The current status and further developments of geohazard monitoring and early warning program in China

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Abstract. China is one of most severely threatened countries by geohazard in the world. To further improve the capacity of geohazard prevention and reduce potential damage, meteorological early warning on various scales, mass prediction and disaster prevention and professional monitoring have been implemented and achieved great progress, which lead to the great reduction in number of casualties. However, with the increase of engineering disturbance, tectonic activity and extreme climate events, the prevention and mitigation of geohazard should be further strengthened from different perspectives including the implementation of field investigation on geohazard triggering conditions, advancement and application of regional geohazard mapping, improvement of regional meteorological early warning, monitoring of geohazard development using integrated technologies involving remote sensing, LiDAR, InSAR, etc, and capacity of observation and monitoring by public.

1. Introduction

China is one of the most threatened countries by geohazard in the word. The area of plateau and mountainous is about 6.6 million km$^2$, accounting for 69.4% of China's territory, debris flow and landslide (including collapse) are the most frequently occurred geohazard, and are widely distributed in the mountainous areas [1]. From 2008 to 2018, approximately 152 thousands of sudden geohazard such as collapses, landslides and mudslides have occurred in China, causing 7035 deaths (excluding geohazard and deaths caused by earthquakes). According to statistics, the number of deaths caused by sudden geohazard accounts for nearly 30% of the total deaths of natural disasters every year. Based on the previous experiences, geohazard monitoring and early warning is practical and efficient in reducing the overall damage induced by geohazard. Therefore, in this study, the monitoring and early warning program in China are comprehensively presented.

2. The development of geohazard monitoring and early warning system in China

2.1. Geohazard meteorological warning program

Since 2003, the former Ministry of Land and Resource, P.R.C and the China Meteorological Administration jointly carried out the geohazard meteorological early warning and prediction program in the flooding season (from May to September) annually [2]. By 2018, the geohazard meteorological early warning program were conducted in 309 cities and 1660 counties that are mostly located in the highly susceptible area in China. Based on the early warning models that were established based on the previous survey results of geohazard and triggering mechanisms by rainfall in different geological units, the program can release the level of early warning for different regions, as well as the temporal
and spatial distribution. The meteorological early warning and prediction program have played an important role in the prevention of rainfall induced geohazard in these areas.

In 2003-2007, the first generation of early warning model (so called “Critical Rainfall criterion method”) based on the implicit statistical prediction method was widely used on various scales of geohazard meteorological early warning operations. The model only involved very limited parameters (critical rainfall parameters), which was easy to be popularized. Since 2008, the second generation of early warning model based on the explicit statistical prediction method has been established. In the model, additional more parameters such as geological environment conditions and rainfall parameters were considered comprehensively, which significantly improved the precision and efficiency of early warning. In 2003, the geological map of 1:6 million scale was applied in national geohazard meteorological early warning system to achieve 24-hour early warning once a day with a spatial precision of 60 km. In 2012, the geological map of 1:1 million scale was used to conduct the 24h early warning with spatial accuracy of 10 km once a day.

According to the characteristics of geological environment in different areas and different triggering mechanisms of geohazard, the targeted early warning model has gradually diversified development. For example, the joint effect of earthquake and rainfall is considered early warning models in both Yunnan and Sichuan provinces, where seismic events and extreme rainfall could occur frequently and sometimes even occurred consecutively; the joint effect of rain and wind of typhoon is concerned in the early warning models in Zhejiang and Fujian provinces; the joint effect of snow thaw and rainfall is concerned in the regional early warning models in Qinghai and Xinjiang provinces.

2.2. Mass prediction and disaster prevention in China

The system of geohazard mass prediction and disaster prevention is very important for geohazard prevention and mitigation in China due to its greater efficiency and low cost. According to incomplete statistics, more than 200,000 landslides have been involved in the program of mass prediction and disaster prevention. Nearly 300,000 observers, who were mostly from local, use the simple methods such as pile embedding, nail embedding and patch, to measure the deformation of geohazard semi-quantitatively after a training program provided by professionals (Figure 1). The geohazard being involved in the program are mostly near the residential areas, and could easily cause tremendous damages. Therefore, particularly during the flooding season each year, the observers would routinely conduct inspections on the unstable slopes, and prepare to release the warning single if any sign of slope deformation being identified. Due the significant number of geohazard being involved in the mass prediction and disaster prevention, the system have played an important role in reducing casualties and losses of people and enhancing the public awareness and ability of disaster prevention.

![Figure 1. Pile embedding to measure the deformation of geohazard.](image1)

![Figure 2. Displacement alarm to measure the deformation of geohazard.](image2)

During the implementation of the system, the warning information reporting and management as well as the measuring equipment have continuously optimized and upgraded to improve the accuracy and efficiency of geohazard observation and prediction. Crack alarm, displacement alarm, laser
rangepointer, etc were applied to improve the data measuring accuracy, and by involving mobile Internet and other information-based means, daily monitoring data are also recorded from paper notes (Figure 2). It is gradually changing to collect and upload through mobile app, which greatly improves the efficiency of monitoring and early warning.

2.3. Professional monitoring

In 1999, the "Demonstration area of geohazard monitoring in the Three Gorges Reservoir area of the Yangtze River" was established, and the GPS monitoring network for geohazard in the Three Gorges Reservoir area and the multi-parameter monitoring network for some single landslides were initially established [3].

Since 2002, more than 5700 automatic geohazard monitoring stations have been established in China. According to different monitoring categories, three types of information are normally involved in the monitoring program: slope deformation feature, geohazard controlling factors, and inducing factor monitoring. Deformation features monitoring can be divided into the following categories: ① absolute ground displacement monitoring, ② relative ground displacement monitoring, ③ deep displacement monitoring. The controlling factors being involved in the monitoring program is mainly to monitor the groundwater and stress changes of landslide mass. There are four types of induced factor monitoring: ① earthquake monitoring, ② rainfall monitoring, ③ freeze-thaw monitoring, ④ human activity monitoring.

3. Successful experiences

With years of efforts for promoting an efficient and practical geohazard prevention by the government in China, the number of deaths has decreased from about 1000 per year in the Tenth Five Year Plan (2001-2005) period to about 300 since the Thirteenth Five Year Plan period (2016 - 2020) (Figure 3).

The system of mass observation and disaster prevention played an important role in the prevention and control of geohazard in China. For example, on January 28, 2013, in Zhenxiong County, Yunnan province, due to the mass observation and disaster prevention, the local government transferred 1227 people without causing casualties [4]; on July 8, 2014, in Panzhihua City in Sichuan Province, the landslide of Jiangbian group, Shengli village, Qianjin town was deformed due to the sudden rainstorm, and the crack monitor installed on the landslide and the full-time monitor immediately both sent out the deformation signal, therefore, 105 people from 29 households were transferred to the safety zone, and 10 minutes later, the disaster occurred and caused damage to 23 households of agricultural houses, without causing any casualties.

The meteorological early warning program have also achieved significant results. On August 13, 2010, in Qingping Township in Sichuan province, torrential rain and mud rock flow occurred, traffic, communication and power were all interrupted, resulting in 379 buildings including residential houses,
schools, police stations and other public facilities being completely damaged, and more than 600 houses flooded [5]. Due to the timely monitoring and early warning, the emergency plan was established firmly, and more than 5000 people living in the hazard area were successfully and timely evacuated.

In conclusion, numerous experiences on geohazard monitoring and early warning in China can be generated:

① Meteorological early warning played a role in geohazard prevention. Although the accuracy of the current meteorological early warning is limited, it is well known by the majority of population especially for those living in the highly susceptible regions. Under the overall governmental framework, once the early warning message is released, the corresponding regional disaster prevention system will be initiated immediately.

② The system of mass observation and disaster prevention is important and effective measure to prevent geohazard. Due to its practicability and low cost, a great number of geohazard that could cause severely damage to surrounding regions are being managed and monitored without requiring large number of professionals and technicals. Practice also have showed that group survey and group prevention play an important role in reducing casualties caused by geohazards.

③ The combination of mass observation and disaster prevention and professional monitoring and early warning is important. The professional staff strengthen the support of group measurement and prevention work and the use of more and more monitoring equipment, which greatly increases the accuracy of monitoring and improves the efficiency of early warning.

4. Discussion and conclusion

With the increase of engineering disturbance, the tectonic activity and the extreme climate events, serious geohazard that causing mass casualties occurred frequently. Geohazard have the characteristics of concealment, complexity, high-speed and long-distance. Not only the surrounding areas of geohazard would be damaged but also the areas within several kilometers from the deformed slope would be influenced due to the formation of disaster chain. Therefore, there are still many challenges and difficulties to be resolved, various measures should be taken to strengthen the geohazard monitoring and early warning (Table 1).

Table 1. Contents and methods of strengthening geohazard monitoring and early warning.

| Content                                    | Method                                                                 |
|--------------------------------------------|------------------------------------------------------------------------|
| Geohazard meteorological warning           | Improving the accuracy of weather forecast and build more precise early warning model |
| Regional monitoring for highly susceptible regions | LiDAR, InSAR etc                                                     |
| Mass prediction and disaster prevention    | Standardization of manual monitoring data collection and transmission, simple and cheap auto devices |
| Professional geohazard monitoring         | Three-dimensional comprehensive monitoring of space sky earth integration |
| Database and information system            | Deep mining of multi-scale and multi-source heterogeneous data        |

4.1. Further improvement of the geohazard meteorological warning

At present, the precision of national and provincial meteorological early warning established in China is mainly in the scale of 1:500 thousand to 1:1 million. Although most administrative regions have carried out geohazard meteorological early warning work, the overall construction and function of the early warning system is preliminary, the precision and comprehension of early warning products is fairly low, and the accuracy rate needs to be improved. The reasons are: ① the large-scale...
meteorological early warning research and early warning model have not been carried out in most regions; ② the regional rainfall monitoring stations are insufficient to provide adequate rainfall monitoring data; ③ the information sharing among multiple departments is inadequate; ④ it is difficult to obtain high-precision dynamic rainfall information; ⑤ it is difficult to support the revision and improvement of geohazard early warning model; ⑥ it is difficult to predict the local short-term heavy rainfall in the mountainous areas with high occurrence of geohazards.

In order to improve the accuracy of meteorological early warning, it is important to build a more precise national level (1:500000 or above) and provincial level early warning model (1:250000 or above), and carry out the research on the city level early warning model of 1:50000-1:100000 in highly and intermediately susceptible risk areas. Also, the temporal and spatial accuracy of rainfall prediction in mountainous and hilly areas through the construction of Doppler radar and other means should be further strengthened. Last, rainfall data sharing among the different departments including natural resources, meteorology and water conservancy should be improved.

4.2. Gradual implementation of regional monitoring for highly susceptible regions
With the development of high-precision remote sensing, InSAR, LiDAR and other earth observation technologies, it is possible to carry out regional monitoring with great cost efficiency and working efficiency. A integrated system of space-based earth observation technologies including RS, LiDAR, InSAR etc for geohazard identification, investigation and monitoring should be established, and used for geohazard identification (geometric characteristics, development trend of deformation), terrain information acquisition and surface deformation monitoring in large areas. Therefore, the observation results can be used to guide the scientific layout of ground investigation and on-site monitoring stations.

4.3. The technical level of mass observation and disaster prevention should be improved
Currently, there are several problems regarding with the mass observation and disaster prevention program: simple monitoring methods such as pile, nail, patch and paint were usually used in the mass observation and disaster prevention program, and the data obtained are mainly qualitative; paper and pen records are mostly used for monitoring content recording and reporting, and the data can not be transmitted and analyzed efficiently; monitoring data analysis and disaster warning judgment are also insufficient by professionals. Particularly for the high speed and long distance geohazard, it is also difficult conduct early warning based on mass observation and disaster prevention because people are difficult to access in these regions. Therefore, it is necessary to establish a more unified construction standards and monitoring technical regulations, and vigorously promote the standardization of manual monitoring data collection and transmission information, obtain with simple automatic and semi-automatic monitoring equipment and improve the efficiency and accuracy of group monitoring and prevention monitoring, improve and promote the manual monitoring data collection app, realize the real-time upload of data to the monitoring and early warning system, and improve the early warning work scientifically.

On the basis of mass observation and disaster prevention program, for the highly susceptible regions with intensive geohazard, it is also important to build simple monitoring stations by involving simple and cheap monitoring devices such as deploy automatic rain gauge, surface deformation monitoring equipment, sound and light alarm, etc., to ensure that the monitoring data could be the automatically collected and transmitted for monitoring and early warning to the monitoring and early warning information system. Therefore, the efficiency of monitoring and early warning can be further improved.

4.4. Technologies development of professional geohazard monitoring
Currently, there are only few professional monitoring facilities, and most of the geohazard located in the high-risk areas are covered by the program of mass observation and disaster prevention. The monitoring data obtained are far from meeting the requirements of early warning and prediction. The
investment of professional monitoring funds is also difficult to ensure the long-term continuous operation of monitoring work, resulting in the discontinuity of monitoring data and the lack of long-term research on early warning models and criteria. The support of effective data leads to the difficulty of disaster warning and prediction. The reliability of geohazard monitoring and early warning technology and equipment needs further improved; the mutual data sharing and integrated analysis among different data collection platforms and each equipment manufacturer should be further improved.

For the geohazard of high risk, the three-dimensional comprehensive monitoring of space sky earth integration should be carried out. The monitoring contents include surface displacement, deep displacement, stress, pore water pressure, groundwater, precipitation and other elements. Through monitoring data analysis of its deformation development trend, early warning and prediction are made in time and scientific and reasonable prevention and control countermeasures are put forward.

In order to meet the needs of monitoring and early warning, it is necessary to develop new technical equipment and promote the standardization and industrialization of the equipment.

4.5. National geohazard database establishment

The current geohazard database and information system have been established nearly two decades, and need to be upgraded with time. Limited by the business requirements and technical conditions at that time, it can be used to mainly store static data, but difficult to meet the needs of large-scale dynamic update of survey data and real-time dynamic collection and analysis of massive monitoring data. Due to the disunity of geohazard information platforms in the country and provinces, it is difficult to share data in the country, provinces, even cities. The sharing of monitoring data among different departments is almost blank, which seriously restricts the monitoring and early warning of geohazards.

The next step is to establish a national geohazard information platform with comprehensive data, complete functions, timely update and efficient operation based on the overall layout and unified management requirements of the country for geohazard prevention and control, so as to realize efficient integration and deep mining of multi-scale and multi-source heterogeneous data and support geohazard prevention and control.

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