chen et al. (2022) conducted the in-depth analysis of the causes of drought risk in the Loess Plateau, combining with the climate characteristics of the Loess Plateau and the occurrence of drought events. A natural disaster risk assessment system of "disaster stress-social vulnerability-exposure" was selected and corresponding remote sensing data and socioeconomic data were used as the data source of drought disaster risk. The drought disaster risk assessment model was constructed by Analytic Hierarchy Process (AHP). The spatial superposition analysis of the three index factors was carried out using GIS technology. Finally, the natural breakpoint method was used to analyze the drought risk classification and assessment.

Using the geographic data including county-level administrative division data of Qingyang City, digital elevation model (DEM) data, Palmer Drought Index (PDSI) data, vegetation cover index (NDVI) data, land surface temperature (LST) data, land cover data, soil moisture data, the constituent elements of the drought disaster risk assessment system can be determined. The Analytic Hierarchy Process (AHP) is used to calculate the weight of each index factor, and then GIS software is used to normalize the individual indicators contained in each element. The drought risk zoning can be constructed from the drought disaster data in Qingyang City. The technical framework is shown in Figure 1.6 (Chen et al., 2022).

Drought disaster risk assessment is jointly determined by multiple factors, and the dimension units of each factor are different. In order to eliminate the dimensional influence of the factors under

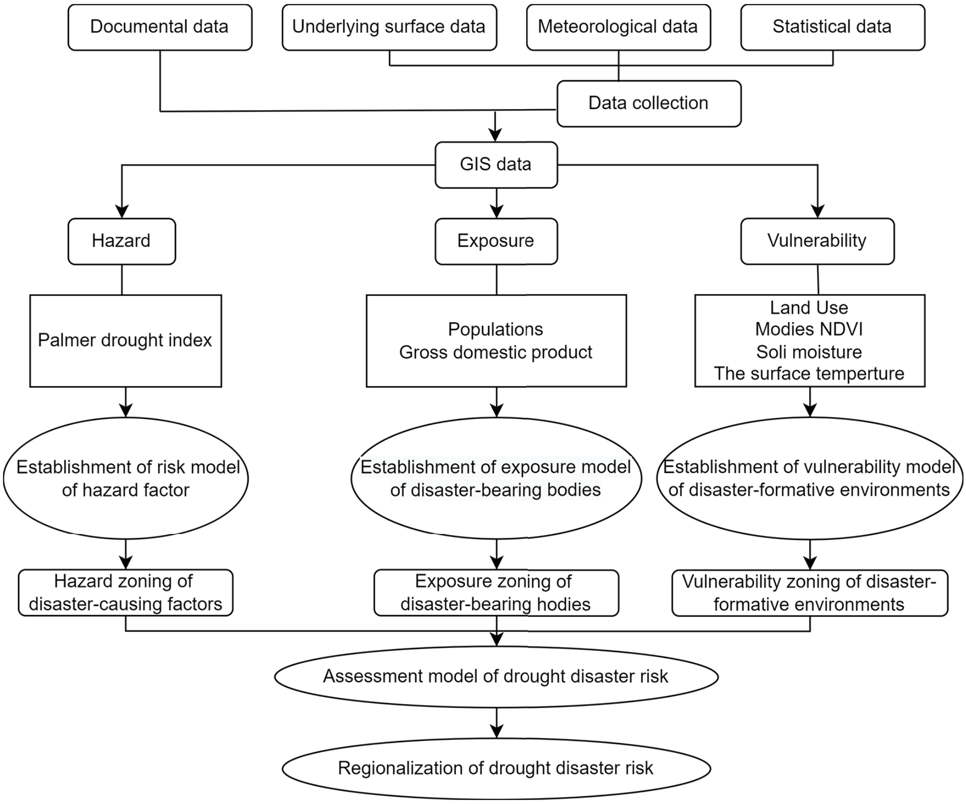

FIGURE 1.6 Framework of drought risk assessment in Qingyang City.

Source: Chen et al. (2022)

each index, normalization processing is required for each factor. According to the nature of indicators, it can be divided into positive indicators and negative indicators. Positive indicators are the reflected risk factor indicators. The larger the corresponding value, the higher the risk. The negative indicator is the larger for the corresponding value of the reflected risk factor indicator, the lower the risk is (Chen et al., 2022).

1.3.3 High Temperature Disaster Risk Assessment

1.3.3.1 High Temperature Disaster

High temperature disasters change the city's thermal environment, which will seriously impact the climate, air quality, hydrological conditions and urban soil of the whole city (Shan et al., 2022; Liu et al., 2015). At the same time, it will also change the distribution and activity of organisms in the city, resulting in a series of urban ecological problems. Research on high temperature disasters and putting forward countermeasures can effectively alleviate the impact of high temperature disasters on the ecological environment and improve the ecological environment, e.g., improving the abnormal weather caused by high temperature, reducing the frequency of urban disasters creating a suitable environment for urban organisms and restoring their growth environment.

High temperature disasters, especially persistent high temperature heat wave disasters, have a wide range of social impacts, which can endanger human health and cause diseases or death. At the same time, the formation of high temperature disasters is closely related to urban energy consumption and these factors complement each other. During the high temperature disaster in summer, the use of engineering measures to cool down consumes a lot of energy, and the energy consumption of electricity and water for urban production and living increases, which leads to the shortage of urban electricity consumption. When energy is used at the same time, a large amount of exhaust gas and heat will be emitted, which will aggravate the rise of urban temperature and aggravate the high temperature disaster in the city, forming a vicious circle. Therefore, through the study of high temperature disasters, strategies to deal with and mitigate high temperature disasters are proposed to reduce urban temperature and break this vicious circle.

The risk zoning of high temperature heat damage mainly includes four aspects: the hazard of hazard-causing factors, the sensitivity of disaster-forming environment, the vulnerability of hazard-bearing bodies, and the ability of disaster prevention and mitigation. The occurrence frequency of high temperature heat damage, topography, population density, local economy, etc., were selected as evaluation factors, and relevant indicators were established. The distribution of high temperature heat damage risk coefficient can be obtained by weighted synthesis and analytic hierarchy process.

1.3.3.2 High Temperature Disaster Risk Assessment

In order to provide references for reasonable responses to high temperature disasters, Fang et al. (2016) adopted a multi-factor weighted comprehensive evaluation method, using the meteorological observation data in Jiangsu, Zhejiang and Shanghai from 1961 to 2009 and the socioeconomic data in Jiangsu, Zhejiang and Shanghai from 2008 to 2010. Based on the comprehensive assessment of the disaster environment, disaster-bearing bodies and disaster resistance capabilities, the risk map of high temperature disasters in Jiangsu, Zhejiang and Shanghai was obtained. Using the daily maximum temperature data of 144 meteorological stations in Jiangsu, Zhejiang and Shanghai from 1961 to 2009, the daily maximum temperature, daily average temperature and duration of high temperature disasters are extracted. Based on the 2008–2010 Jiangsu, Zhejiang and Shanghai urban construction statistical yearbooks, economic yearbooks, statistical bulletins and other references, the socioeconomic data in Jiangsu, Zhejiang and Shanghai were obtained.

Traditional methods for analyzing disaster-causing factors include field investigation, searching for historical disaster data, building models, laboratory analysis and remote sensing acquisition. The risk of hazards refers to the abnormal degree of meteorological disasters, which is mainly determined by the scale and frequency of activities of hazards. The risk of disaster-causing factors is first determined based on the principle that the higher the level of high temperature disasters is, the greater the harm is, and the weight of the hazard-causing factors is determined (Fang et al., 2016).

Topography, land cover and water system are the main factors reflecting the high temperature disaster-forming environment. Among them, altitude has the most obvious impact on high temperature disasters, and the higher the altitude, the smaller the impact. Based on this principle, the terrain impact index of Jiangsu, Zhejiang and Shanghai is calculated. According to the sensitivity of land cover type to high temperature and the ordering principle of city, cultivated land, grassland, woodland and water area, assign values from high to low, and draw the impact index of different land use types in Jiangsu, Zhejiang and Shanghai. During the disaster period, the water system has the function of alleviating and mitigating the high temperature disaster, through the evaluation and analysis of the river network density and the flow buffer zone, the assignment of the water system impact index can be normalized (Fang et al., 2016).

The vulnerability of hazard-bearing bodies refers to the objects of meteorological disasters, including the material and cultural environment of human beings, which is the collection of various resources in human activities and the society in which they live. Combined with the socio-economic data of Jiangsu, Zhejiang and Shanghai, the vulnerability indicators of disaster-affected bodies are evaluated by selecting indicators such as population density, per capita GDP, proportion of cultivated land, and per capita energy consumption. The indicators of population density, per capita GDP, proportion of cultivated land, and per capita energy consumption are normalized and interpolated. The vulnerability index of high temperature disaster-affected bodies in Jiangsu, Zhejiang and Shanghai is calculated comprehensively using equal weight and natural breakpoint methods (Fang et al., 2016).

The grid calculator in the ArcGIS spatial analysis module was used to analyze the four factor layers of the high temperature disasters in Jiangsu, Zhejiang and Shanghai: the risk of hazards, the sensitivity of disaster-forming environments, the vulnerability of disaster-affected bodies, and the ability to resist disasters. Based on the superposition calculation, according to the grading method of high-risk areas, sub-high-risk areas, medium-risk areas, sub-low-risk areas and low-risk areas, the comprehensive risk zoning of high temperature disasters in Jiangsu, Zhejiang and Shanghai was obtained (Fang et al., 2016).

To assess the high temperature risk on 973 communities in Wuhan city, Shan et al. (2022) used the geography-weighted regression method using remote sensing data and geographic information data. A risk assessment model of high temperature disasters is established from disaster-causing danger, disaster-generating sensitivity and disaster-bearing vulnerability. The spatial distribution of high disaster-causing danger in the community is very consistent with its surface temperature. The spatial distribution of disaster-generating sensitivity in the community shows the spatial characteristics of the clustered distribution of high sensitivity areas.

1.3.3.3 High Temperature Disaster Risk Mapping

According to the high temperature characteristics of Fujian, combined with the analytic hierarchy process, expert scoring method and the spatial analysis function of GIS, the possibility, severity, sensitivity of the disaster-forming environment and the effectiveness of disaster prevention in Fujian were analyzed (Jin, 2017). Based on the evaluation of the regional differences in the degree of high-temperature disaster risk in Fujian, the risk level of high-temperature disasters in Fujian was divided, which provided the basis for the relevant departments to carry out urban planning, disaster management and formulate disaster prevention and mitigation measures.

Different data have been utilized to map a high temperature disaster risk zone, such as the daily temperature data from 67 meteorological stations in Fujian Province, the basic geographic information data, and social and economic data including the road area, GDP and per capita medical beds in each city at the end of 2009. The analytic hierarchy process was used to calculate the index weight coefficient. In fact, on the basis of establishing an orderly and hierarchical index system, the pros and cons of each index in the system were judged through pairwise comparisons between the indexes, and this evaluation result was used to synthesize and calculate the weight coefficient of each indicator. Through the analytic hierarchy process, the high temperature disaster risk assessment system is established by using three factors: the risk of disaster-causing factors, the sensitivity of the disaster-forming environment and the disaster-resistant ability. Comparing the scores to get the weight of each impact factor. The evaluation system is divided into target layer (A), index factor layer (B) and impact factor layer (C) from top to bottom. The index factor layer mainly considers the risk of disaster-causing factors, the sensitivity of disaster-forming environment and the ability to resist disasters.

Through the use of related functions in the spatial analysis and spatial statistics toolbox in ArcGIS software, based on remote sensing image data and basic geographic information data, the data are spatially calculated, integrated and superimposed, and visualized. The application of the GIS spatial analysis method provides technical support and guarantees for the analysis of the comprehensive risk of high temperature disasters, the spatial distribution characteristics of each index and the spatial heterogeneity of the factors affecting the built environment of the community. The ArcGIS software was used to perform inverse distance weighted interpolation, and the observation point data were interpolated into raster data. The grid overlay calculation is performed in ArcGIS, and natural breaks (Jenks) classification is used to obtain the distribution map of the high temperature risk level.

The degree of heat disaster risk is also affected by the effectiveness of local disaster control measures and post-disaster remedial measures. Disaster resilience refers to the ability of the disaster-affected area to resist and recover when and after being hit by a high temperature disaster. The ratio of per capita garden and green area, the number of medical beds per capita in hospitals and the per capita GDP are used to represent the effectiveness of existing disaster resistance capabilities. After normalizing these data, the weighted comprehensive evaluation method of AHP was used to obtain the weighting coefficients for the percentage of garden area per capita, number of hospital medical beds per capita and GDP per capita, respectively, and the disaster resistance index was calculated in ArcGIS software. The larger the index value, the more effective the control measures and the lower the risk of high temperature. The high temperature disaster resilience index of each city is divided into four grades: low, second-low, medium and high.

1.3.4 Agricultural Frost Damage Risk Mapping

1.3.4.1 Agricultural Frost Damage

Freezing injury is a kind of agricultural meteorological disaster that belongs to a low-temperature disaster. It refers to the sudden drop of the temperature near the plants to 0℃ or below, causing the water seal in the crops to freeze, causing damage to the crops and affecting the plants' normal growth, leading to reduced production or crop failure. Freezing damage includes low temperature freezing, cold wave, strong cooling, frost, late spring cold and low temperature in autumn. The impact of meteorological disasters on agriculture has become an important factor restricting the steady and sustainable development of agriculture. Data show that the losses caused by agrometeorological disasters such as droughts, frosts, floods and low temperature freezes account for more than 60% of agricultural disasters, and years of severe low temperature disasters can cause grain output losses of more than 10 billion kilograms. In addition, meteorological disasters are often accompanied by other secondary disasters, and the risk of disasters continues to increase. At the same time, disaster chains and disaster clusters will be formed, which will cause more serious and huge losses. Frost damage occurs in a wide range in my country, ranging from Heilongjiang in the north to Guangdong and Guangxi in the south.

The development of remote sensing technology has made it possible to monitor changes in large areas and long-term sequences. It can realize rapid extraction and accurate identification of crop information and obtain the required temperature information, spatial distribution of crops, planting area, growth status and production and other information. The spatial analysis ability and cartographic expression of GIS technology can establish the comprehensive risk index of freezing injury and the assessment model of freezing injury risk, and based on this, establish the freezing injury risk zoning. Remote sensing methods can be broadly divided into three types: minimum surface temperature retrieval methods, vegetation index difference methods and hyperspectral methods.

1.3.4.2 Agricultural Freezing Damage Monitoring

The vegetation index difference method is an index that can reflect the growth status of plants by combining data from different bands of hyperspectral data. After the crops are subjected to freezing injury and low temperature stress, the activity will decrease rapidly, and the vegetation index will also be reduced when the activity is reduced. The vegetation index and the degree of freezing injury show a significant positive correlation. Therefore, the severity of freezing injury can be judged by comparing the vegetation index before and after freezing injury of crops. The hyperspectral has the characteristics of high spectral resolution, strong band continuity, and a large amount of spectral information. It can monitor crop canopies and leaves and construct narrow-band spectral indices through hyperspectral to explore its impact on crops under low temperature stress.

3S technology has been utilized to assess the freezing damages on agriculture, and two case studies are given here. Wang et al. (2021) used the FY-3 satellite and the split window algorithm to invert the surface temperature, established a regression analysis with the ground minimum temperature measured by the meteorological station, and used the variational technology to correct the more accurate remote sensing ground minimum temperature, and then collected the late frost disaster indicators and winter wheat development period data to realize remote sensing monitoring of late frost. They developed a winter wheat late frost remote sensing monitoring system supported by GIS, and carried out remote sensing monitoring of late frost damage according to the freezing damage indicators of winter wheat at each period after jointing, produced a spatial distribution map of winter wheat occurrence, and calculated the affected areas of different regions and different levels of freezing damage, to realize remote sensing monitoring and evaluation of winter wheat. Li et al. (2015) selected the harmful extreme cold and frequency (danger) of winter wheat late frost, winter wheat planting area (exposure), irrigation-to-plow ratio and the number of machine wells per unit of irrigation area (vulnerability) to establish a risk assessment system, determine the weight of winter wheat late frost risk assessment indicators by analytic hierarchy process, and build a winter wheat late frost risk assessment model. Based on the climate data from 1984 to 2013, the risk assessment of winter wheat late frost in Henan Province was carried out. According to the risk assessment model of winter wheat late frost, ArcGIS was used for grid calculation, and the risk zoning map of winter wheat late frost in Henan Province was obtained (Li et al., 2015).

1.3.5 Snow Risk Mapping and Assessment

1.3.5.1 Snow Mapping

Snow cover is an important part of land cover, an important source of water resources and one of the important elements in the global climate system. It can regulate river runoff and guarantee ecosystems' sustainable development. Its duration and coverage will affect the surface radiation and heat balance, the energy exchange of the earth-atmosphere system, etc. In addition, changes in snow cover also significantly affect the global and regional climate system, ecological environment and human production and life. Therefore, by obtaining or retrieving information about snow accumulation, the climate and ecological environment can be effectively adjusted, and the impact of snow accumulation on human production and life can be greatly reduced. Therefore, the snow cover is mainly elaborated from four directions: the calculation and inversion of snow cover depth, the identification and extraction of snow cover information, the temporal and spatial changes of snow cover, and the disaster risk analysis of snow cover.

Snow depth (SD) is one of the basic attributes of snow and an important parameter reflecting the distribution and change of snow. By obtaining continuous and uniform high-precision snow depth data, it can provide a scientific basis for research on climate change, water resource analysis and snow distribution. In addition, it can forecast, monitor, and warn of snowmelt flood disasters. The main methods of snow depth observation include ground observation and remote sensing data observation. However, ground observation mainly refers to meteorological stations or manual measurements. On the one hand, the obtained data is inefficient, scattered and poorly representative, and cannot meet the observation requirements of large-area snow depth information. On the other hand, it also has limited temporal and spatial resolution, high cost, low precision and other shortcomings; a single application of remote sensing data cannot ensure its accuracy. Therefore, using 3S data combined with measured data to calculate and invert snow depth has become increasingly widespread.

Currently GPS, InSAR and related extended technologies (such as GNSS-R, GNSS-IR and D-InSAR technology) are mainly used to retrieve snow depth. GNSS multipath information is obtained mainly through the signal-to-noise ratio at low altitude angles. Similarly, the multipath reflection information at low altitude angles has a significant impact on the signal-to-noise ratio. Therefore, the GNSS signal-to-noise ratio data at low altitude angles can be analyzed and processed, and then the surface environment parameters (snow depth) can be obtained. The band of the SAR satellite can penetrate the snow layer, so the SAR image is used to perform interferometric processing on the image data before and after the snowfall. The generated interference fringe pattern will also contain the phase information of the snow that can be used to retrieve the snow depth.

1.3.5.2 Snow Information Extraction

Snow information includes snow area, snow albedo, snow water equivalent and other information. Obtaining snow cover information can provide necessary and reliable reference materials for major research such as the hydrological cycle in cold regions, water resource management and snow

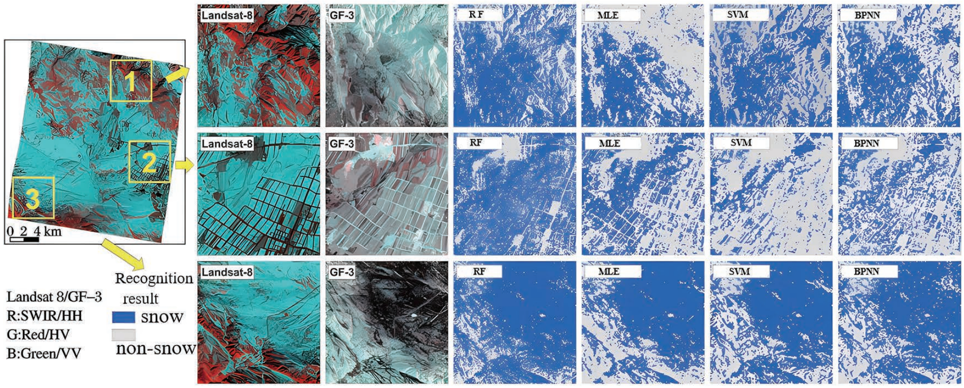

FIGURE 1.7 Details of Landsat-8, GF-3 and snow cover recognition.

Source: Ma et al. (2020)

disaster warning. Snow cover area (SCA) is one of the most important snow cover parameters. Rapid, real-time and accurate monitoring of changes in snow cover is of great significance for climate evolution simulation, water resource utilization management and disaster analysis and assessment. Snow albedo is one of the most important parameters of snow cover, and it has a significant impact on the snow hydrological process, snow mass-energy balance process and snowmelt runoff process. In addition, snow radiation information dominated by snow albedo can significantly affect the climate and hydrological cycle at different scales. Snow water equivalent (SWE), which is the liquid depth of snowmelt, is one of the main characteristics of snow cover and an important indicator for snowmelt runoff forecasting and water resource management. Therefore, obtaining snow water equivalent in time can provide a great reference value for snowmelt runoff forecast and water resource management.

Ma et al. (2020) extracted features for snow identification using domestic GF-3 data, five polarization decomposition methods (Pauli decomposition [a common coherent target decomposition method], H-A-α decomposition, Freeman decomposition, Yamaguchi decomposition and Anyang decomposition). The random forest method calculates the importance of each candidate feature; then selects the feature that contributes more to the recognition, constructs the feature optimization rule to generate the optimal feature set, and finally identifies the snow based on this feature set, forming a feature-based optimization method. The proposed method is compared with the three classifiers of the maximum likelihood method, support vector machine and BP neural network, as shown in Figure 1.7. It was found that the recognition accuracy was highest using the optimal feature set and the random forest method (the proposed method).

1.3.5.3 Snow Disaster Risk Assessment

Snow disasters are mainly caused by large-scale snow accumulation caused by heavy snowfall. The disasters seriously affect the environment and the survival and health of humans and livestock, and are likely to have a greater impact on transportation, communications, agriculture and electricity. Therefore, timely and effective disaster analysis of snow disasters can reduce their impact on the environment and human life and help the government and other relevant departments to make timely and effective disaster reduction and rescue measures.

Based on the principle of disaster risk assessment, GIS technology is used to select the influencing factors related to snow disasters, and the weights of the influencing factors are calculated. Finally, according to the weights, GIS is used for spatial superposition to obtain the snow disaster risk zoning map to further analyze the disaster. Xi (2020) extracted and processed snow data from 63 stations in Heilongjiang province from 1983 to 2015. He used methods such as trend analysis, spatial analysis in ArcGIS and Kriging interpolation to analyze the temporal and spatial variation characteristics of snow cover in Heilongjiang Province in the past 33 years. Combined with the theory of natural disaster risk, from the four aspects of the risk of disaster-causing factors, the sensitivity of disaster-forming environment, the vulnerability of disaster-affected bodies and the ability to reduce and prevent disasters, as well as the analytic hierarchy process and weighted comprehensive evaluation method, the snow disaster risk assessment index system in Heilongjiang Province was established and the risk was assessed for local snow disasters.

1.3.6 Hail Disaster Risk Assessment

1.3.6.1 Hail Disaster

Hail is a hard spherical, cone-shaped or irregularly shaped solid precipitation. It is a severe weather phenomenon caused by a strong convective weather system. Its impact range is small, and its time is short, but it is sudden and often accompanied by strong winds, development, rapid cooling and other paroxysmal weather. Hail occurs worldwide, and different countries have different degrees of hail disasters. Generally speaking, the geographical distribution characteristics are related to surface morphology and dimensional factors. Plains are less than mountainous areas, coastal areas are less than inland areas, and high-dimensional and low-dimensional areas are less than mid-latitude areas. However, due to its violent onset, often accompanied by thunderstorms or strong winds, it will cause great damage to agriculture, livestock, transportation, people's lives and property every year. Fujian Province, Tibet Autonomous Region and Inner Mongolia Autonomous Region are provinces with more frequent hailstorms and more serious hail disasters in China. According to statistics, the economic losses caused by hail disasters in China are as high as hundreds of millions or even billions of dollars every year. In China, hail mostly occurs in spring, summer and autumn, and April to July accounts for about 70% of the total. It is in the golden period of crop growth, so the occurrence of hail will cause a devastating blow to agriculture. In addition, hail will also cause losses in construction, communication, electric power, transportation and other industries. Therefore, it is very necessary to apply scientific detection equipment to warn of hail weather, implement artificial hail suppression operations and keep hail from growing, thereby reducing disaster losses.

Usually, a hail disaster lasts about ten minutes. Although the duration is not long, it will cause huge damage to vegetation and ecology. It will cause different damage to crops in different seasons. For example, autumn will cause sharp harvests. In spring, a large number of seedlings will die, and in summer, it will cause devastating damage to the growing crops. By processing the monitored data through satellite remote sensing technology, recording and analyzing the vegetation index before and after the hail disaster can monitor the damage's degree of size.

1.3.6.2 Hail Disaster Monitoring

Multi-temporal and multi-angle satellites can observe hail clouds and analyze the spectral characteristics, structural situation, range, boundary shape, color tone, shadow (specific to visible light cloud images) and texture features of hail clouds and other characteristics of hail clouds. By analyzing various features of satellite cloud images to obtain cloud types, horizontal scales, boundary shapes, relative heights and thicknesses, etc., hail clouds can be identified along with their spatial distribution and intensity.

GIS has accumulated a wealth of spatial data visualization and statistical analysis methods. It has the function of integrating various spatial data and performing powerful spatial analysis. It can provide powerful tool platform support for the identification of strong convective weather thunderstorms from radar data. The lightning location system can be used to identify hail clouds. During the formation and development of hail clouds, accompanied by strong lightning activities, the frequency of lightning increases sharply. Monitoring lightning activity using the Lightning Locating System allows the identification and location of hail clouds.

1.3.6.3 Hail Disaster Risk Assessment

3S technology has been used to assess the hail disaster risks. Peng et al. (2019) used fine-grained township hail frequency, historical disaster situation, DEM data, land and population density and other data in Chengde City to assess hail disasters in a targeted manner. A hail disaster risk assessment model is constructed from three aspects: disaster environment, disaster prevention and mitigation capabilities. The comprehensive weighted analysis method and the AHP are used to calculate the weight of each index, the evaluation index is gridded by GIS spatial analysis technology, and the hail disaster risk map of Chengde City was made with the grid as the basic evaluation unit. Yang et al. (2016) studied the hail disaster by using the hail data of 39 meteorological stations from 1981 to 2015 to fully analyze Tibet's climate background and economic environment. According to the disaster occurrence theory, the formation mechanism of regional hail distribution selects the factors of landform, disaster frequency, population and social economy from three aspects: the disaster-causing environment, the possibility of disaster occurrence and the vulnerability of disaster-affected bodies. They used the cluster analysis method to establish mathematical models such as meteorological disaster disaster-pregnant background, disaster risk and hazard-bearing body vulnerability, and operated the attribute database and graphic database by MapInfo professional software to obtain various disaster background, disaster risk, and vulnerability evaluation layers. After layer stacking, plate merging and level division, the risk partitions of various meteorological disasters were obtained.

1.3.7 Wind Disaster Risks Assessment

1.3.7.1 Wind Disaster Assessment Method

At present, the evaluation method of wind disasters is mainly divided into indicator evaluation methods and statistical simulation methods. The evaluation of wind disaster indicators is mainly aimed at the macro range, such as the severity of a certain wind disaster to damage the affected areas or the general degree of destruction. The current research mainly adopts regression analysis, fuzzy comprehensive evaluation method and analytic hierarchy process.

The statistical simulation assessment of the wind disaster is mainly based on the intensity and frequency of wind disasters and the statistical simulation of the specific structure of the disaster, namely the frequency, intensity and specific characteristics and location distribution of the disaster body, are used to determine the threat of wind disasters. Corresponding statistical simulation is performed to evaluate wind disasters or risks. The statistical simulation method of typhoon disaster generally includes typhoon frequency, intensity, path simulation, wind field simulation, wind damage simulation of engineering structure and expected insurance loss simulation.

Index evaluation methods are commonly used, which are the mainstream method of typhoon disaster risk and loss assessment. There are many specific implementation methods. At present, the main problem of the statistical simulation method of wind disasters is that the complexity of each aspect of the simulation process and the choice of various parameters result in uncertainty and differences in the results. For example, in the meteorological module, the uncertainty and differences between the wind speed model and the near-ground wind farm parameters will cause the final estimated wind disaster loss to be more unstable.

The fuzzy comprehensive evaluation model is a comprehensive analysis method based on fuzzy transformation theory based on fuzzy reasoning, combining qualitative and quantitative, accurate and inaccurate. At present, it is widely used in the multi-index comprehensive evaluation. AHP is a relatively simple and feasible decision-making method. Its main advantage is that it can solve complex multi-objective problems. The AHP method is also a combination of qualitative and quantitative methods. It can quantify the qualitative factors, express the subjective judgment of people in mathematics, and test and reduce the subjective influence to a certain extent, making the evaluation more scientific. It can provide decision makers with a variety of decision-making methods, in the combination of quantitative and qualitative, according to the standard weight of each decision scheme.

1.3.7.2 Wind Disaster Risk Mapping Based on 3S Technology

Based on the annual extreme wind speed data, natural environment and social and economic factors in Hangzhou, Chen (2012) constructed a regional wind disaster risk assessment model by integrating disaster-causing factors, disaster-pregnant environment, disaster-bearing bodies and disaster prevention and mitigation capabilities. The appropriate disaster risk assessment indicators and the risk assessment indicators are selected with a greater correlation with the wind disaster, the spatial overlay analysis of each index is conducted using the spatial analysis technology and the risk status of the wind disaster are evaluated and mapped with the grid as the basic evaluation unit. The Hangzhou area is divided into five levels of risk: high, sub-high, medium, sub-low and low, as shown in Figure 1.8 (Chen, 2012).

Sun et al. (2021) used the powerful data function of ArcGIS to establish the Xingtai gale disaster risk database and construct the risk assessment model of gale disaster. Through comprehensive analysis and evaluation of the data, the risk map of the disaster-causing factors of the strong wind disaster, the disaster-pregnant environment sensitivity of the strong wind disaster, the vulnerability of the disaster-bearing body of the strong wind disaster, the disaster prevention and resilience of the strong wind disaster, and the strong wind disaster in Xingtai City were obtained.

Zhou et al. (2013) introduced the typhoon disaster risk index, comprehensively considered the risk, vulnerability, exposure and local disaster prevention and mitigation capabilities of typhoon disasters, and constructed a comprehensive risk assessment index system for typhoon disasters. Taking Zhejiang Province as an example, each evaluation index was quantified according to historical statistical

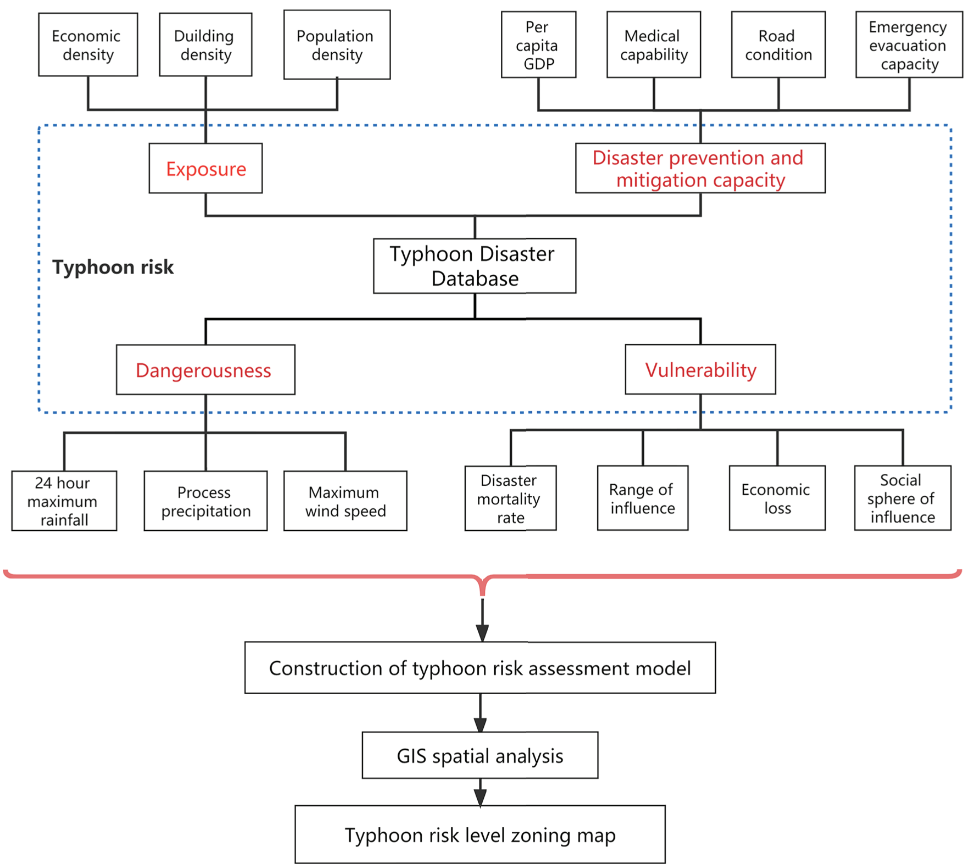

FIGURE 1.8 Flowchart of typhoon disaster risk assessment.

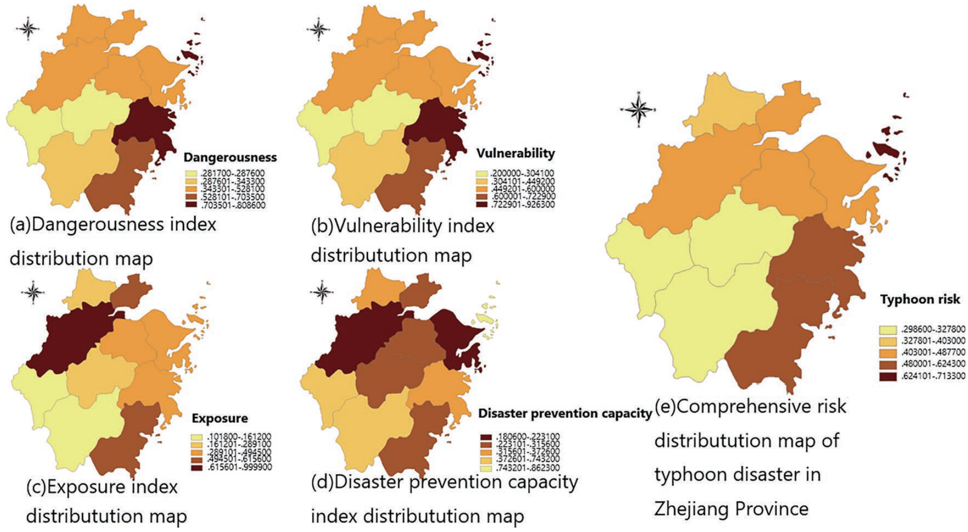

FIGURE 1.9 The risk index distribution map (a), vulnerability index distribution map (b), exposure index distribution map (c), disaster prevention and mitigation capacity index distribution map (d), and typhoon disaster comprehensive risk distribution map of various cities in Zhejiang Province (e) were obtained.

Source: Zhou et al. (2013)

data, and the spatial analysis function of GIS was used to overlay the evaluation indexes according to their weights. The risk index distribution map (Figure 1.9a), vulnerability index distribution map (Figure 1.9b), exposure index distribution map (Figure 1.9c), disaster prevention and mitigation capacity index distribution map (Figure 1.9d), and typhoon disaster comprehensive risk distribution map of various cities in Zhejiang Province (Figure 1.9e) were obtained (Zhou et al., 2013).

1.3.8 Lightning Risk Evaluation and Mapping

1.3.8.1 Lightning Risk Assessment Method

The formation and development of lightning disasters are subject to a variety of natural and socio-economic factors. According to its mechanism and change speed, the factors affecting the risk assessment of lightning disasters can be classified into four categories: lightning hazard, exposure, vulnerability and the ability of disaster prevention.

Lightning hazard is the dynamic factor causing lightning disasters. Meteorological disaster risk is a natural attribute, including disaster environment and disaster-causing factors. The loss caused by meteorological disasters depends on the risk of trigger factors. Hazard refers to the possibility of adverse events. Risk analysis is to study the possibility of adverse events from the perspective of risk inducing factors. The risk analysis of lightning disasters is to study the intensity and frequency of lightning in the area threatened by lightning. The intensity is expressed by the lightning intensity index, and the frequency is the probability, which can be expressed by lightning frequency. Here, the ground lightning frequency and intensity are mainly considered as the index factors to measure the lightning risk.

Exposure is divided into two elements: natural physical exposure and social physical exposure.

Vulnerability indicates the extent to which exposed objects in the affected area are affected by lightning disasters.

The ability of disaster prevention and mitigation mainly describes the level of social and economic development in the affected areas, reflecting the regional disaster bearing capacity and loss rate. Generally, it can be described by various statistical data, and has great regional differences and volatility in the time process.

The process of regional natural disaster risk formation, danger, exposure and vulnerability are indispensable. In the process of the formation of lightning disaster risk, in addition to the above natural disaster formation factors: danger, exposure and vulnerability, the role of disaster prevention and mitigation capacity in the risk of lightning disaster is relatively large. Therefore, when analyzing the risk of lightning disasters, it is necessary to consider the ability of disaster prevention and mitigation. Lightning disaster risk can be expressed as a multivariate function of dangerousness, exposure, vulnerability, disaster prevention and mitigation capacity.

The risk of lightning disaster is composed of four main factors: the risk of disaster-causing factors, the sensitivity of disaster-pregnant environment, the vulnerability of disaster-bearing bodies and the ability of disaster prevention and mitigation. Each factor is composed of several evaluation indexes. According to the theory of natural disaster risk and the formation mechanism of lightning disaster risk, the conceptual framework of lightning disaster risk zoning is established. According to the above conceptual framework of lightning disaster risk, a number of specific indicators are selected to evaluate the degree of lightning disaster risk.

1.3.8.2 Lightning Risk Mapping Based on 3S Technology

The "Regulations on the Prevention of Meteorological Disasters" implemented on 1 April 2010 stipulates:

> local people's governments at or above the county level should organize meteorological and other relevant departments to carry out meteorological disaster censuses on the types, frequency, intensity, and losses of meteorological disasters occurring in their administrative regions, establish a meteorological disaster database, conduct meteorological disaster risk assessment according to the types of meteorological disasters, and delineate meteorological disaster risk areas according to the distribution of meteorological disasters and the results of meteorological disaster risk assessment.

Lightning disaster is one of the ten most serious disasters announced by the United Nations. For a long time, lightning prevention work only focused on engineering protection, and lightning disaster risk mapping is lagging behind. Therefore, delineating the lightning disaster risk area based on the lightning disaster database is an urgent need to perform the administrative functions of the meteorological authorities. The lightning disaster risk zoning enriches the content of meteorological disaster comprehensive risk zoning and lays the necessary foundation for the preparation of meteorological disaster prevention planning.

Based on GIS technology, natural disaster risk assessment method and analytic hierarchy process, Lv et al. (2020) used lightning location monitoring data, geographic information data and socio-economic data in Jiangxi Province from 2010 to 2019 to carry out lightning disaster risk mapping from three aspects: disaster-causing factor, disaster-pregnant environment and disaster-bearing body, and formed lightning disaster risk zoning in Jiangxi Province. Based on the theory of natural disaster risk assessment, Cheng (2019) used lightning location data, geographic information data, socio-economic data and lightning disaster data to study the lightning disaster risk assessment and the risk of disaster-causing factors, the exposure of disaster-bearing bodies and the vulnerability of disaster-bearing bodies. The quantitative relationship between evaluation indicators and risk assessment was established, and the method of lightning disaster risk assessment in Henan Province was formed. At the same time, combined with GIS technology, the hazard distribution map of disaster-causing factors, the exposure distribution map of disaster-bearing bodies and the vulnerability distribution map of disaster-bearing bodies were formed. Finally, the comprehensive risk zoning map of lightning disaster in Henan Province was formed by superposition.

Based on the theory of natural disaster risk, Liu et al. (2019) selected 11 indicators to construct the lightning disaster risk index using the analytic hierarchy process and established the lightning disaster risk assessment model. By selecting the lightning disaster data, the grey correlation assessment of lightning disasters was carried out to verify the correctness of the zoning results. The assessment results were generally consistent with the distribution of lightning disaster risk zoning. The maps of the environmental sensitivity of lightning disaster, the risk of lightning disaster-causing factors, the vulnerability of lightning disaster-bearing bodies, the ability of lightning disaster prevention and mitigation, the comprehensive risk of lightning disasters, and the grey correlation degree of lightning disaster were obtained.

1.3.9 Risk Mapping of Dense Fog

1.3.9.1 Dense Fog

Fog is a disastrous weather phenomenon in which a large number of water droplets or ice crystals are suspended in the air near the surface, and the horizontal visibility distance is reduced to less than 1 km. Fog seriously affects atmospheric visibility and can pose a certain threat to traffic, transportation and military activities. In recent years, the economic losses caused by fog-induced traffic accidents have increased with the city's development. According to statistics, about 1/4 of traffic accidents are caused by bad weather with low visibility, such as dense fog. The traffic accident rate on the expressway in dense fog weather is 10 times higher than that of normal. The pollutants carried by fog may induce various diseases and adversely affect human health. Therefore, the impact of fog on traffic and the human living environment has been widely recognized by all sectors of society.

In recent decades, many experts and scholars have made in-depth analysis, research and discussion on fog weather phenomenon through field observation and experiments on fog, summarized the long-term climate change characteristics and environmental impact of fog, studied fog prediction theory and methods, conducted numerical simulation research on fog and obtained many meaningful results.

The spatial and temporal distribution of fog days of different grades in different regions has strong locality, and the dense fog and heavy dense fog with low visibility and long duration are more harmful. The classification of fog days plays an important role in mastering the law of fog disaster and objectively evaluating the disaster. According to the general survey of fog meteorological data and disaster investigation, when the following three conditions are met, there are usually disasters (flight delays, traffic accidents, etc.). Therefore, the meteorological conditions for fog disasters are defined as follows: (1) More than half of the stations in the city have visibility < 1000 m (range); (2) Visibility ≤ 100 m (intensity) observed in some areas; (3) Duration ≥ 6 h (duration).

In the actual fog disaster risk assessment, the appropriate fog disaster classification standard can be selected according to the actual situation of the evaluated area to make the evaluation results more objective and accurate. The evaluation of fog disaster risk should consider the comprehensive effect of four factors, such as the risk of disaster-causing factors, the sensitivity of disaster-pregnant environment, the vulnerability of disaster-bearing bodies and the ability of disaster prevention and mitigation. The evaluation factors mainly include the location of the fog disaster, the scope of influence, the frequency of historical occurrence, the level of visibility. The environmental sensitivity of fog disasters refers to the effect of natural factors on the formation of fog disasters in a certain area without considering the weather background. Its evaluation indexes include the coastline index, river network density index and topography index. Vulnerability refers to the degree of vulnerability of a disaster-affected body to natural disaster events. The evaluation indicators mainly include road network density, population density and per capita GDP. The ability of disaster prevention and mitigation mainly includes the ability of human recovery and reconstruction of disaster-bearing bodies and the ability of government emergency response. The economic development level of the region and the construction of basic disaster prevention facilities are the important basis for the evaluation of disaster prevention and mitigation capacity.

1.3.9.2 Dense Fog Risk Evaluation

In the fog disaster risk assessment, some have tried to use the grey correlation method and achieved good results. Based on the observation data of foggy weather in the Beijing area in the past 20 years and the disaster survey data derived from foggy weather, Zhang et al. (2008) analyzed the disaster evaluation index and disaster classification of fog by using the grey correlation method, established the evaluation model and evaluated 22 fog disaster cases. The results showed that the grey correlation method had the characteristics of a small amount of calculation without requirement for the number of samples, and obeyed a certain distribution law. It is a simple and feasible method of fog disaster risk assessment combining qualitative analysis and quantitative estimation.

There are precedents to evaluate the risk of fog disaster by grid overlay analysis, such as Hu et al. (2010), using GIS software to divide a certain size of square grid units in the study area. The fog observation data are used to measure the fog disaster risk index in urban areas. The regular grid is used as the evaluation unit, and the road network density in the grid area is calculated grid by grid, which is used as the spatial vulnerability index of fog disasters. The population density in the grid is selected as the vulnerability index of fog disasters. The risk index of fog disaster is calculated according to the distribution ratio of 5:2:1. Ma et al. (2014) analyzed the temporal and spatial distribution characteristics of marine fog in Qingdao based on the climate data from 1978 to 2007. Marine fog is a meteorological disaster with a great impact on urban construction and social and economic activities in Qingdao. Combined with the fog disaster census data from 1984 to 2007, the index-weighted comprehensive model of disaster risk assessment was used to carry out the sea fog meteorological risk assessment with geographic information system (GIS).

1.3.10 Fire Risk Assessment

1.3.10.1 Fire Risk

Due to the combined effects of climatic conditions, human activities, environmental factors, management and protection policies, the forest fire losses in different regions show significant regional differences (Bowman et al., 2009; Csiszar et al., 2006; Schroeder et al., 2008). In order to better prevent the occurrence of forest fires and effectively use resources, it is necessary to take different preventive policies for different regions and carry out forest fire risk mapping (Jaiswal et al., 2002; Dhar et al., 2023). Forest fire risk mapping refers to dividing the study area into different levels according to the risk of forest fires in the study area with the regional disaster-bearing capacity and socio-economic conditions (Eugenio et al., 2016). Forest fire risk mapping is used to estimate the possibility of forest fires and the potential losses caused by the vulnerability of forest systems to attacks, so as to quantitatively or qualitatively measure, predict, analyze and evaluate the potential losses caused by the uncertainty of forest fires in a certain period. Accurate fire risk classification can play a good early warning role, reduce the number of fires, protect forest resources, protect the life safety of firefighters and reduce the loss of personnel and resources caused by fires. According to the forest fire risk map, it can provide decision-making opinions for the forestry department in forest fire prevention, firefighting, fire prevention work construction and other aspects. Combined with qualitative and quantitative methods, the weight of each disaster-causing factor was determined by the analytic hierarchy process. According to the weight coefficient of different factors, the forest risk map model was established, and the risk zoning was carried out according to the model's results.

1.3.10.2 Fire Risk Evaluation

With the understanding of the fire process and mechanism, ones have successively studied fire risk models and risk map methods, including the Bayesian network, catastrophe progression method, cluster analysis method, cellular automata, optimal segmentation method, factor weighted overlay comprehensive analysis method, artificial neural network, entropy method, fuzzy comprehensive evaluation method, semi-parametric space model, logistic regression model and geographical weighted regression. Fire risk is the result of the comprehensive effect of hazard, exposure and vulnerability of bearing body, and regional fire prevention and disaster reduction capability.

The study on fire risk early warning has gone through three stages. In the 1960s and 1970s, meteorological factors were used as the main prediction parameters to predict fire risk. In the 1980s and 1990s, the development of remote sensing and geographic information system technology promoted the research of fire risk index, and the multi-factor fire risk prediction. Since the 1990s, the fire risk index has been calculated by taking into account the fuel conditions, climate conditions, terrain and other factors, making the use of the fire risk index faster and more convenient. Various indexes based on these factors, such as the Fire Weather Index (FWI), the Keetch-Byram Dry Index (KBDI) and the Forest Fire Danger Index (FFDI), have been widely used.

The development and application of satellite remote sensing technology have made contributions to the study of fire risk on combustible types and water content through remote sensing monitoring and inversion technology. For example, unsupervised classification methods are used to classify combustibles, greenness maps are used to quantify the moisture content of combustibles, vegetation index NDVI and VCI are used to monitor the state of combustibles, and remote sensing is also used to estimate drought and soil moisture for fire risk assessment (Kaufman et al., 1998). Many GIS spatial analysis methods are used for fire risk assessment. A multi-distance spatial clustering function was proposed by Ripley in 1976, belonging to the multi-distance spatial clustering analysis method. This function assumes that geographical things are uniformly distributed in space and counts the number of samples within the search circle according to a certain radius distance. By comparing the measured value and theoretical value of the average number of these samples and the ratio of sample density in the region, it finally determines whether the distribution characteristics of the actual observed geographical things are spatial aggregation, spatial divergence or spatial random. The ensemble empirical mode decomposition method decomposes the time series of a variable into the oscillation components and a nonlinear trend with different time scales such as inter-annual, inter-decadal and inter-year. Kernel Density Estimation can estimate the probability density value of geographical objects in their surrounding neighborhood by setting bandwidth without any prior density assumption.

Lin et al. (2013) used meteorological factors such as precipitation, maximum temperature, relative humidity, average wind speed, snow days and thunderstorm days, geographical factors such as elevation, slope and aspect, vegetation factors such as vegetation type and NDVI, and social factors such as traffic, population and residence as four risk factors for forest fire risk. The forest fire risk in Tibet was quantitatively evaluated by index normalization method, analytic hierarchy process and weighted comprehensive evaluation method. According to the fire risk level, the whole region was divided into five risk areas: low, lower, medium, higher and much higher. Using the analysis function of GIS software, the map of forest fire risk level in Tibet was compiled to provide a reference for improving the prediction level of forest fire risk.

Forest fire is the result of many natural factors and social factors. Its occurrence is closely related to climate, vegetation, human activities and terrain. According to the four risk factors of meteorology, geography, vegetation and society, the spatial distribution of forest fire risk factors was calculated, and the results of each risk factor were normalized to the range of 0–1 according to the normalization method.

Meteorological factors mainly include precipitation, temperature, sunshine duration, evaporation, wind and air humidity. Meteorological factors can affect fire occurrence and fire behavior by changing the fire environment. The area with the highest meteorological risk factors is located in the southeastern region, where the altitude is the lowest. The temperature is high, and the dry and wet seasons are distinct. The main precipitation is concentrated in the summer flood season, and the precipitation in the fire prevention period only accounts for less than 10% of the annual precipitation. The number of snow days is small, which is most conducive to forest fires.

Using high-resolution DEM data to derive the corresponding terrain data such as altitude, slope and aspect as the geographical factors of forest fire danger, different scores are given according to their different effects on forest fire. For forest fires, as the altitude increases, the temperature decreases, the vegetation distribution decreases and the possibility of forest fires decreases. The influence of slope on the occurrence and spread of forest fire was high in the middle and low on both sides. With the increase of slope, the surface runoff accelerated, the fuel on the ground was easy to dry and the fire risk was high. However, when the slope reached a steep slope, the distribution of trees decreased, and the risk of forest fire decreased. The slope direction directly affects the amount of solar radiation received by the ground, resulting in temperature differences in different slope directions. The southern slope receives higher solar radiation than the northern slope, and the air is drier and more likely to cause fire.

According to the provisions of the national forest fire danger zoning grade on the flammability of vegetation, different vegetation types are divided: the inflammable coniferous forest is given 1, the more inflammable broad-leaved forest is 0.7, the more refractory grassland is 0.3, the refractory plateau meadow is 0.1 and the non-combustible lake and desert are given 0. The spatial distribution of vegetation risk factors was calculated by normalized NDVI and vegetation type.

In addition to natural factors, human-induced fires are an important threat to forests. Therefore, forest fire risk factors formed by human factors must be considered. Considering the influence of traffic, population density and village density, the highway is analyzed by the 5 km buffer zone. The population density is obtained by dividing the agricultural population by the county area. Considering the low settlement of villages in Tibet, a buffer analysis of 3 km is used for villages. After standardizing the three indicators, the standardized spatial distribution of social risk factors is obtained.

The normalized meteorological, topographic, vegetation and social factors were given weights of 0.30, 0.15, 0.40 and 0.15, respectively. The comprehensive evaluation value of forest fire risk in Tibet was obtained by comprehensive calculation, and then the risk evaluation value in the range of 0–1 was obtained by standardization. According to the boundary of 0.2, it was divided into five levels: sub-low-risk areas, low-risk areas, medium-risk areas, sub-high-risk areas and high-risk areas, and the forest fire risk zoning map of Tibet was obtained.

1.4 OPPORTUNITIES AND PROSPECTIVE

The 3S technology has been widely used in meteorological disaster monitoring and assessment. RS technology is mainly used to obtain the data source of disaster monitoring at a large scale. GIS links spatial data and attributed data to perform spatial analysis, query and cartographic comprehensive management of geometric features in the study area. GNSS technology is mainly used to quickly obtain location information in real time. In the field of basic landslide data acquisition, 3S technology can play the key function in landslide geographic data acquisition and rapid update, establish a complete landslide catalog database as much as possible, and effectively express landslide mapping (Zhang et al., 2015). Also, 3S technology can obtain information such as elevation, vegetation coverage, surface humidity, water system distribution and topographic relief in a large area.

With the acceleration of urbanization, the demand for 3S technology is becoming increasingly urgent, and its application field is expanding. The construction of smart cities involves basic image map data and a large amount of spatial location data information. Based on the real-time location information provided by GNSS, the data transmission and processing capabilities of the system are further improved based on the existing path analysis of GIS, and the optimal path planning is provided in a short time. Reasonable diversion of traffic flow will help alleviate the current traffic congestion in large cities. Affected by human activities and climate change, natural disasters occur frequently, and emergency management of geological and meteorological disasters based on 3S technology is particularly critical. 3S technology has unique advantages in data acquisition and management, two-dimensional and three-dimensional visualization of spatial information, emergency monitoring and analysis, spatial data analysis and so on, which can help to better reduce the impact of disasters on people's lives and property.

Although 3S technology has made great achievements in the application of various fields, many problems also need to be solved in the practice process. (1) The inconsistency of data standards leads to low efficiency of 3S technology applications. Affected by different sensors of remote sensing satellites, the spatial resolution, radiation resolution and spectral resolution of satellite images from different sources are not uniform, and no better methods can be compatible with different data sources. In addition, raster data and vector data have different data structure characteristics. Integrating the advantages of raster and vector data to build a unified standard and compatible geographic information database with different data types is one of the goals of 3S technology integration. (2) Data accuracy needs to be further improved. At present, precise GNSS navigation and positioning for outdoor and indoor have not yet made a breakthrough, which makes it difficult to meet the needs of indoor high-precision positioning applications. Improving the accuracy of remote sensing data and GIS models will help apply 3S technology applications to more fields. (3) As a multidisciplinary interdisciplinary technology, 3S technology not only achieves internal integration, but also deeply integrates with other fields such as computer networks, artificial intelligence and big data. The construction of the 3S system requires not only the knowledge base of 3S technology, but also availability of computer software and hardware. Therefore, it is necessary to strengthen the cultivation of multidisciplinary high-quality compound talents and provide sufficient talent reserve for the development of 3S technology.

REFERENCES

Aja D., E. Elias, O. Obiahu. Flood risk zone mapping using rational model in a highly weathered Nitisols of Abakaliki Local Government Area, South-eastern Nigeria. Geology, Ecology, and Landscapes, 2020, 4(2): 131–139.

Allan C., A. Curtis, N. Mazur. Understanding the social impacts of floods in Southeastern Australia. Advances in Ecological Research, 2006, 39: 159–174.

Bowman D., Jr, K. Balch, P. Artaxo, et al. Fire in the earth system. Science, 2009, 324: 481–484.

Campbell J., R. H. Wynne. Introduction to remote sensing, Fifth Edition, The Guilford Press, 2011.

Chen S., A. Huo, D. Zhang, et al. Key technologies for drought disaster risk assessment in typical vulnerable areas of eastern Gansu Province. Agricultural Research in the Arid Areas. 2022, 40(2): 197–204.

Chen X. Division into districts on wind disaster risk of Hangzhou. Nanjing University of Information Science and Technology, 2012.

Cheng L. The application of analytic hierarchy process (AHP) and geographic information system (GIS) in lightning disaster risk-zoning in Henan province. Journal of Nanjing University of Information Science and Technology (Natural Science Edition), 2019, 11(2): 234–240.

Csiszar I., J. Morisette, L. Giglio. Validation of active fire detection from moderate-resolution satellite sensors: The MODIS example in Northern Eurasia. IEEE Transactions on Geoscience and Remote Sensing, 2006, 44(7): 1757–1764.

Dhar T., B. Bhatta, S. Aravindan. Forest fire occurrence, distribution and risk mapping using geoinformation technology: A case study in the sub-tropical forest of the Meghalay, India. Remote Sensing Applications: Society and Environment, 2023, 29: 1–19.

Dong S., L. Jiang, J. Zhang, et al. Research on flood vulnerability curves off rural dwellings based on "3S" technology. Journal of Catastrophology, 2012, 27(2): 34–39.

Dow J., R. E. Neilan, C. Rizos. The International GNSS Service in a changing landscape of Global Navigation Satellite System. Journal of Geodesy, 2009, 83: 191–198.

Eugenio F., A. dos Santos, N. Fiedler, et al. Applying GIS to develop a model for forest fire risk: A case study in Espirito Santo, Brazil. Journal of Environmental Management, 2016, 173: 65–71.

Fang X., W. Du, W. Quan, et al. Study on high temperature disaster risk regionalization in Jiangsu-Zhejiang-Shanghai region. Journal of Meteorology and Environment, 2016, 32(6): 109–115.

Gomarasca M. Basics of geomatics. Springer Dordrecht, 2009.

Goodchild M. F. Geographic information systems and science: Today and tomorrow. Annals of GIS, 2009, 15(1): 3–9.

Guan Y., F. Zheng, P. Zhang, et al. Spatial and temporal changes of meteorological disasters in China during 1950–2013. Nature Hazards, 2015, 75: 2607–2623.

He Y., X. Wang, C. Chai, et al. Flood damage assessment and visualization based on NPP-VIIRS nighttime light remote sensing. Journal of Natural Disasters, 2022, 31(3): 93–105.

Hofmann-Wellenhof B., H. Lichtenegger, E. Wasle. GNSS—Global navigation satellite systems: GPS, GLONASS, Galileo, and more. Springer Wien New York, 2007.

Hu H., Y. Xiong, S. Zhang. The risk assessment of the fog disaster based on vulnerability calculating related to the urban transportation network. Journal of Applied Meteorological Science, 2010, 21(6): 732–738.

Jaiswal R. K., S. Mukherjee, K. D. Raju, et al. Forest fire risk zone mapping from satellite imagery and GIS. International Journal of Applied Earth Observation and Geoinformation, 2002, 4(1): 1–10.

Jin S. Global navigation satellite systems—Signal, theory and applications. IntechOpen, 2012.

Jin X. The risk evaluation and regionalization of heat wave in Fujian Province within the background of risk society. Master Degree, Fujian Normal University, 2017.

Kaufman Y., R. G. Kleidman, M. D. King. SCAR-B fires in the tropics: Properties and remote sensing from EOS-MODIS. Journal of Geophysical Research Atmospheres, 1998, 103(D24): 31955–31968.

Khorram S., F. H. Koch, C. F. van Wiele, et al. Remote sensing, Springer, 2012.

Lechner W., S. Baumann. Global navigation satellite systems. Computers and Electronics in Agriculture, 2000, 25(1–2): 67–85.

Li D., Q. Li. The formation of geospatial information science. Advances in Earth Sciences, 1998, (4): 2–9.

Li D. Digital Earth and “3S” technology. China Surveying and Mapping, 2003, (2): 30–33.

Li H., Q. Li, X. Li, et al. Discussion on the algorithms of a new siphon rain gauge. Wseas Transactions on Circuits and Systems, 2010, 9(6): 389–398.

Li J., H. Zhang, S. Cao. Assessment and zonation of late frost injury of winter wheat in He’nan Province based on GIS. Journal of Arid Meteorology, 2015, 33(1): 45–51.

Lin Z., H. Lu, C. Luobo, et al. Risk assessment of forest fire disasters on the Tibetan plateau based on GIS. Resources Science, 2013, 35(11): 2318–2324.

Liu G., L. Zhang, B. He, et al. Temporal changes in extreme high temperature, heat waves and relevant disasters in Nanjing metropolitan region, China. Natural Hazards, 2015, 76: 1415–1430.

Liu X., L. You, H. Song, et al. Analysis and evaluation of lightning disaster risk regionalization based on GIS and AHP in inner Mongolia. Chinese Agricultural Science Bulletin, 2019, 35(20): 75–82.

Lv Z., Z. Yu, C. Wang. Risk zoning of regional lighting disaster in Jianxi province based on GIS technology. Meteorology and Disaster Reduction Research, 2020, 43(3): 228–233.

Ma T., P. Xiao, X. Zhang, et al. Recognition of snow cover based on features selection in GF-3 fully polarimetric data. Remote Sensing Technology and Application, 2020, 35(6): 1292–1302.

Ma Y., Y. Hao, Y. Wang. Characteristics of sea fog and risk assessment for fog disaster in Qingdao. Periodical of Ocean University of China, 2014, 44(11): 11–15+29.

Mishra A., V. P. Singh. A review of drought concepts. Journal of Hydrology, 2010, 391: 202–216.

Norman B. A brief history of Global Navigation Satellite Systems. The Journal of Navigation, 2012, 65(1): 1–14.

Peng J., D. Wang, Y. Zhao, et al. Hail disaster risk zoning in Chengde City based on GIS. Desert and Oasis Meteorology, 2019, 13(1): 105–109.

Qin D. Exploration of the application and development prospects of geographic information systems. Beijing Agriculture, 2015, 626(21): 179–180.

Ramkar P., S. M. Yadav. Flood risk index in data-scarce river basins using the AHP and GIS approach. Natural Hazards, 2021, 109: 1119–1140.

Schroeder W., E. Prins, L. Giglio, et al. Validation of GOES and MODIS active fire detection products using ASTER and ETM+ data. Remote Sensing of Environment, 2008, 112: 2711–2726.

Seejata K., A. Yodying, T. Wongthadam, et al. Assessment of flood hazard areas using Analytical Hierarchy Process over the Lower Yom Basin, Sukhothai Province. Procedia Engineering, 2018, 212: 340–347.

Shan Z., Y. An, L. Xu, et al. High-temperature disaster risk assessment for Urban Communities: A case study in Wuhan, China. International Journal of Environmental Research and Public Health, 2022, 19(1): 183.

Sun J., X. Zhang, B. Hou. Application of ABC-based BP neural network in integrated navigation system. Journal of Telemetry, Tracking and Command, 2016, 37(5): 40–48.

Sun J., Z. Zhao, D. Li, et al. Risk Zoning of Gale disaster in Xingtai City based on GIS in the past 35 years. Journal of Agricultural Catastropholgy, 2021, 11(6): 82–84+86.

Sun X., T. Li, X. Mao, et al. High precision Indoor/outdoor positioning system and positioning method based on Beidou UWB. Integrated Circuit Applications, 2020, 37(5): 118–119.

United Nations. The human cost of weather-related disasters 1995–2015. UN Report, 2015.

Wang F., Q. Wei, J. Chang, et al. Remote sensing monitoring technology of winter wheat late frost based on FY-3. Journal of Agricultural Catastropholgy, 2021, 11(2): 192–194.

Wang J. Application of GPS/GPRS/GIS integrated technology in vehicle positioning and monitoring. Wuhan University, 2005.

Wang L., L. Zengzeng, Remote sensing monitoring of Poyang Lake flood disaster in 2020 based on Sentinel-1A. Geospatial Information, 2022, 20(6): 3–46.

Wang Y., D. Zheng, Q. Li. Urban meteorological disaster. China Meteorological Press, 2009.

Xi W. Risk assessment and regionalization of snow disaster in Heilongjiang Province. Harbin Normal University, 2020.

Yang J., J. Lie, C. Yang. Risk assessment model of hail disaster in Tibet supported by GIS. Plateau and Mountain Meteorology Research, 2016, 36(2): 69–74.

Ye P. Remote sensing approaches for meteorological disaster monitoring: Recent achievements and new challenges. International Journal of Environmental Research and Public Health, 2022, 19, 3701.

Yi Y. Study on risk assessment of flood disaster in Guilin area based on GIS. Guangxi University, 2012.

Zhang C., M. Chen, R. Zheng. Landslide hazard risk assessment and zoning of Huadu District of Guangzhou based on "3S" technique and logistic regress-weighted SVM model. Journal of Ecology and Rural Environment, 2015, 31(6): 955–962.

Zhang J., J. Ni, S. Ma, et al. GIS-based analysis of flood submergence in Jinpu New District, Dalian City. Geology and Resources, 2021, 30(5): 590–594.

Zhang K. Review on geological disaster monitoring and early warning system based on "3S" technology in China. The Chinese Journal of Geological Hazard and Control, 2020, 31(6): 1–11.

Zhang S., D. Ding, Z. Fu, et al. Application of grey relational grade in fog disaster evaluation in Beijing Region. Journal of Catastrophology, 2008, 88(3): 54–56+61.

Zhou F., W. Zhang, L. Lei, et al. GF-3 and Sentinel-1 flood inundation information extraction. Geospatial Information, 2021, 19(6): 17–21.

Zhou Y., X. Cheng, J. Cai, et al. Study on comprehensive risk assessment of Typhoon disasters. China Public Security. Academy Edition, 2013, 30(1): 31–37.