Volunteered Geographic Information for Disaster Management with Application to Earthquake Disaster Databank & Sharing Platform

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Abstract. All phases of disaster management require up-to-date and accurate information. Different in-situ and remote sensor systems help to monitor dynamic properties such as air quality, water level or inundated areas. The rapid emergence of web-based services has facilitated the collection, dissemination, and cartographic representation of spatial information from the public, giving rise to the idea of using Volunteered Geographic Information (VGI) to aid disaster management. In this study, with a brief review on the concept and the development of disaster management, opportunities and challenges for applying VGI in disaster management were explored. The challenges, including Data availability, Data quality, Data management and Legal issues of using VGI for disaster management, were discussed in detail with particular emphasis on the actual needs of disaster management practice in China. Three different approaches to assure VGI data quality, namely the classification and authority design of volunteers, a government-led VGI data acquisition framework for disaster management and a quality assessment system for VGI, respectively, were presented and discussed. As a case study, a prototype of VGI oriented earthquake disaster databank & sharing platform, an open WebGIS system for volunteers and other interested individuals collaboratively create and manage the earthquake disaster related information, was proposed, to provide references for improving the level of earthquake emergency response and disaster mitigation in China.

1. Introduction

Disasters have long been presented as tragic disruption to the humans' lives, properties, infrastructure, economy, capital investment and development process. Disaster management is a continuous process that aims at avoiding or reducing the impact of disasters. All phases of disaster management require large volumes of accurate, relevant, on-time geo-information that systematically create and maintain by various organizations. Disaster contingency, however, have changed both in people's sense of connection to distant places and in their ability to contribute to relief efforts. Both changes are strongly relied on ITs, which support the collection, dissemination, and cartographic representation of

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spatial information from the public [1]. VGI, a special case of the larger Web phenomenon known as user-generated content, is the harnessing of tools to create, assemble, and disseminate geographic data provided voluntarily by individuals, has proven very successful as a means to acquire timely and detailed geographic information at very low cost. And there is nowadays a growing consensus in recognizing the role of VGI in disaster management practices [2].

The concept of VGI was first proposed by Goodchild [3]. It is the fusion of some enabling technologies, namely Web 2.0, geo-referencing, geo-tags, GPS, graphics and broadband communication, etc. Which enables a large number of non-professional users to create, store, update and manage geographic information through an online collaborative manner. In recent years, with the advantages of rapid renewal, low-cost data acquisition, easy operation and high quality of local contribution data, VGI has gradually become the third kind of geographic information acquiring method that helps fill deficiencies of the traditional mapping technology and remote sensing. Numerous studies stressed the added-value of using VGI in earthquakes [1], forest fires [4], hurricanes [5] and floods [6].

However, the research on the VGI in terms of depth and breadth now is still at the preliminary stage of exploration in China. It is very necessary to clarify the concepts of disaster management, the important position of VGI applications for disaster management and some of the outstanding problems and challenges of current researches and applications. In this study, VGI was mainly introduced to apply in the field of earthquake disaster management. The key technologies and methods of VGI data management, fusion, and distribution were elaborate, which was a useful attempt to improve the level of information in China's earthquake disaster management, and had the certain promotion and application value.

2. VGI for disaster management

2.1. Opportunities of using VGI for disaster management

For decades, different in-situ sensors have been used in monitoring of a variety of hazards parameters, such as rainfall, water level, shaking of ground, etc. Advances in information and communication technologies, make it possible for these sensors obtaining and expressing data in near real time. But most of these sensors are highly specialized and stationary, causing that they generally can only measure one or very few parameters and the pros and cons of their monitoring results have a strong dependence on their locations, which are the result of careful planning and optimisation, and do not have flexibility.

Remote sensing is another important data source of the earth observation. With the rapid development of satellite technologies, high-resolution data products and various types of active and passive remote sensing system are gradually popularization. Numerous examples have shown that remote sensing plays an increasingly important effects in all phases of disaster management, such as monitoring of the scope floods [7] and forest fire [8].

Despite recent advantages in both in-situ and remote sensing system, there are still some phenomena that cannot be sufficiently measured, and these in-situ sensors for example water pressure gauges may be destroyed due to very severe floods. For remote sensing, some optical images may not be available in severe weather conditions when sensors are often obstructed by clouds and smoke. The satellites may not pass over the affected area for several days and the ground conditions may prevent the rapid downloading of images due to Internet connections, or computer hardware and software. These gaps may be filled by VGI. As Goodchild [3] has proposed to consider "Citizens as Voluntary Sensors". They continuously observe the environment around them and obtain information. Compared with a variety of physical sensors, human beings can get more different parameters by their own senses [2]. Moreover, they can move freely, and familiar with the area. It is possible for them to interpret their surrounding circumstances accurately, and thus complementing the framework of geographic data, providing rich detail and updating in real time through multiple terminals, using voice, text, or pictures in order to have a better understanding of the complexities of disaster management characteristics.

2.2. Challenges of using VGI for disaster management
As such VGI offers substantial advantages of involving the public in gathering information relevant for disaster management, but there are also some challenges cannot be ignored, specifically in terms of data availability, data quality, data management and legal issues of using VGI for disaster management.

2.2.1. Data Availability. VGI data has a characteristic of unknown, that it is not clear beforehand about how much, which, and from where information will be supplied. Unlike a sensor network that can be planned in advance and using a structured approach to configure pathways of data acquisition. Therefore, unless its accuracy and reliability are assured, VGI should only be used as a supplement to the authoritative geographic data sources.

2.2.2. Data Quality. Data quality problem is one of the major obstacles for using VGI widely. Since VGI are usually provided by the public, most of whom are lacking professional knowledge and trainings. However, because lacking unified standards, that the information often has a certain degree of subjectivity, or even can be biases and extreme factors. As a result, the data may be biased, repeated or wrong. As a kind of geographical information, VGI has its unique nature, that is, each information has a designated location with one or several related attributes description. The location here can be expressed as different kinds of geometry objects, such as point, line, polygon, etc. which may exist distribute unevenly, difficult to query and update and other issues [9]. For disaster information, someone may exaggerate the facts for personal interests or make panics, while some valuable information may be deleted or polluted maliciously. Therefore, taking some measures to assess and improve the quality of data is one of the most important challenges of current VGI research and application.

2.2.3. Data Management. The role of VGI in disaster management can be summarized as the acquirement, processing, express and analysis of information. In the basic model of online VGI application for disaster management, high-resolution satellites images are adopted as base maps. Users interpret features to create vectors of geometric objects with related attributes description, and release them through multiple terminals to gradually accumulate and form an open sharing geographic information database. Metadata can control and tracking data effectively and has a major impact on data quality. While it is difficult for users to ensure the accuracy and completeness of metadata even in OpenStreetMap, Google Map Maker VGI project [10]. Therefore, how to build a comprehensive framework to take full use of VGI is essential.

2.2.4. Legal Issues. Successful operation of the VGI project involves complex activities among tripartite, namely web site operators, contributors and users, respectively. Issues such as intellectual property, personal privacy, legal responsibility, caused by them began to be emphasized. Summarizing problems in present studies on legal issues, including: (1) research visual angle is unitary, which is always only considered from the perspective of web site operators, but lacking omnidirectional considerations from the perspective of the government and ordinary citizens; (2) and since VGI applications are in their infancy, construction of relevant laws and regulations are still in the exploratory stage.

Therefore, although VGI for disaster management has huge potential and demand, there are still many theoretical and technical issues to be resolved, especially when working with data quality problems of VGI. It will be necessary to adopt some methods to control and improve data quality of

VGI to enable it to be an effective supplemental information into authoritative geographic information database.

3. Mechanisms for quality assurance and a case study

3.1. Mechanisms for quality assurance

3.1.1. Classification and authority design of volunteers. Usually the main functions of a complete VGI platform for disaster management, should include system management, feature updating, information inquiry, data updating, map services, metadata services, disaster information acquisition, management and sharing, etc. And rational classification of user community will exert an important and fundamental influence on VGI applications. In this paper, the users of VGI platform for disaster management are broadly classified as general public, organization, professional personnel, decision maker and system administrator, as shown in Table 1.

The general public, namely who are lacking the specialized knowledge of geographic information science, but interested in sharing disaster information spontaneously. The organization is a type of personnel with some specialized knowledge, and focuses on specific types of disasters, such as insurance institutes, charitable organizations and medical teams, which can take charge, follow-up and feedback the related disaster information. The professional personnel are people with expertise in field of geographic and disaster, and can review, correct errors and filter the information. The design makers announce measures base on VGI, such as deployment of rescue teams and relief distribution, etc. They are commanders of disaster management. And the system administrator is particularly technical person to ensure the normal operation of system and features updates. Moreover, rational configuration of the user authority bases on the above classification of volunteers, can improve the accuracy and reliability of VGI data to some extent.

Table 1. Classification and authority design of volunteers

Function	User classification and authority				
	General public	Organization	Professional personnel	Decision maker	Administrator
System management					√
Features updating					√
Information inquiry	√	√	√	√	
Map services	√	√	√	√	
Metadata services			√		
Data acquisition	√	√			
Data updating	√	√	√	√	
Information response		√		√	

3.1.2. Government-led VGI data acquisition framework. Most of current VGI applications are based on non-governmental organizations' data collection system, such as OpenStreetMap, which are lacking of effective convergence with authoritative geographic database, leading to extract VGI data very much difficult. And according to disaster management, it is necessary to provide structured data collection standards, models and process to guide the users to provide accurate and reliable disaster related information. Therefore, a four-tier government-led VGI data Acquisition framework was illustrated in Figure 1. Of which, the guiding role of government performs in the aspects of determination of disaster theme, publishing requirements of data, providing of VGI management platform and establishing regime of liability and reward, etc. In practical terms, when facing a serious disaster, the government decision makers firstly announce requirements of VGI data and specify the data classification standards and the data model, then provide platform for VGI management. And related organizations or professional personnel can get permissions to join in rapidly to deal with a large number of information from the public. Finally, the decision makers can carry out disaster response works in time based on the valuable information. Thus a framework of disaster management involved in the public, can effectively make up for lack of important and dynamic disaster related information and provide all aspects of the guidance for improving the level of disaster mitigation.

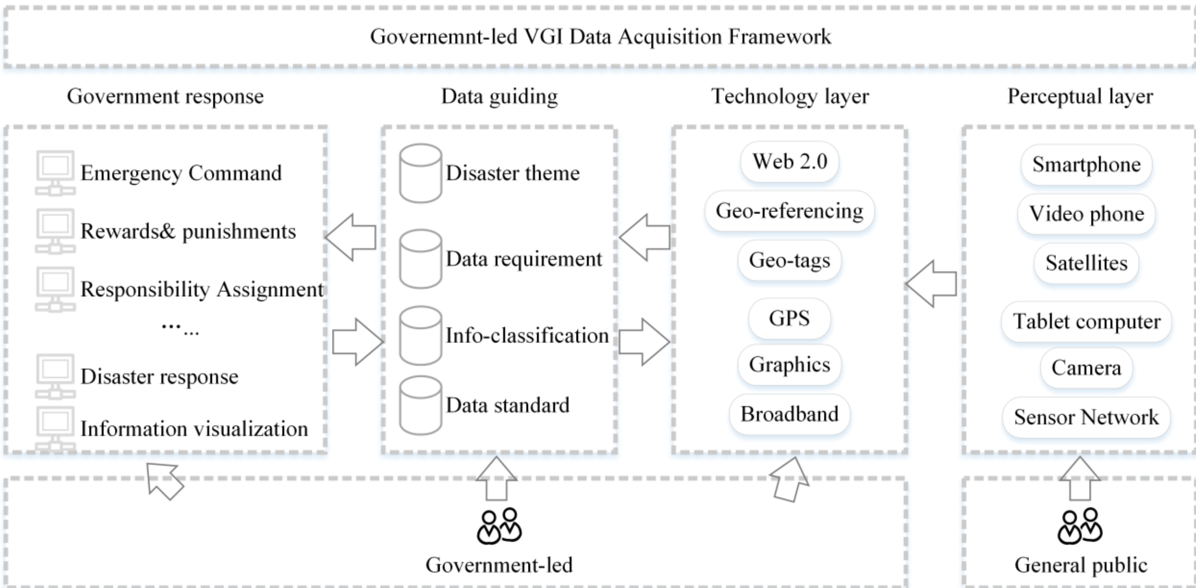

Figure 1. A government-led VGI data acquisition framework

3.1.3. Quality Assessment System for VGI. According to the actual demand of disaster management platform, we discussed the effectively quality assessment approaches from two aspects of the platform users and the data content to construct a quality assessment system. Firstly, from the perspective of the users, decision maker, organizations and professional personnel can timely update and feedback the general public's volunteered information, and to assess their abilities and reputation of contributing data, then raise or lower the privilege level of the users, namely affirming contributors who provide high quality and valuable data, while timely filtering out low-grade or junk data publishers. Secondly, from the perspective of data content, Oort [11] put forward 11 elements of spatial data quality, including lineage, positional accuracy, attribute accuracy, logical consistency, completeness, semantic accuracy, temporal quality, variation in quality, meta-quality and resolution, etc. Therefore, it is very necessary to organize a volunteered team with professional knowledge and experience to participate in activities of optimizing the accuracy and reliability of VGI data based on specific disaster management platform.

However, how to ensure data quality is still one of the research & application hotspots and difficulties for using VGI in disaster management. Three approaches we introduced here are just small part of data quality studies. With further research, more scientific and effective methods will play an important role in practice.

3.2. Case Study: A prototype of VGI oriented earthquake disaster databank & sharing platform

3.2.1. Data and methods. The platform construction requires large amount of data, including temporal-spatial information of earthquake disasters, such as locations, origin time, magnitude, depths and distribution of intensity. Basic geographic information and ecological environment data, involving multi-source satellites images, topography, land use and land cover, etc. Socio-economic data such as the type of economy, GDP, distribution of population and so on. As well as disaster information in pictures, text, videos and many other formats. These data vary in format, covering the relational data model, vector and raster data model, are very difficult to manage. In this study, we put forward an object & theme-oriented data model based on the rapid development of spatial database techniques to manage the multi-source heterogeneous data, as shown in Figure 2, in order to enhance the data expression, retrieval and simulation capabilities, which can greatly improve the efficiency of earthquake related information.

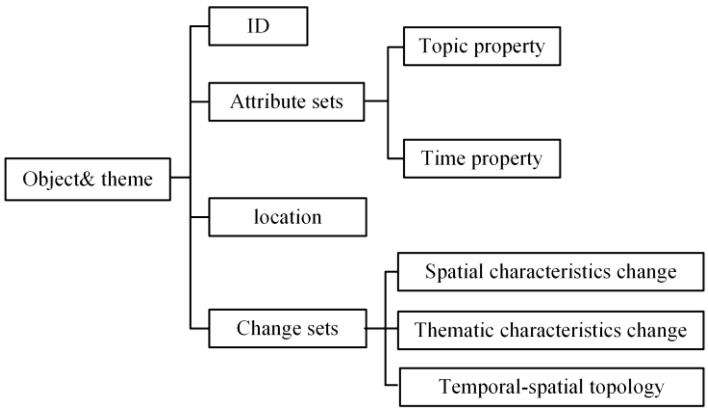

Figure 2. Object & theme-oriented data model

Seismic object & theme-oriented data model is composed of object ID, attribute sets, spatial location and change sets. Of which, object ID is a unique code used to identify the object. The attribute sets contain the object's topic and time properties, and time property represents a continuous renewal process, which characterizes the temporal variation of the object, while the topic property describes the object's natures, characteristics, which can be in multi format such as text, number, picture, video, etc. The location describes the position and shape of the object, which may be as different kinds of vector objects, such as point, line, polygon, or a row, column position of raster data. And the change sets are based on version, encapsulating the object's thematic characteristics change, spatial characteristics change and temporal-spatial topology. Of which, the spatial characteristics change mainly refer to the geometry changes and location moving, as well as the split and merge of the object, such as ground cracking, etc. While the thematic characteristics change recode changes as deltas, for example, acquisition and distribution of charity after an earthquake. The temporal-spatial topology is a reflection of the feature data quality, involving spatial topology and temporal topology and the relations of feature classes, such as causality, etc. Which can be used to ensure the quality of earthquake disaster related data and as a basis for further data mining.

The development techniques of the prototype system were mainly based on ArcGIS and its related products. We used the spatial database engine ArcSDE combining with SQL Server database as well as the object & theme-oriented data model to design an online earthquake emergency response and mitigation database. Advance techniques such as RS, communication, Internet and networking were integrated to obtain, store and manage the multi-source heterogeneous information from the public.

3.2.2. Result of the Case Study. Based on design of the data model, we constructed a comprehensive database system, as shown in Figure 3, including basic background database, earthquake disaster database, case knowledge database, disaster information database and extensional database, respectively. In practise, the basic background database, includes geographical data, socio-economic and demographic data, land use and building information, multi-source satellites images, etc. Which was used to create basic information about the disaster rapidly after a disaster happened. The earthquake disaster database was built to revolve around a broad seismic object (theme) that contained basic earthquake information, seismic network data, lifeline engineering data, etc. Which played a supplementary role in disaster assessment, decision-making. The case knowledge database mainly involved legal and regulatory information, emergency plans as well as historical earthquake experiences for current earthquake disaster management. The disaster information database is the main part of the database system, because it closely coupled with VGI from a large number of volunteers. The database revolved around a current earthquake object (theme) for dynamic data acquisition, analysis and sharing in real time, involving of basic information of the earthquake, disaster assessment information, secondary disaster information and public opinion information, etc. These data were core information for emergency dispatching and decision-making. While the extensional database was mainly for the unique circumstances of each earthquake disaster area, which can be extended in time, including data with some uncertainties, such as social relief supplies, funds of non-profits and insurance, etc. And integrating some specialized models of earthquake destruction, degree of damage, and the risk of earthquake of the factory warehouse building, etc.

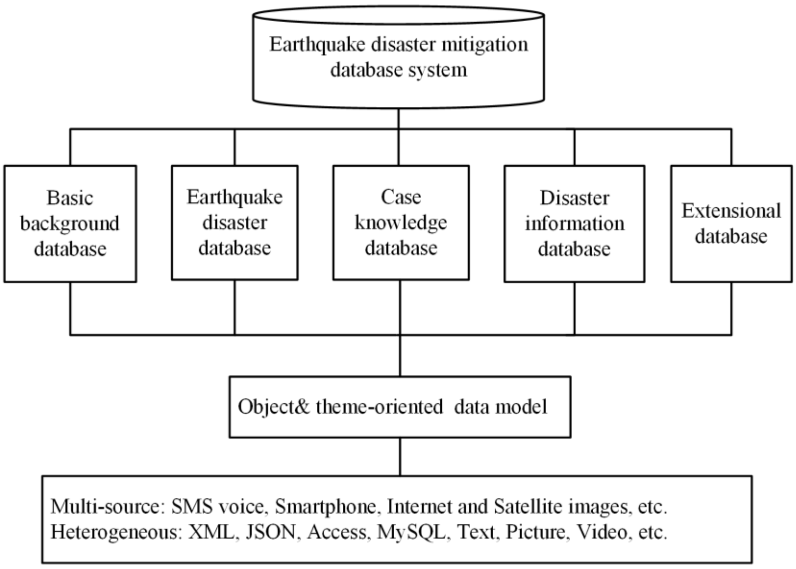

Figure 3. The main interface of VGI oriented earthquake disaster information sharing platform

While the disaster related information sharing platform is the bridge between specialization and popularization. Which made it possible for ordinary people to obtain, manage and share disaster information through multiple terminals, using voice, text, or pictures. Thus, in the prototype system, we integrated timeline list and map techniques to visualize the plenty of dynamic disaster information in order to aid decision-making, and the main interface of VGI oriented earthquake disaster information sharing platform is shown in Figure 4.

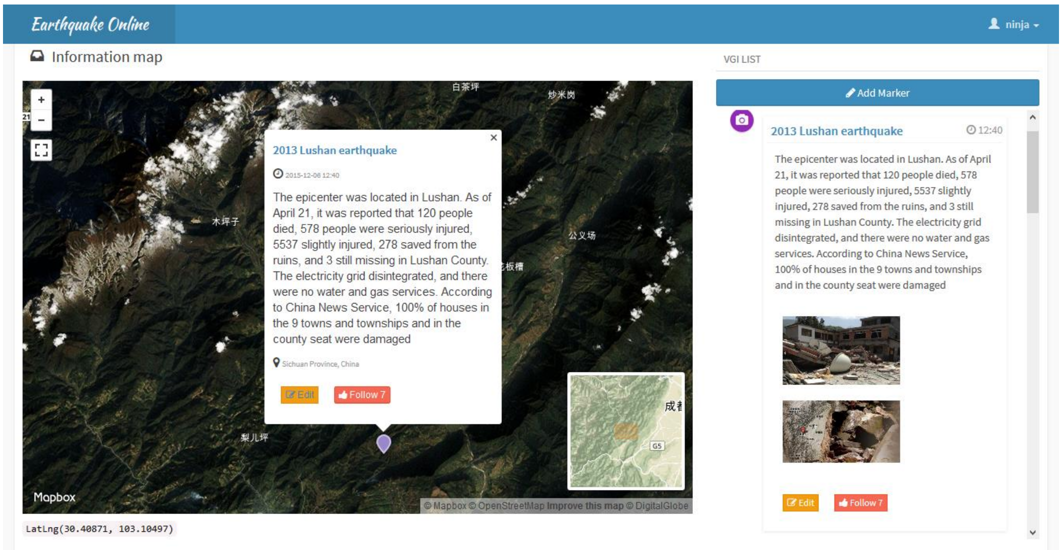

Figure 4. Earthquake disaster mitigation database system

4. Conclusion

System construction by using VGI for disaster management has huge potential and demand, and it is now in a stage of rapid development and improvement. This study systematically introduced the concepts related to disaster management, and discussed the opportunities and challenges for applying VGI in disaster management. Three different approaches to assess VGI data quality were presented and discussed in detail with particular emphasis on the actual needs of disaster management practice in China. However, they are only a tiny proportion of data quality studies. With further research, more scientific and effective methods will play an important role in practice.

Moreover, in the case study, an online integration database system for earthquake mitigation was built by using the object & theme-oriented data model. And a sharing platform mainly by using VGI from the public was developed, which acted an open WebGIS system for volunteers and other interested individuals collaboratively create and manage the earthquake disaster related information. It has shown significant advantages of information richness, timely feedback and accurate data, etc. However, as a new born concept of geographic information collection, theory research and practice of VGI are still not mature. It is necessary to carry out studies widely and thoroughly, in order to effectively integrate VGI to all phases of disaster management, and ultimately to improve the service level of disaster management.

Acknowledgements

This study is funded by CRSRI Open Research Program (CKWV2015226/KY), and the National Key Technologies R&D Program of China (No. 2016YFA0602302 and No. 2016YFB0502502).

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