Integrated Geospatial Information Service for Disaster Management in China's Wenchuan Earthquake

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Abstract

An integrated geospatial information system was established immediately after Wenchuan Earthquake, which struck on 12 May 2008, in order to support disaster relief, damage assessment, and post-earthquake restoration and reconstruction. Built upon China's national Spatial Data Infrastructure (SDI), the geospatial information system comprised three essential components: geospatial data acquisition and updating, cartographic support, and ad-hoc spatial decision support systems (SDSSs). Administrative boundary maps, topographic data, and orthophotos were provided to rescue operators and disaster staff immediately after the earthquake. Updated data were provided by acquiring large-scale new images and creating image maps covering the affected area. Numerous thematic maps were produced to accommodate the requirements of government officials, relief staff, disaster researchers, and local municipalities. Three ad hoc spatial decision support systems were designed and

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developed to facilitate rescue operations, damage assessment, and reconstruction planning. The availability of this geospatial information service has substantially improved the efficiency of operational disaster management in Wenchuan Earthquake. This study demonstrates the usefulness of a national SDI for disaster management.

Key words: Spatial Data Infrastructure, Image Map, On-demand Thematic Mapping, Spatial Decision Support System

1. Introduction

A strong earthquake with the magnitude of Ms8.0 struck on 12 May 2008, with the epicenter near Yingxiu, Wenchuan County, Sichuan Province, China (hereafter referring as Wenchuan Earthquake). The major affected area by this earthquake was located between the Qinghai-Tibet Plateau and Sichuan Basin with rolling relief and complicated alpine valleys. It is in a transitional area between wettish subtropical monsoon climate and semi-arid warm temperate continental monsoon climate, and thus heavy rainfall and storms occur frequently. Stratigraphically, the affected area mainly comprises loose phyllite and gneiss, thus favoring the development of earthquakes and related secondary disasters. The tremendous energy released from the earthquake has resulted in the collapse of numerous buildings and the death of nearly 80,000 people throughout China's provinces of Sichuan, Gansu and Shaanxi. Moreover, the earthquake and its aftershocks have triggered numerous secondary disasters, such as landslides, mudflows, and quake lakes (Wang et al. 2009).

Immediately after the earthquake, a geospatial information service was launched in order to support citizens, troops, and government departments at different levels, as well as oversea volunteers for disaster relief (Chen et al. 2009a, Li 2009, Zhang et al. 2009). This integrated geospatial information service was built upon China's national Spatial Data Infrastructures (SDIs). It comprised three essential components: geospatial data acquisition and updating, cartographic support, and ad-hoc spatial decision support systems (SDSSs). With this geospatial information service, better situation awareness, adequate crisis response, and optimal spatial decision-making were achieved during the phases of disaster relief, damage assessment, and post-disaster reconstruction. The efficiency of operational disaster management in the Wenchuan Earthquake has been significantly improved. This is an excellent example of the successful application of Spatial Data Infrastructures (SDIs) enabled geo-spatial information for disaster management. The methodology developed here can be used for the management of other types of disasters.

This paper is organized into several sections. Section 2 introduces the overall methodology for SDI-enabled geospatial information service development. Section 3 explains the data services emphasizing rapid generation of image maps. Section 4 discusses the on-demand thematic mapping. Section 5 examines the development and utilization of an ad-hoc SDSSs through three different stages for disaster management. Some future research needs are discussed in section 6.

2. SDI-enabled geospatial information service

A SDI refers as an integrated geospatial information framework consisting of geospatial data sets, access network, technology, standards, policies, institutions, and human resources. Since the last twenty years, the SDI development has became a top priority for governments at different levels in the world (Masser 2005, Hjelmager et al. 2008). The Australian SDI, Canadian Geo-spatial data infrastructure, China's SDI, and US national SDI are among the examples of national SDIs. The Infrastructure for Spatial Information in the European Community (INSPIRE), the United Nation SDI, and the Global Mapping project are examples of regional and global SDI initiatives (Armenakis 2008, Boccardo et al. 2008).

Substantial human and financial resources have been invested in China during the past twenty years to establish geospatial databases, to set up institutional frameworks, to formulate SDI-related policies, to develop technical systems and standards, as well as to develop network-based geo-information services (Chen and Chen 2002).
Geo-spatial databases for operational uses normally include vector-based topographic data at different scales, multi-resolution orthophotos and digital elevation models, as well as multi-level administrative boundary data and geographic names. The capability of geo-spatial data acquisition, processing, management and dissemination has also been enhanced due to the introduction of advanced techniques, such as digital airborne sensors, digital photogrammetric grid, unmanned aerial vehicles, among

others (Zhang et al. 2009, Li et al. 2008). Nowadays SDIs have become an underpinning component of national development strategy in many countries and serve as an enabling platform for promoting geospatial data sharing and for supporting the vast majority of the society (Masser et al. 2008).

The utilization of SDIs for disaster management and emergency response has been reported (Zlatanova et al. 2007). The International Charter on 'Space and Major Disasters' is an international operational network of collaborative remote sensed data acquisition and has provided successful emergency service to many disaster events. The Global Monitoring for Environment and Security (GMES) initiative is another European initiative for promoting integrated access to space-based data assets and *in situ* data networks. The United Nations has decided to establish the United Nations Platform for Space-based Information for Disaster Management and Emergency Response (UN-SPIDER) as a new program 'to ensure that all countries have the access to use all types of space-based information to support the full disaster management cycle (Boccardo and Tonolo 2008). A number of successful applications of geo-spatial information in disaster management have been implemented, such as the relief support of the Tsunami in December 2004. Technical progresses in this area include the integration of remote sensing into the operational workflow of rapid emergency response, three dimensional data modeling and visualization for emergency response, change detection in large-size multi-temporal images, web-based disaster information dissemination, and sensor networks, communication and navigation solutions for first responders, early warning systems (ORCHESTRA 2005, Bovolo and Bruzzone 2007, Zlatanova 2008, Brunner et al. 2009).

As one of the most destructive earthquakes since the founding of the People's Republic of China in 1949, Wenchuan Earthquake had seriously destroyed the transportation and communication systems, especially in surrounding mountainous areas. It was very difficult to deliver disaster relief teams and facilities to some worst affected areas. Reliable and updated geospatial information was therefore critical for understanding the scope and severity of this large-scale catastrophic event and for making timely spatial decisions during the cycle of disaster management. An integrated geospatial information service was then designed and implemented by China's National Geomatics Center on the basis of the national SDIs and in collaboration with some other relevant government agencies and organizations. Figure 1 illustrates the overall framework of this integrated geospatial information service with data service, cartographic support and ad hoc Spatial decision Support System (SDSS) as the three major components.

Insert Figure 1 about here

Data services were organized immediately after the earthquake by assembling all the achieved administrative maps, topographic data and orthophotos and acquiring new images covering the earthquake stricken area. Updated information was provided after conducting some necessary data pre-processing, such as geometric rectification and semantic integration of data from different sources. Image maps at scales 1:25,000 and 1:5,000 were further produced to accommodate non-expert users.

Cartographic maps are useful for visualizing earthquake disaster development, intermediate and final damage evaluation results, emergency response, and the reconstruction plan. Four levels of cartographic units were defined by the geographic characteristics in quake-affected areas. Hundreds of thematic maps were designed and produced at the request of decision makers, rescue operators, disaster researchers, as well as local municipalities.

An ad-hoc SDSS was developed to help understand the geographic environment in the earthquake-stricken area, to facilitate disaster assessment, and to assist formulate reconstruction plan. All available geospatial data were integrated, and specialized functionalities were developed by combining geographic processing and domain-specific knowledge.

3. Image map production

Wenchuan Earthquake affected an area of approximately 500,000 km^2, which covers 417 counties in 10 provinces including Sichuan, Shaanxi and Gansu. All archived geo-spatial data covering this affected area were assembled and made available to rescue operators and decision makers immediately after the earthquake. They include vector-format topographic data at scales ranging from 1:50,000 to 1:250,000, digital orthophotos with resolutions from 2.5 to 10 meters, and country-level administrative maps with scale varying from 1:20,000 to 1:80,000. Airborne sensors were used to acquire new high-resolution imagery covering the affected area, which were made possible through a collaborative effort with organizations such as the International Charter on Space and Major Disasters. Despite the poor weather conditions in the quake-stricken areas, large amounts of high-resolution image data were successfully acquired and provided to different users after an initial geometric rectification and radiometric processing using digital photogrammetric and image processing techniques. Large-scale landslides, quake lakes, damaged bridge, and disturbed vegetation were easily observed and studied from these newly acquired images.

High-resolution images provide intuitive information to disaster relief staff. On the other hand, they also are like vector-format topographic maps providing location information, such as place names, road networks, among others. For facilitating the use of geospatial information by non-experts, image maps covering the earthquake-stricken area were designed and produced by combining high-resolution images with selected location information derived from topographic data. Figure 2 illustrates the methodology for image map production, which includes the processing of multi-resolution images and the generalization of selected topographic information.

Insert Figure 2 about here

The resolutions of the images used in this project range from 0.1, 0.2, 0.5, 0.6, 2.5 and 10 m, and some data preprocessing procedures, such as geometric rectification, color transformation, image mosaic and dodging were carried out. For some areas where good quality of newly acquired images were not available, archived images were then used through data fusion. Geographic names, roads and administrative boundaries were the three types of vector data that were overlaid with images. Vector features were initially selected by analyzing the relationship between image resolution and the visibility of vector features when overlaying with the image. Selective omission of roads and geographic names was then implemented by using hierarchy, Voronoi diagram, image texture and mesh density as the factors. Symbolization and conflict processing were conducted to assure the consistency of image data with symbolized vector data in the production of the image map.

Three categories of image maps were produced for the earthquake-stricken areas to accommodate users' needs. The first category was prepared for each county that was affected during the earthquake, with scales ranging from 1:40,000 to 1:100,000. The second category was prepared for covering several severely affected counties, with a scale of 1:25,000. About 2500 image map sheets were produced under the second category, covering approximately 270,000 km^2. The third category comprises 1813 image map sheets at 1:5,000, mainly covering the most seriously affected towns, and with a total ground coverage of 12,500 km^2. The production of these image maps was completed within two months after the earthquake.

4. On-demand thematic mapping

A number of agencies and organizations had been involved in the cycle of disaster management in Wenchuan Earthquake. Each agency or organization had different emphases according to their obligations , and produced their own outputs. Cartographic mapping was used as a primary mechanism to visualize the outputs, highlight the proposed solutions, and communicate with others (Armstrong et al. 2008). On-demand thematic mapping service was provided in collaboration with other agencies or organizations. Figure 3 illustrates the thematic maps depicting the scope and magnitude of Wenchuan Earthquake disaster. The seismic intensity ranging from Grade VI, VII, VIII, VIIII, X and XI was represented with isolines in different colors and in quasi-ellipses. Four different levels of quake-affected areas were displayed in various colors: the worst affected area (10 counties) in dark green, the most seriously affected area (41 counties) in green, the slightly seriously affected area (186 counties) in pea green, and the affected area (419 counties) in fawn. This map can help better understand the spatial scope and magnitude of the disaster.

Insert Figure 3 about here

Four levels of cartographic units were defined to characterize the Wenchuan Earthquake disaster, such as the affected area, the most serious affected area, the worst affected area, and the counties within the most seriously affected disaster area. The first-level unit covers 417 countries with approximately 500,000 km^2. The second-level unit comprises 41 countries with approximately 130,000 km^2. The third-level unit covers 10 countries with approximately 26,000km^2.

To accommodate different users, five groups of thematic maps had been produced for the affected area, including natural environment, affected area, socio-economic system, natural hazards, disaster assessment, and restoration and reconstruction. Maps about the natural environment mainly show the geographic boundary of the impacted areas by Wenchuan Earthquake as well as the basic information about natural environment, geological structure, and land cover, among others. The socio-economic system was mapped as “hazard-affected bodies” showing the information concerning population, administrative units, transportation, communication, irrigation, resource, economy, etc. The natural hazards maps illustrate the earthquake disaster and the related secondary disasters. The disaster assessment maps show the temporal and spatial distribution of casualties, loss of properties, and damage to the resource and environment for each county. The restoration and reconstruction maps provide the information concerning the reconstruction plan and the designated supporting forces. Advanced spatio-temporal representation techniques were used for the on-demand thematic mapping, such as three dimensional landscape models, specific symbols for the earthquake disaster.

It should be pointed out that effective information sharing among various agencies involved in the disaster management was critical for us to access reliable data sources for the on-demand thematic mapping. For example, large amounts of first-hand data were collected by the earthquake relief expert group affiliated with China’s National Disaster Reduction Committee and Ministry of Science and Technology; disaster assessment data were collected by Ministry of Civil Affairs; earthquake monitoring results were acquired by National Earthquake Administration; and the recovery and reconstruction plans were made by National Committees for Planning and

Development. A disaster atlas for Wenchuan Earthquake was compiled and published in early 2009, with the use of the on-demand thematic maps (Chen et al. 2009b). This atlas illustrates the comprehensive mechanisms controlling the Wenchuan Earthquake, the major derived disaster, the emergency response, and the reconstruction plan. It is considered as an essential reference for the studies of natural disasters, disaster recovery, and public awareness of natural disasters.

5. Development of an ad-hoc spatial decision support system

Decision making in a catastrophic event is a dynamic process in which spatial analysis of geographical environment and formulation of appropriate solutions are critical. More efforts should be devoted to reinforce the interaction of human expertise and computerized geographic information processing capabilities (Andrienko et al. 2007). We carefully examined the requirements of spatial decision support for three important user groups, i.e., China's National Expert Committee of Wenchuan Earthquake, the planner Group led by National Committees of Planning and Development, and the joint expert group affiliated with National Disaster Reduction Committee and Ministry of Science and Technology. Then, we designed and developed an ad-hoc spatial decision support system in order to assist these users for situation awareness, disaster assessment, and planning analysis in the cycle of disaster management. Figure 4 shows SDSS' major architecture. The SDSS comprised three components: integrated data sets, special functionalities, and user interfaces.

Insert Figure 4 about here

The ad- hoc SDSS was implemented in three stages. Firstly, the SDSS was developed to support the disaster relief. As the live lines were destroyed or interrupted by landslides or mudflows, it was very difficult for the disaster relief teams and facilities to access the worst affected areas. A variety of geo-spatial data of the quake-affected area were assembled into the system, and image pyramids were built and stored as individual files for accelerating data access and assure high quality visualization. With the functionalities of the system, users can easily examine in detail the real landscape after the quake, fly over terrain, annotate points of interests, hyperlink to additional geospatial data and compare sequential images. Such a system was installed on either client/server or browser/server environments according to the user's requirement.

Wenchuan Earthquake caused tremendous losses of lives, properties and extensive deconstruction in resources and the environment. Seriously damages found in infrastructures, residential properties, agriculture, industries, service sectors, government administrative facilities, social welfare and culture heritage. Figure 5 provides two examples of the damages identified from high-resolution images. The SDSS was then extended to integrate and manage the entire damage inventory and other related data, such as natural hazards (seismic data, landslides, debris flow, etc), natural environment (geology, soil, etc), and social and economic data. Special functionalities were developed to facilitate the multi-layer comparison and multi-factor analysis. This allowed us to better understand the spatial distribution of the disaster and the derived damages.

Insert Figure 5 about here

The SDSS was further extended to meet the requirements of post-quake restoration and reconstruction. The suitability evaluation results, zoning data and ecological evaluation data were integrated into the system. Planning alternatives for the 41 seriously affected counties and 10 mostly seriously affected counties were studied by using the image maps at 1:5000 to 1:25,000. The SDSS provided computerized assistance to the formulation and selection of appropriate planning alternatives. For example, selecting a new capital site for Beichuan County was conducted in a digital 3-D environment. The system was also used to demonstrate different planning alternatives and visualize their possible impacts.

6. Conclusions

Built upon China's national SDIs, an integrated geospatial information service was successful implemented for disaster management in Wenchuan Earthquake. It allowed better situation awareness, adequate crisis response, and optimal spatial decision-making in the different phases of disaster relief, damage assessment, and post-disaster reconstruction. The experiences discussed in this paper demonstrated the value of a national SDI for disaster management.

We also learned some lessons from this emergency information service. Firstly, it was very difficult to obtain high quality images due to the unfavorable weather condition. The ability of airborne and space-borne data acquisition should be improved.

Secondly, information systems of some agencies and organizations were separated and fast data sharing could not be guaranteed. An SOA (service-oriented architecture) and web-based information sharing platform needs to be extended to connect all related agencies and organizations for facilitating spatial data sharing and utilization during the cycle of disaster management.

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List of Figures

Figure 1 SDI enabled geospatial information service for disaster management in China's Wenchuan Earthquake

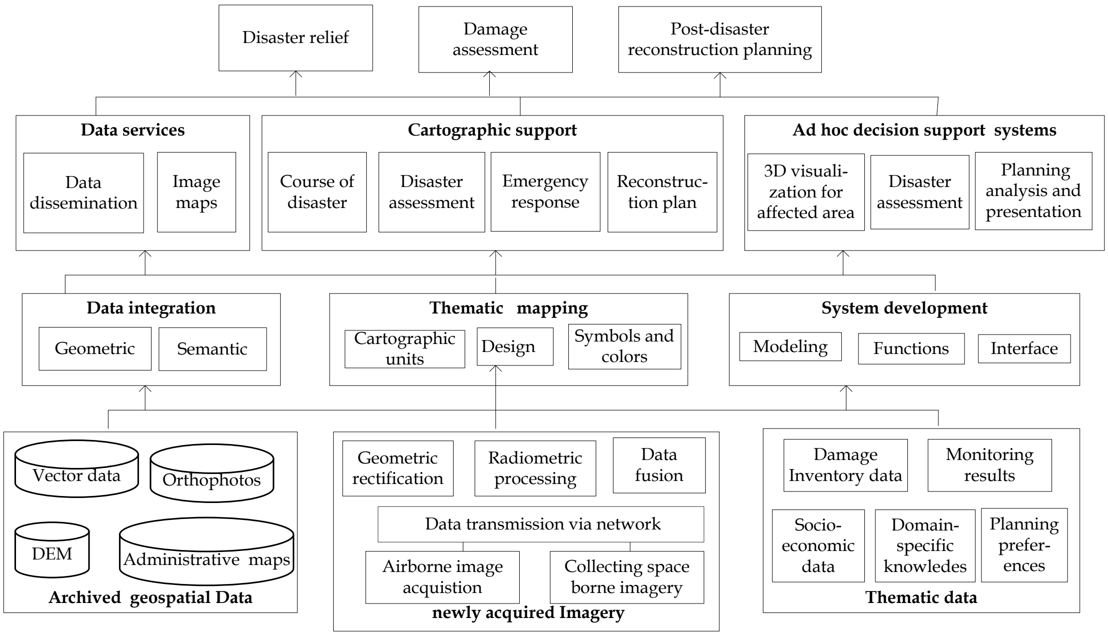

Figure 2 Technical framework for image map production

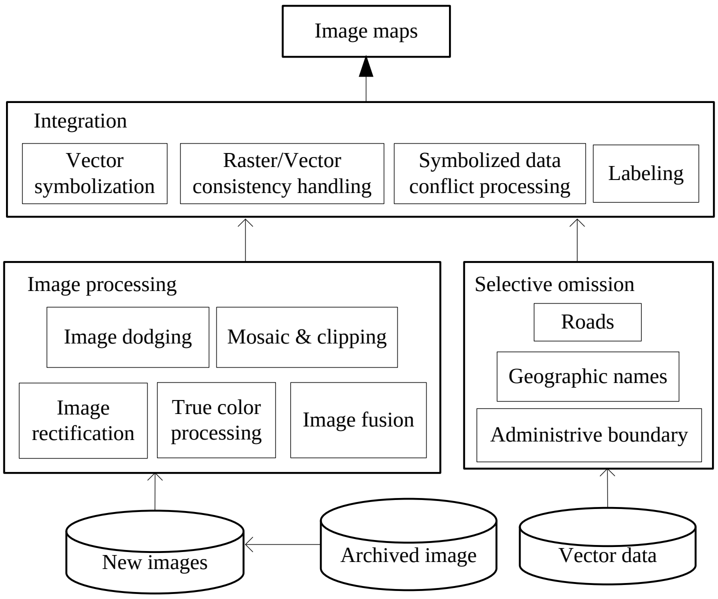

Figure 3 The scope and magnitude of the Wenchuan Earthquake disaster

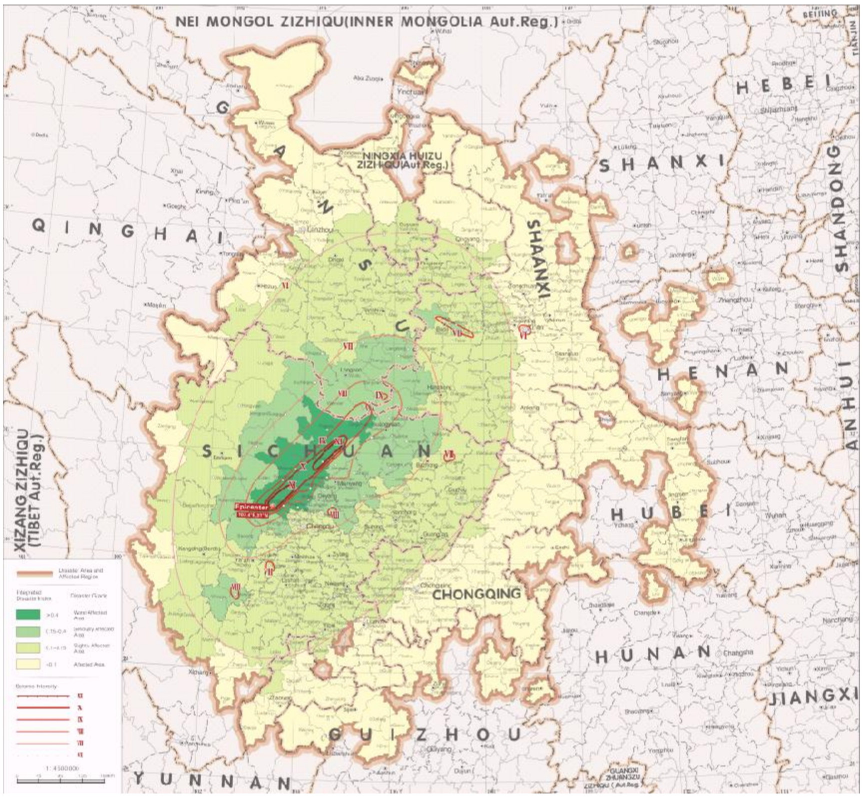

Figure 4 Framework of the ad-hoc spatial decision support system

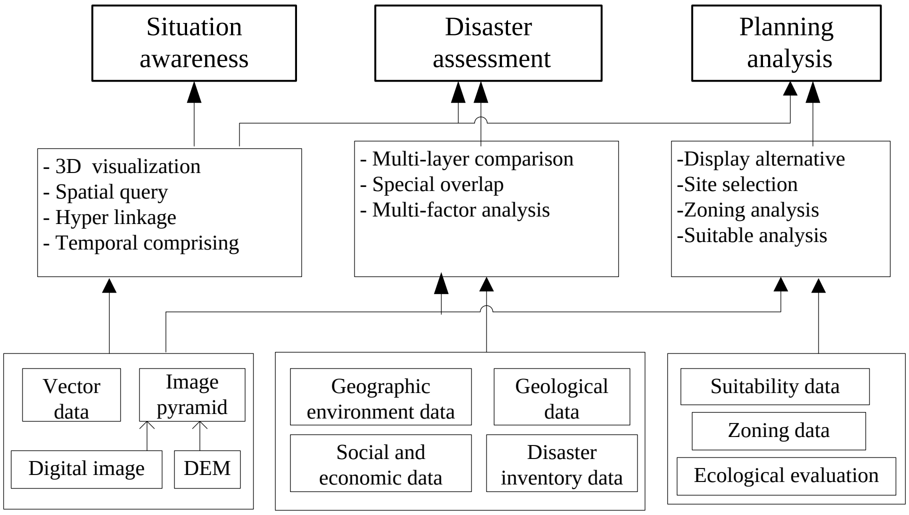

Figure 5 Examples of earthquake-derived damages delineated from high-resolution images

a. Damages near the Yingxiu town, Wenchuan County

b. Damage near the Qushan town, Beichuan County