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Disaster Risk Reduction Knowledge Service: A Paradigm Shift from Disaster Data Towards Knowledge Services

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Abstract—Earthquakes have caused tremendous damage in China and around the world; the Wenchuan earthquake that occurred in China 10 years ago is among the deadliest earthquakes in history. The importance of earthquake monitoring and seismic data analysis is now recognized in China. However, the effective dissemination of earthquake-related disaster risk reduction (DRR) knowledge to decision-makers and the public has not been adequately addressed. Under the auspices of the United Nations Educational, Scientific, and Cultural Organization (UNESCO), the International Knowledge Centre for Engineering Science and Technology (managed by the Chinese Academy of Engineering) launched the Disaster Risk Reduction Knowledge Service in 2016. This service, based on the development of disaster metadata standards, was constructed to share disaster information and provide thematic knowledge services; it facilitates the integration and sharing of disaster data, disaster maps, expert opinions, institutional knowledge, research literature, and videos. A series of earthquake DRR knowledge services applications have been implemented using this knowledge service platform, including (1) a global earthquake daily distribution map service, (2) a spatiotemporal map of historical earthquakes in the One Belt One Road region, (3) a Wenchuan earthquake disaster relief knowledge service, and (4) a thematic knowledge service for disaster relief work and contingency planning during the Jiuzhaigou earthquake. In the long term, this system will support the conversion of disaster data into DRR knowledge and provide services for international organizations, government institutions, research and educational institutions, enterprises, and the general public.

Key words: Earthquake disaster, disaster risk reduction, data sharing, knowledge service.

1. Introduction

The Earth is mankind's only home, but it is not a completely stable planet. According to current statistics, earthquakes of Richter magnitude 8.0, 7.0, 6.0, 5.0, and > 2.0 occur 2–3 times, $\sim$ 20 times, $\sim$ 180 times, $\sim$ 2000 times, and $\sim$ 1,000,000 times every year around the world, respectively. Due to the tremendous damage caused by earthquakes, earthquake monitoring and data acquisition have become important priorities for many countries. China, one of the first countries to begin monitoring earthquakes, has been recording their occurrence since 2300 BCE when Zhang Heng invented the seismoscope during the Han Dynasty. Seismograph stations have been constructed on a large scale since the founding of the People's Republic of China, thus establishing a multidisciplinary, multicategory seismographic network that covers the entirety of the country. This seismographic monitoring network includes seismic, electromagnetic, deformation, and fluid monitoring networks, as well as a mobile physical field monitoring system whose measurement lines have a cumulative length of 150,000 km (Liu and Peng 2009). To improve the management of seismology data, the China Earthquake Administration (CEA) officially launched the China Earthquake Data Center (CEDC, http://data.earthquake.cn) on 28 September 2016, at the National Earthquake Disaster Mitigation

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Center. As of 2017, the scientific data sharing platform of the CEDC includes data about earthquake monitoring, earthquake detection, earthquake surveys, earthquake-related experiments, thematic earthquake content, and earthquake disaster risk reduction (DRR). These data were derived from a variety of disciplines, including seismometry, strong-motion seismology, gravimetry, deformation, geoelectricity, geomagnetism, subsurface fluid monitoring, as well as historical earthquake records and studies of seismic damage in artificial constructions, earthquake case studies, volcanic disasters, and crustal stress environments. Over 100 earthquake databases have been formed, and the amount of data hosted by the CEDC exceeds 300 TB (National Science and Technology Infrastructure Center 2016, 2017).

Disaster data are a necessity for establishing DRR capabilities. A number of integrated disaster databases (including earthquake databases) have emerged at global and regional level to accommodate the ever-growing demand for disaster information. Among the searchable integrated disaster databases worldwide (Liu et al. 2008), the USA and the United Nations Development Programme (UNDP) account for 26.9% and 19.2% of these databases, respectively, while the European Union (EU), Japan, Canada, Australia, the World Health Organization (WHO), and Belgium each account for 3.8% of the databases. The Regional Disaster Information Center Latin America and the Caribbean (CRID) and the Asian Disaster Reduction Center (ADRC) are examples of regional disaster databases. Databases that focus on a single disaster type include the National Weather Service (NWC) of the USA (National Oceanic and Atmospheric Administration 2017), the real-time typhoon database managed by the National Institute of Informatics (NII) of Japan (Yan 2016), and the United States Geological Survey (USGS) seismic hazard forecast maps, which have included human-induced seismic events since 2016 (USGS 2016). Some of the most well-known international disaster databases for disaster-related applications include the emergency events database (EM-DAT) managed by the Centre for Research on the Epidemiology of Disasters (CRED) (Si et al. 2007), the DesInventar Project maintained by the United Nations International Strategy for Disaster Reduction (UNISDR) and the UNDP (DesInventar 2015), the NatCatSERVICE disaster database of the Munich Reinsurance Company (Münchener Rückversicherungs-Gesellschaft, Topics GEO natural catastrophes 2017), and the Sigma database of the Swiss Re Institute. Compared with the rest of the world, there is a clear lack of disaster databases in China. Some of the searchable databases in China are the China Natural Disaster Database (Fang and Wang 1998), the Natural Disaster Case Database (Xu et al. 2000), and the widely utilized National Natural Disaster Information Management System (NNDIMS) (National Disaster Reduction Center of Ministry of Civil Affairs of the People's Republic 2019).

With the continuous accumulation of disaster data, the effective management and utilization of disaster data have become a focal point for DRR research. A number of platforms for disaster risk assessment have already been constructed. These include the comprehensive approach to probabilistic risk assessment (CAPRA) platform, the disaster risk overview platform, the DesInventar platform, the global disaster alerting coordination system (GDACS), the global identifier number (GLIDE), global earthquake model (GEM), the KatRisk platform, the global assessment report on disaster risk reduction (GAR), the world risk index (WRI), and the global risks report (Lin and Zhou 2017; Han and Zhou 2017; Zhang and Zhou 2017; Wang and Zhou 2017; Zhou 2017). The integration and sharing of DRR data and the provision of knowledge services is an emerging trend in the field of DRR (Xie 2017). Knowledge services are a product of library and information science (LIS); in recent years, these services have become an important outlet for the processing of information, and they have grown rapidly in a number of fields and industries. Since 2011, the importance of knowledge services in academia has grown significantly, and it is now one of the most popular topics for DRR research (Mo 2015). Knowledge services are based on the possession of superior knowledge resources, and their function is to provide reliable information and decision support services through advanced information techniques and a diversity of service delivery modes. Knowledge services, therefore, represent a fundamental transformation of knowledge resources from "possession" to "application." Innovations in knowledge service theories, methods, and techniques are necessary to drive the continuation and development of knowledge services (Wen and Jiao 2011), which are expected to deeply influence the growth of human society in the near future.

The losses caused by natural disasters such as earthquakes have severely hampered the sustainable development of China's economy. As major disasters tend to be followed by other disasters, there are often direct or indirect causal relationships between disasters. Thus, the construction of a modern, comprehensive, multidisciplinary, cross-sectoral, and cross-regional DRR service that is able to provide an overview of any disaster situation is extremely important. UNESCO has always prioritized global cooperation in DRR by promoting DRR knowledge sharing services (UNESCO DRR 2019). With the implementation of the Sendai Framework for Disaster Risk Reduction (United Nations 2015a, b), UNESCO hopes to strengthen cooperation in disaster data standards, DRR education, and both national and regional disaster databases in a greater number of developing countries. In 2015, UNESCO proposed a set of requirements for the construction of a DRR knowledge service by the International Knowledge Centre for Engineering Sciences and Technology (IKCEST), which is managed by the Chinese Academy of Engineering (CAE). Based on current trends towards data integration and international collaboration, this DRR knowledge service for information sharing and knowledge service provision was established to address the demand for DRR work around the world, especially on knowledge service applications for earthquake DRR. This knowledge service will provide a long-term source of DRR information and thematic knowledge services for international organizations, government institutions, research and educational institutions, businesses, and broader society.

2. *Technical Methodologies*

The overall method of building the disaster risk reduction knowledge service system is to take the standard formulation for disaster-related metadata as the breakthrough point to realize the collection of various knowledge resources, including a metadata-based disaster science database, disaster map resources, a disaster expert database, a disaster institution database, a disaster event database, a database of disaster open directory projects, a database of disaster-related information, Web mining, a disaster literature database, a disaster popular science database, and a disaster video courseware database. In the development environment of an open platform, the system delivers visualized subject-specific knowledge services in typical disasters, including earthquakes, droughts, flooding, and freezing rain and snow, and it enables interactive application by users through the online system.

2.1. *Standard Formulation for Disaster-Related Metadata*

On the basis of thorough investigation and research, a comparative analysis of the structure of disaster-related metadata is conducted for three aspects, including the comprehensive metadata standards for natural disasters, metadata standards for a single natural disaster, and metadata standards for related information fields. Afterwards, the common metadata standard subsets and the corresponding metadata elements are extracted. A disaster metadata framework was designed consequently, which contains ten subsets, including information about the metadata entity set, identification, content, data quality, constraint, dissemination, reference system, citation and responsible party, etc. The disaster metadata standards are constructed at two levels—disaster core metadata and disaster universe metadata. Overall, the disaster metadata standards consist of 39 entities and 114 elements. The core metadata include 3 entities and 27 elements. A combination of unified modeling language (UML) diagrams and a data dictionary is used to describe the disaster metadata and generate the extensible markup language (XML) schema.

The data of the disaster risk reduction knowledge service system are based on various information resources, including data resources, map resources, the expert database, the institution database, the literature database, the multimedia database, the popular science database, the video courseware database, open resources, Web mining information, and disaster events. The association between each resource can be illustrated by the UML diagram shown in Fig. 1. This metadata link mechanism can ensure more resources can be retrieved even when users just search or access only one kind of resource; For example, when a user is searching earthquake relief technology and related documents, more related materials can be linked to the search results list supported by this metadata link mechanism, including earthquake relief experts, relief institutions, resilience research literature, disaster relief experiments, popular science videos, etc.

To establish the interconnection among different types of disaster-related resources, the basic metadata items of each type of resource are specified. The disaster map database includes nine metadata items: the unique system identifier, map title, type of disaster, temporal range, spatial range, brief introduction, map source, update time, and web address. The disaster expert database contains 18 metadata items: the unique system identifier, the identifier of its dataset, the expert's name, gender, month and year of birth, academic qualifications, professional titles, educational background, work experience, research field and orientation, achievements and awards, work unit, nationality, email address, homepage, update time, resource construction method, and web address. The disaster organization and institution database comprise ten metadata items: the unique system identifier, Chinese name, English name, country, city, longitude of the institution, latitude of the institution, type of disaster, overview of the institution, and its official website. The disaster event database consists of 11 metadata items, including the unique system identifier, data thumbnail, data name, data category, keyword, data description, location (the continent), date of occurrence, longitude and latitude (detailed location of the disaster), and data source. The database of the disaster open directory projects incorporates 15 metadata items, including the unique system identifier, Chinese name, English name,

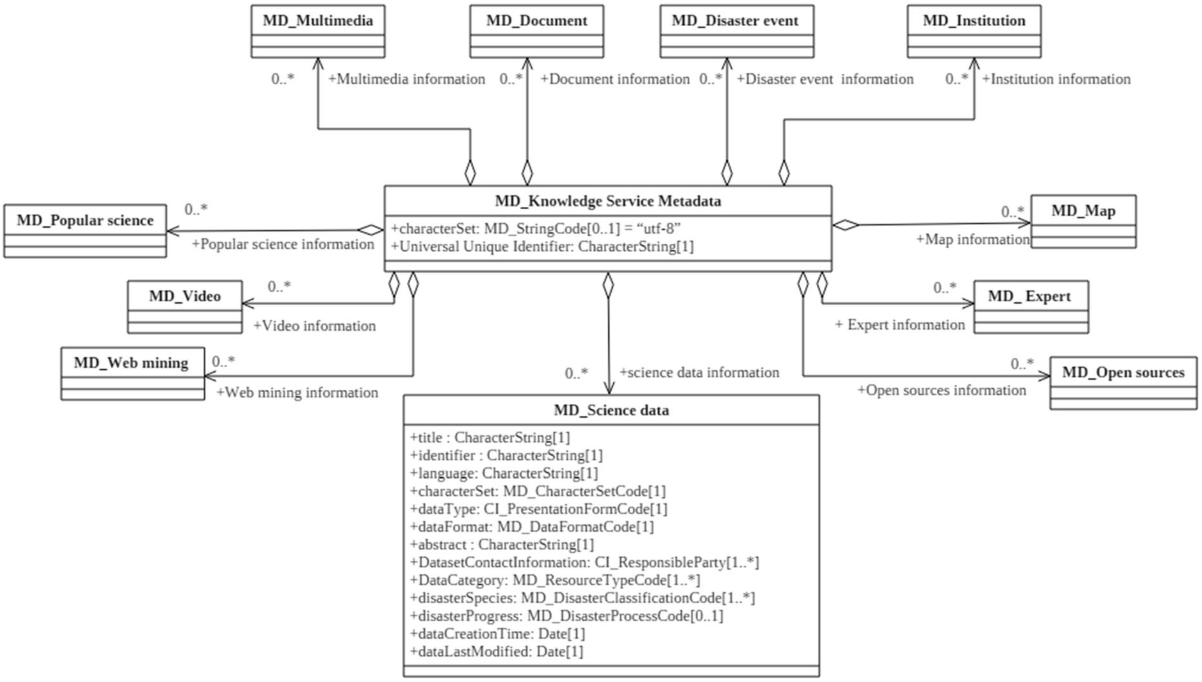


Figure 1
Disaster metadata association

uniform resource locator (URL), time of establishment, language, affiliated institution, introduction, contact, publisher, type of disaster, discipline, category (tutorial/academic/technical/popular science), attribute [nonprofit organization (NPO)/government/enterprise/individual], and address. The database of disaster-related information Web mining has eight metadata items, including the unique system identifier, the identifier of the disaster event, type of disaster event, time of occurrence, place of occurrence, disaster intensity, cause of disaster, and disaster-related loss. The disaster literature database involves nine metadata items, which are the unique system identifier, serial number, category, title, journal name, year, author, abstract, and keyword. The disaster video database consists of eight metadata items, including the unique system identifier, video number, title, release time, publishing unit/author, main content, URL, and measures for disaster prevention and relief. The above metadata items can be associated with the disaster core metadata through the unique system identifier.

2.2. *Research and Development of the Disaster-Related Thematic Knowledge Service System*

Disaster prevention and mitigation involves a great variety of disciplines and departments. With priority given to the use of open international technical standards and open-source Web technologies, the disaster risk reduction knowledge service system adopts the technical architecture of an information service platform with on-demand scalability and a modular mechanism. The iterative development model is adopted, so the system can be put into use in the system's development life cycle. Through this system, users can gain quick access to various disaster-related knowledge resources and subject-specific knowledge services, including data, maps, literature, and videos.

The general technical development framework of the DRR knowledge service system is illustrated in Fig. 2. The data storage scheme at the bottom layer adopts the Alibaba Cloud computing model to construct the file server, meta-database server, data server, map server, and web server, which are used to analyze the front-end user access. Supported by a series of open Web technologies, a variety of editing, operation, and maintenance functions are realized, including data entry, information publishing, permission management, etc. Functions such as cartographic visualization, full-text literature retrieval, analysis of user behavior, and tag filtering for multiple disaster subjects can also be performed. This supports knowledge application functions related to the distribution of disaster organizations and institutions, disaster map browsing, and subject application for disaster prevention and mitigation. On the user-friendly and interactive front-end Web interface, a series of operations are performed, including access to, retrieval of, and visual analytics of disaster-related knowledge and information.

The DRR knowledge service system is developed based on the browser/server structure and the application framework of Python + Tornado + TorCMS. For front-end development, HTML5 and CSS3 technologies are utilized, combined with the jQuery and Bootstrap 3 framework. The backstage programming language is Python 3.4 or above. The PostgreSQL database is used to store the data. The core attributes are mapped into the database field, and the extended attributes are stored in the JSONB fields of PostgreSQL. The back-end of WebGIS, which is applied to the visualization of disaster maps and spatial data, uses the MapServer. In the front-end, the Leaflet and OpenLayers 3 JavaScript database are adopted. The software pycsw is applied for metadata management. This is an Open Geospatial Catalogue Service for the Web (OGC CSW) server implementation written in Python. This CSW standard defines a set of unified interfaces for the retrieval, query, and browsing of spatial information and related data.

3. *Realization of Thematic Knowledge Applications*

3.1. *Framework for Knowledge Service Applications*

The use of thematic knowledge services is an important approach for the organization of services in the DRR knowledge service platform. Based on the needs of its target users and featured resources, a knowledge service system constructs specialized service products by means of online and offline

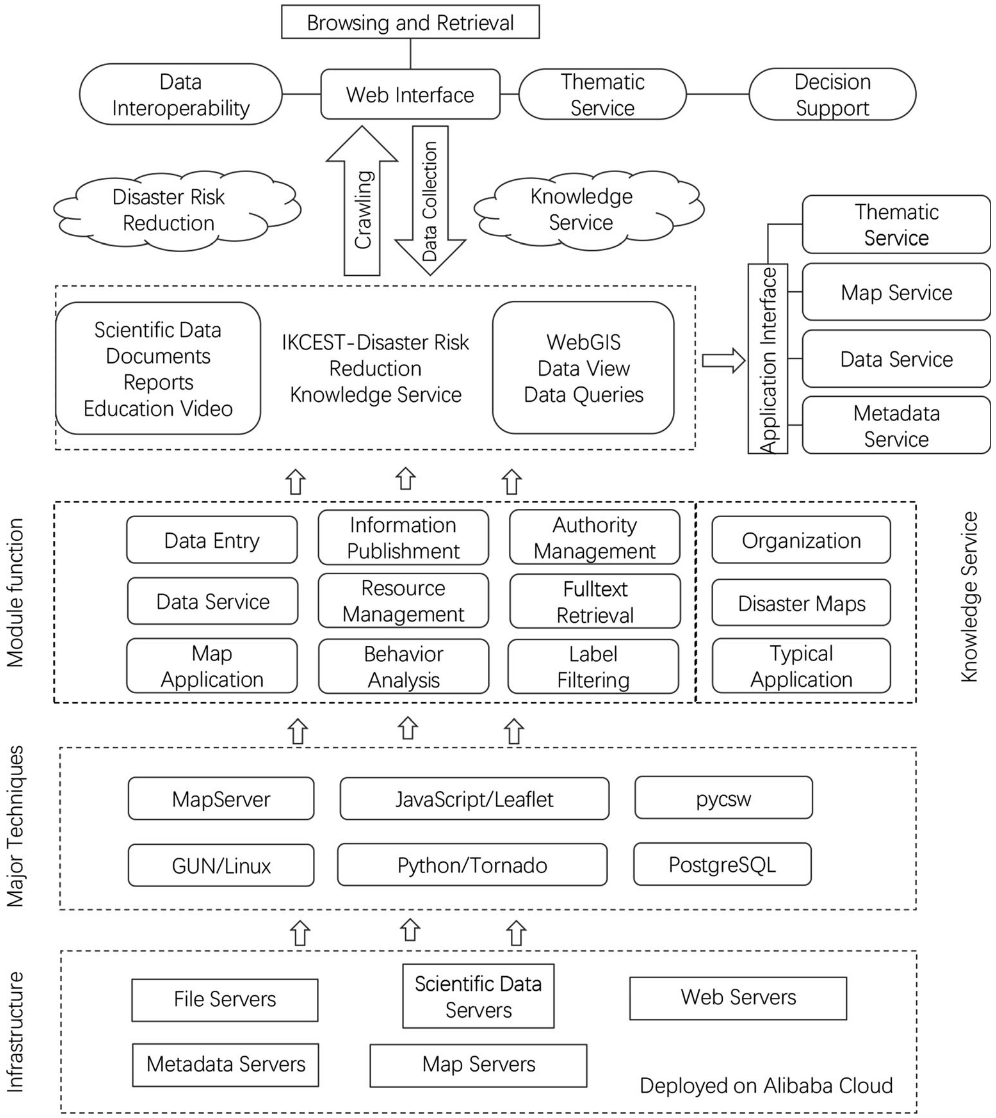


Figure 2
Development framework of disaster risk reduction knowledge service

models, to provide valuable DRR knowledge services to users around the globe. DRR provides knowledge services regarding the platform, technology, data, education, and other aspects of current global disaster prevention and mitigation. As shown in Fig. 3, the modes of service include the query, browsing, downloading, analysis, and visualization of various types of disaster-related knowledge and resources. The service contents cover eight aspects in three main categories: resource content (including data services, map services, institution services, expert database services, and disaster event services), resource dissemination (including video courseware training services and science popularization services), and resource and knowledge applications (e.g., global earthquake daily distribution map service, China and international experience in natural disaster relief, map visualization services of China historical disasters, etc.).

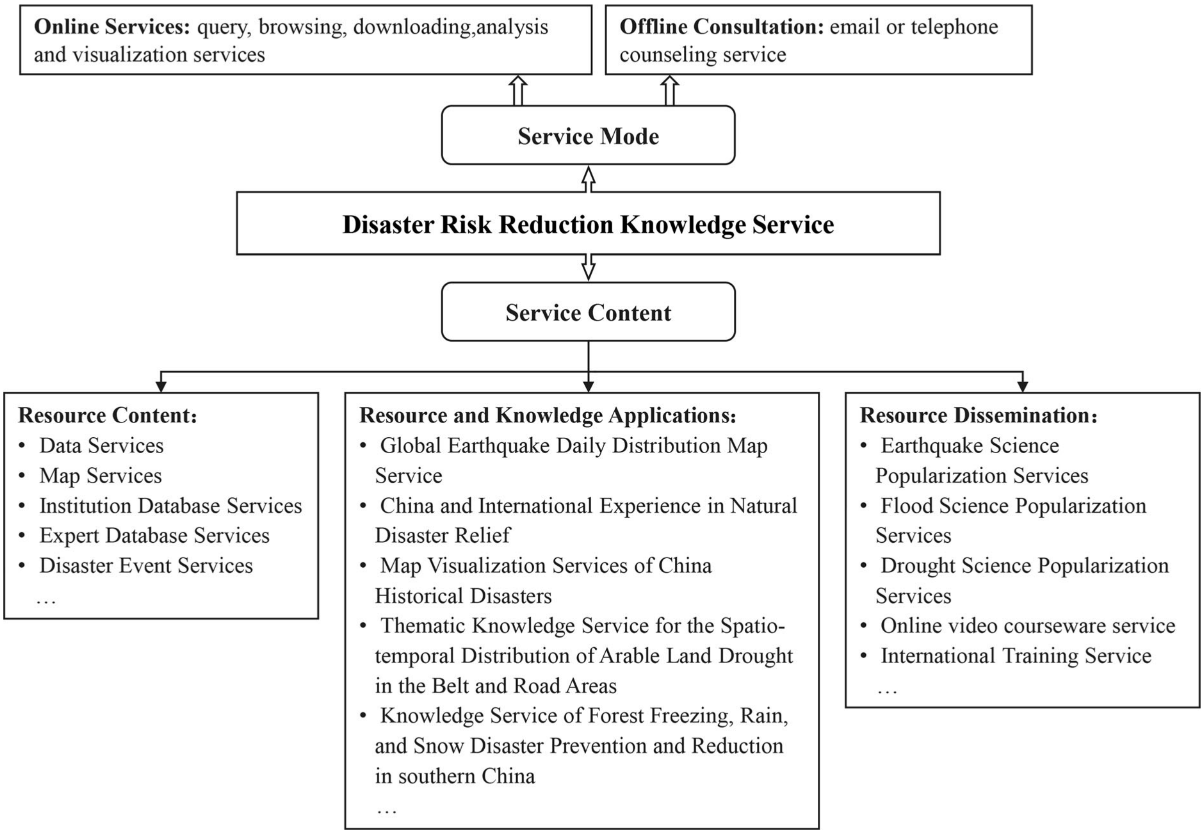


Figure 3
Knowledge service architecture of disaster risk reduction platform

3.2. Examples of the Application of Thematic Earthquake DRR Knowledge Services

Knowledge application services, as the integration of external knowledge services for disaster prevention and mitigation, leverage bottom-layer resources including various data, maps, institutions, experts, videos, and courseware. They are guided by specific application needs. The front-end user interaction and display on the platform are supported by the integrated processing of data and visualization technologies. Five representative cases of the earthquake knowledge application services mentioned are highlighted below.

1. Global earthquake daily distribution map service

The visualization of global earthquake distribution is a real-time daily update of professional earthquake information, such as the geographical distribution, magnitude, and focal depth of earthquakes occurring around the globe. The global daily earthquake data are acquired through the application programming interface (API) provided by the USGS, after which the data are combined with the API of open map services through LeafletJS to generate a map view. Users can view the distribution of all current seismic events through the map view (http://drr.ikcest.org/app/s9834). When users click any coordinate point (map view), the corresponding earthquake information, including the magnitude and location of the earthquake, is shown. Between 1 April 2017 and 23 August 2018, the global earthquake visualization service operated for 509 days and recorded 165,491 seismic incidents around the world—an average of 325.13 incidents per day. Figure 4 shows the front page of the DRR knowledge service system (http://drr.ikcest.org), and the map in the middle-left part of the page shows the global

August 21, 2018 Earthquake Information of 20km NNW o...
August 20, 2018 Earthquake Information of 178km WSW...
August 19, 2018 Earthquake Information of 280km NNE...
August 18, 2018 Earthquake Information of 257km SE of...
August 17, 2018 Earthquake Information of 109km NNW...
August 16, 2018 Earthquake Information of 250km SE of...
August 15, 2018 Earthquake Information of 7km SSE of J...

Knowledge Map Service of Major Organization for Disaster Risk Reduction
Global Earthquake Daily Distribution Map Service
Map Visualization Services of China Historical Disasters
China and International Experience in Natural Disaster Relief
Knowledge service of forest freezing, rain and snow disaster prevention and reduction in southern China
Application of Flood Control Knowledge Service in Songliao Basin
Knowledge Service of the Spatio-temporal Distribution of Arable Land Drought in the Belt and Road Areas
Poyang Lake suspended matter concentration retrieval Season-by-quarter spatial distribution data

Figure 4
Spatiotemporal distribution of seismic events in the interface of the DRR knowledge service system

distribution of seismic incidents that occurred on the 24 August 2018.

2. A spatiotemporal map of historical earthquake disasters in the One Belt One Road region

Earthquake monitoring records of the One Belt One Road (B&R) region from 2000 to 2015 were selected from the USGS's historical earthquake database. The monthly spatiotemporal distribution of earthquake disasters in countries along the B&R region (as shown in Fig. 5) was generated, followed by the reclassification of these data according to earthquake magnitude and distance. It is evident that earthquakes occur most frequently in Southeast Asian regions such as Indonesia, the Philippines, and Taiwan of China, and the magnitudes of these earthquakes are relatively high, with > 7.0 magnitudes in most cases. China and West Asia were second in this respect; earthquakes in these regions range between magnitude 4.0 and 5.0 and are thus relatively weak in comparison. Earthquakes occurred least frequently in Eastern Europe and Western and Central Russia, and the earthquakes that do occur in these regions are typically quite low in intensity. A brief analysis of these results reveals that a total of 371 earthquakes occurred in countries along the B&R region from 2000 to 2015. The greatest number of earthquakes (35) occurred in 2013, while 2001 had the fewest number of earthquakes (15). The most powerful earthquake had a magnitude of 9.1, while the weakest had a magnitude of 2.7. The vast majority of earthquakes in the B&R region range between magnitude 6.0 and 7.0; 264 earthquakes had magnitudes in this range, and they account for 71.16% of all earthquakes in this region.

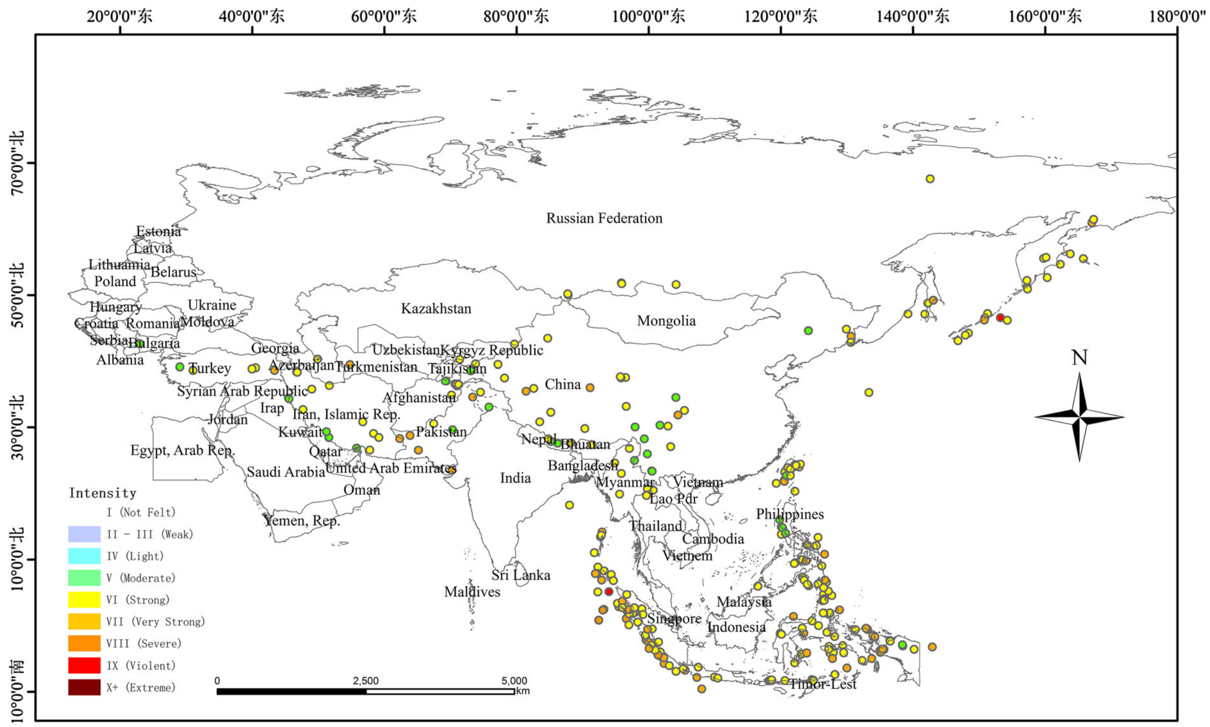


Figure 5
Distribution of earthquakes in the B&R region from 2000 to 2015

3. Wenchuan earthquake disaster relief knowledge service

The Wenchuan earthquake occurred at 14:28:04 Beijing Time on 12 May 2008. According to CEA data, the strength of the Great Wenchuan Earthquake was 8.0 Ms on the Richter magnitude scale, 8.3 MW on the moment magnitude scale, and 11 on the Mercalli intensity scale. The area severely damaged by the Wenchuan earthquake exceeded 100,000 km^2; in particular, 10, 41, and 186 counties suffered extremely severe, severe, and medium levels of damage, respectively. As of 24:00 on 18 September 2008, the Wenchuan earthquake resulted in 69,227 casualties, 374,643 injured persons, and 17,923 missing persons. It is the most destructive earthquake that has occurred in the People's Republic of China since its inception and the deadliest earthquake since the Great Tangshan Earthquake. To organize the experience gained from disaster relief operations relating to the Wenchuan earthquake, we performed the collection and organization of data considering predisaster preparations, disaster relief operations, and postdisaster reconstruction work. The collected data included scientific data, maps, research literature, photographs, videos, postdisaster construction plans, analytical figures and tables, thematic maps derived from the disaster loss data, postdisaster psychological intervention plans, and popular science information. The application interface is shown in Fig. 6. When a user clicks on the location of a disaster, the corresponding title of the event appears. The page linked to the title then shows the area affected by the disaster via satellite maps, the severity of the disaster, the location of the epicenter, photographs and videos taken before, during, and after the disaster, bearing capacity assessment models, postdisaster reconstruction policies, guideline reports and standards, analytical figures, tables and thematic maps of the disaster loss data, and associated popular science publications and information.

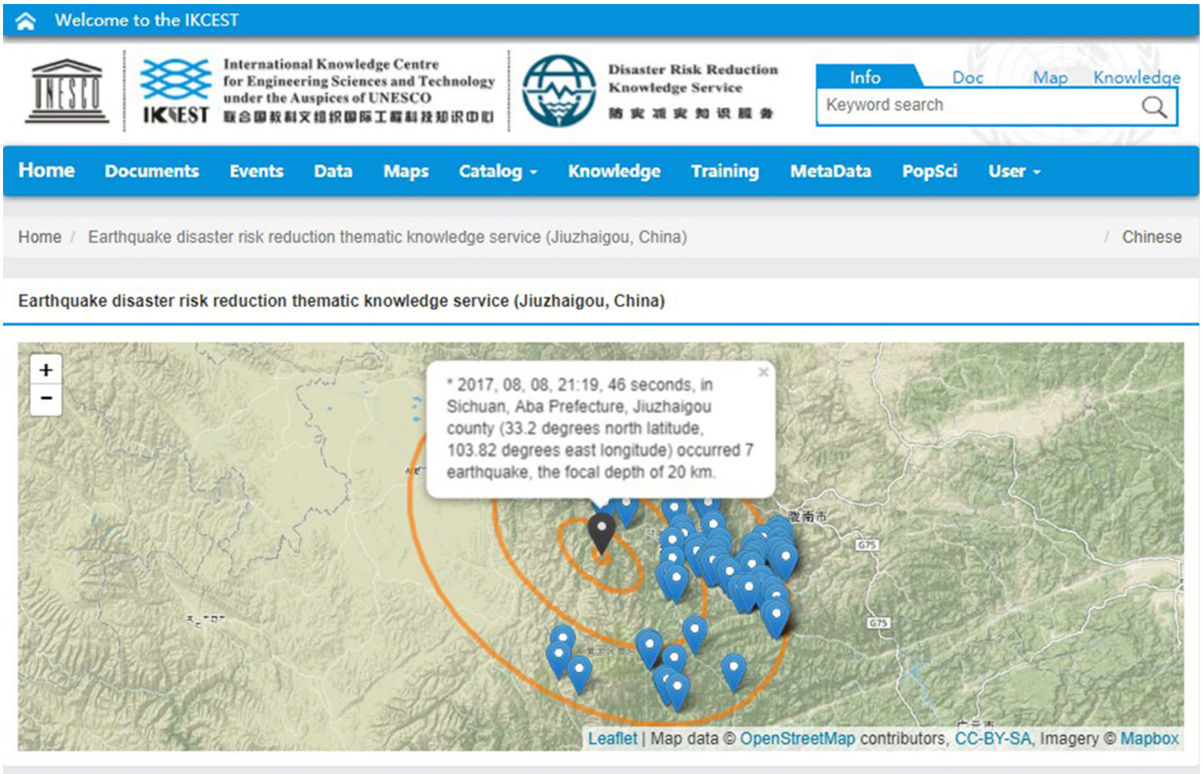
Figure 6
The Web page of the Wenchuan earthquake disaster relief knowledge service

4. Thematic knowledge service for disaster relief work and contingency planning during the Jiuzhaigou earthquake

A magnitude 7.0 earthquake occurred in Jiuzhaigou on 8 August 2017. Based on the aforementioned knowledge service platform, our research team quickly constructed a thematic knowledge service for disaster relief operations (as shown in Fig. 7). The loading and publication of data were completed in a timely manner, and the data were continuously updated for 2 weeks. In this way, our thematic knowledge service served as a timely source of predisaster information, disaster relief information, and postdisaster reconstruction information for governmental institutions and technical staff. Specifically, the following service columns are established: scientific data services (remote imaging data, basic geographic data, ecoenvironmental data, geological disaster data, earthquake disaster data, demographic and socioeconomic data, comprehensive data, and others), disaster relief information services (real-time earthquake reports, including magnitude announcements and aftershock warnings, current damage reports, disaster-relief progress reports, post-disaster reconstruction reports, relocation, recovery, and analysis reports of the causes of earthquake), and knowledge services for science popularization (earthquake precursors, self-rescue during earthquakes, protection against aftershocks, protection against secondary disasters, and psychological counselling). As of 21 August 2017, each user generated an average of 82 page views per session. The service had 155 page views and 173 page events in total. Based on this disaster relief experience, the disaster risk reduction knowledge service system formulated the contingency plan of knowledge services (CKS) for disaster risk reduction, laying the foundation of the technologies, standards, and institutions for emergency response and disaster relief for major disasters in the future.

4. *Discussion*

A prototype DRR knowledge service based on the aforementioned design and implementation has



* 2017, 08, 08, 21:19, 46 seconds, in Sichuan, Aba Prefecture, Jiuzhaigou county (33.2 degrees north latitude, 103.82 degrees east longitude) occurred 7 earthquake, the focal depth of 20 km.

Figure 7
Interface of the Jiuzhaigou earthquake disaster relief service

already been deployed online (http://drr.ikcest.org). This system will provide a variety of internationally oriented knowledge services, including a DRR metadata catalogue, scientific data resources about disasters, knowledge service applications, disaster maps, educational videos and programmes, and popular science information. By the end of June 2018, the baseline data (i.e., resource-related data, environmental data, and data on national conditions) of 45 countries in the B&R region were successfully uploaded to the DRR knowledge service, along with 50 thematic databases about droughts, earthquakes, floods, and blizzards in this region. Eight online knowledge applications (e.g., the global earthquake map) were also established. The DRR knowledge service has received 12,000 views every month since it launched online, with 25% of its visitors being foreign users. Below, we discuss a few pertinent points about the conversion of disaster knowledge into knowledge services.

The rapid and accurate determination of earthquake losses is a practical need. One of the targets of Goal 11 in the 2030 Agenda for Sustainable Development is, “By 2030, significantly reduce the number of deaths and the number of people affected, and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor, and people in vulnerable situations” (United Nations 2015a, b). The first three of the seven global targets in the Sendai framework are as follows: (a) substantially reduce global disaster mortality by 2030, aiming to lower the average per 100,000 global mortality rate in the decade 2020–2030 compared with the period 2005–2015, (b) substantially reduce the number of affected people globally by 2030, aiming to lower the average global figure per 100,000 in the decade 2020–2030 compared with the period 2005–2015, and (c) reduce direct economic losses caused by disasters in relation to global gross domestic product (GDP) by 2030 (United Nations 2015a, b). The resolution of these problems will require rapid and accurate reporting of casualties, injuries, and economic losses caused by earthquake disasters using a variety of techniques, and it is impossible to obtain these data via monitoring-based methods. New techniques such as big data mining are therefore necessary to acquire this information.

The continuous accumulation and sharing of knowledge resources (e.g., earthquake relief experiences) will contribute to the global DRR. In China and other countries around the world, DRR experiences are generally obtained through the occurrence of major disasters. It is therefore important to share these experiences; For example, the postdisaster reconstruction plans and policies established by China after the Wenchuan earthquake are an excellent reference. In this case, scientists used scientific data to obtain the carrying capacity of the region affected by the Wenchuan earthquake, in terms of its water resources, soil resources, and ecological environment. This information was then used to guide reconstruction plans (Fan 2009). It has been proved that this approach provided a form of scientific assurance for the development of regions affected by the Wenchuan earthquake. The data, models, methods, techniques, and software tools used in these plans may be shared and promoted on knowledge service systems and platforms.

Knowledge service systems could be used to rapidly organize and share emergency relief data during earthquakes. During the rescue operations of the Jiuzhaigou earthquake, a contingency plan was drafted to provide data support during serious earthquakes. This contingency plan was manually formulated as it was not yet possible to autonomously produce a contingency plan using computers and information systems. To this end, earthquake data organization models and data integration techniques that are suitable for disaster relief operations can be constructed. Whenever an earthquake occurs in a region, the knowledge service system can quickly organize and extract data about the terrain, landforms, mountains, rivers, transportation networks, bridges, population, economy, climate, and environment of the region, based on its location, geographical background, historical data, and cultural background. These data would then serve as fundamental data support for emergency earthquake relief work.

The processing of earthquake disaster data requires the support of new technical measures. Big data techniques are especially relevant in this regard. WebGIS techniques are already being used in this study to display spatiotemporal earthquake information. Nonetheless, a greater variety of techniques should be used. For instance, kernel density analysis could be used in the spatiotemporal analysis of earthquake disasters to reveal the spatiotemporal aggregation of earthquakes, while time series analysis could be used to reveal the long-term evolution of earthquakes in different regions. Text recognition techniques could be used to mine and utilize historical earthquake information to obtain earthquake information over longer time sequences and greater periods of time. In addition, since the occurrence of earthquakes is strongly correlated with resource and environmental factors, it may be possible to identify these correlations using big data techniques. These correlations may then be used to investigate intrinsic relationships between natural disasters and geographic environments and the rules that govern the occurrence of natural disasters.

Location-based earthquake information services is one of the important potential directions for knowledge services. The earthquake information system established in this work is based on current and historical information. However, people often travel to unfamiliar regions in their real life or business activities, and they should be informed about the potential risk of earthquakes or other geological disasters in these regions. To address this issue, a knowledge service system should possess a comprehensive collection of historical earthquake information and the ability to provide information about future risks. The knowledge service system should inform the user about past earthquakes and the risk of earthquakes in the user's location and warn the user if an earthquake is currently taking place, using the geographical location of the user. The development of location-based geological disaster information systems is therefore an important application of big data-based DRR knowledge service systems.

5. *Conclusions*

The lessons gathered from the Wenchuan earthquake that took place 10 years ago are painful but very valuable. The focus of earthquake disaster mitigation work has shifted from disaster data to the provision of knowledge services. Under the DRR directives of UNESCO, we have constructed a DRR knowledge service system for the sharing of disaster information and the provision of thematic knowledge services, based on the formulation of disaster metadata standards. This system has successfully actualized the integration and sharing of knowledge resources such as disaster data, disaster maps, expert opinions, institutional data, research literature, and educational materials. A series of earthquake DRR applications have been realized using this service system, including: a global earthquake daily distribution map service, a spatiotemporal map of historical earthquake disasters in the B&R region, the Wenchuan earthquake disaster relief knowledge service, and a service for disaster relief work and contingency planning during the Jiuzhaigou earthquake.

In the long term, this knowledge service system is expected to contribute to the realization of global SDGs and the targets of the Sendai framework by providing DRR knowledge services to international organizations, governmental institutions, research and educational institutions, the business world, and the general public. In the short term, this knowledge service system will focus on the acquisition of earthquake loss data, the application of disaster-oriented big data techniques in the analysis of earthquake information, improving the analysis of relationships between earthquake data and geographic environments, and the development of location-based knowledge services to provide end-user information about historical earthquakes, current earthquake warnings, and the risk of earthquakes in the future.

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