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A Review of 1:10,000 Scale Geological Hazard Risk Investigation and Assessment

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Abstract: This paper comprehensively elaborates on the relevant aspects of 1:10,000 geological disaster risk survey and assessment. It introduces its background and significance, provides a detailed analysis of the main survey and assessment contents, including geological disaster hazard identification, analysis of disaster-pregnant geological conditions, survey of elements at risk, and risk assessment. It discusses the survey methodologies and technologies combining traditional and modern approaches, synthesizes the applications of the outcomes, and prospects future development trends. The aim is to provide a comprehensive reference for geological disaster risk survey and assessment work.

Keywords: Geological hazards; 1:10,000 scale investigation; Risk assessment; Technical methodologies.

1. Introduction

Geological disasters refer to geological phenomena caused by natural geological processes or human activities that cause severe damage to human life, property safety, and the ecological environment, such as landslides, debris flows, rockfalls, ground collapses, and ground fissures [1-3]. In recent years, global climate change and the intensifying scope and scale of human engineering activities have led to an increasing frequency and severity of geological disasters. Statistics show that economic losses caused by geological disasters amount to billions of US dollars annually, accompanied by significant casualties and ecological damage [4]. Accurately grasping the risk status of geological disasters is a prerequisite for effective disaster prevention and mitigation. As a medium-scale survey method, 1:10,000 geological disaster risk survey and assessment can relatively comprehensively identify potential geological disaster hazards within a specific region, providing scientific and precise foundations for disaster prevention and mitigation. It holds a significant position in the field of geological disaster research and prevention [5].

2. Background and Significance of Survey and Assessment

2.1. Impact of Urbanization Development and Human Engineering Activities

With the acceleration of urbanization, large populations are converging into cities, leading to continuous urban expansion and increasingly frequent human engineering activities such as infrastructure construction and real estate development [6]. For instance, activities like large-scale road construction and slope cutting for housing in mountainous areas alter the original topography and structure of rock and soil masses, increasing the likelihood of geological disasters. Relevant studies indicate that in some mountainous towns, the incidence of geological disasters such as landslides and rockfalls has increased by 30% - 50% compared to the past due to unreasonable engineering construction.

2.2. Importance for Disaster Prevention Planning and Territorial Space Utilization

The scale of 1:10,000 offers moderate precision, enabling the detailed identification of the distribution, scale, stability, and other characteristics of potential geological disaster hazards over a relatively large area. Analysis of this information provides detailed data support for disaster prevention planning, such as determining key prevention areas and formulating mitigation measures. Simultaneously, regarding territorial space utilization, the survey and assessment results can guide land development, urban planning, etc., by rationally avoiding high-risk zones, thereby ensuring sustainable socio-economic development. For example, when planning a new district, a city avoided valley areas prone to landslides and debris flows based on 1:10,000 geological disaster risk survey results, effectively reducing potential future disaster losses.

3. Main Contents of Survey and Assessment

3.1. Geological Disaster Hazard Identification

3.1.1. Field Survey

Field survey is the fundamental method for identifying geological disaster hazards [7]. Survey personnel need to carry professional tools such as geological compasses, GPS locators, and total stations to conduct detailed ground reconnaissance of the survey area. In mountainous regions, for landslide hazards, surveyors must meticulously measure parameters like the landslide boundary, depth of the slip surface, sliding direction, and material composition of the landslide body. For instance, during the investigation of a potential landslide site in a mountainous area of Sichuan, field measurements and sample analysis determined that the slip surface depth ranged between 5-8 meters, the landslide body primarily consisted of silty clay and fragmented rock, and the sliding direction aligned with the slope dip.

3.1.2. Remote Sensing Interpretation

Remote Sensing (RS) technology utilizes differences in the reflection and radiation characteristics of electromagnetic waves by various surface features to rapidly identify potential geological disaster hazards from a macro perspective [8].

High-resolution satellite imagery and aerial remote sensing images can clearly display changes in topography, abnormal distributions of rock and soil masses, and other information. For example, analyzing remote sensing images of landslide areas can reveal differences in tone and texture between the landslide body and surrounding rock/soil, allowing preliminary delineation of potential landslide areas. Multispectral remote sensing data can also be used to analyze information such as soil moisture content and vegetation coverage, further assessing landslide stability.

3.2. Analysis of Disaster-Pregnant Geological Conditions

3.2.1. Stratigraphy and Lithology

Stratigraphy and lithology are crucial factors influencing the formation of geological disasters [9]. Different rocks and soils possess distinct physical and mechanical properties, exhibiting significant variations in resistance to weathering and erosion, as well as strength. For instance, soft rocks like shale and mudstone have weak weathering resistance, soften easily when wet, and are prone to landslides and rockfalls. Hard rocks like granite and sandstone, despite their higher strength, can still fragment due to weathering and unloading in areas with developed joints and fractures, potentially triggering rockfalls and other geological disasters. In a certain mountainous area, frequent minor landslide disasters occurred during continuous rainfall due to exposed strata primarily composed of shale and mudstone.

3.2.2. Geological Structure

Geological structures control the structure and stress distribution of rock and soil masses, playing a vital role in the formation of geological disasters [10]. Structural features like faults and folds, where rock masses are fractured and stress is concentrated, are prone to triggering geological disasters. For example, near seismically active fault zones, ground shaking can cause structural damage to rock and soil masses, increasing the probability of landslides, rockfalls, and other geological disasters. Simultaneously, changes in stratum attitude caused by fold structures also affect slope stability; the axial and limb areas of folds are often high-incidence zones for geological disasters.

3.2.3. Topography and Geomorphology

Topography and geomorphology are significant conditions for the occurrence of geological disasters [11]. Steep slopes, deeply incised valleys, and areas with significant elevation differences experience pronounced gravitational effects and are prone to landslides, debris flows, rockfalls, and other geological disasters. For instance, in mountainous areas, slopes steeper than 30° have a higher incidence of landslides and rockfalls. Gully topography, under heavy rainfall conditions, easily concentrates water flow, forming debris flow disasters. Furthermore, unique landforms shaped by processes like river erosion and glacial scour also influence the distribution and occurrence of geological disasters.

3.3. Survey of Elements at Risk

3.3.1. Population Distribution and Density

Understanding the distribution and density of the population within the survey area is crucial for assessing potential casualties caused by geological disasters [12]. Population census data and Geographic Information System (GIS) technology can be used to obtain spatial distribution information of the population. For example, in a mountainous town, using census data and GIS spatial analysis functions, a population density distribution map revealed high densities along river valleys and in the town center – areas coinciding with high geological disaster risk zones. A disaster occurring here could cause significant casualties.

3.3.2. Buildings and Infrastructure

Survey statistics include the type, structure, quantity, and distribution of buildings within the survey area, encompassing residential housing, industrial plants, public buildings, etc. [12]. Different types and structures of buildings exhibit varying capabilities in resisting geological disasters; for example, brick-concrete structures may suffer greater damage than frame structures under earthquakes or landslides. Concurrently, the distribution and importance of infrastructure such as transportation, power, and communications are assessed. Damage to infrastructure not only hinders disaster rescue and recovery efforts but also severely impacts the normal functioning of the socio-economy. For instance, in an earthquake-stricken area, severe damage to roads and power facilities caused by earthquake-triggered landslides and rockfalls hampered rescue operations and slowed the recovery of production and daily life.

3.4. Risk Assessment

3.4.1. Qualitative Assessment Methods

Qualitative assessment primarily relies on expert experience and field survey observations for subjective judgment of geological disaster risk. For example, by comprehensively analyzing factors like the stability of a hazard point, signs of activity, and the surrounding environment, risks are classified into high, medium, and low levels. This method is simple and easy to implement but is highly subjective and lacks precise quantitative indicators. It is widely used in some small-scale geological disaster survey projects.

3.4.2. Quantitative Assessment Methods

Quantitative assessment employs mathematical models and statistical methods to calculate the probability of geological disaster occurrence and potential losses. Commonly used methods include the Analytic Hierarchy Process (AHP) [13] and Fuzzy Comprehensive Evaluation [14]. For example, using AHP, a geological disaster occurrence probability model is established through statistical analysis of historical disaster data combined with geological environmental conditions and triggering factors. This is then integrated with the value assessment of elements at risk to calculate potential economic losses. Quantitative assessment methods provide relatively precise risk evaluation results but demand higher data quality and involve relatively complex computational processes.

4. Survey and Assessment Methods and Technologies

4.1. Traditional Survey Methods

4.1.1. Geological Mapping

Geological mapping is a key traditional geological survey method. Through field measurements and the preparation of geological maps, it visually reflects the distribution, attitude, structure, and other information of geological bodies. In 1:10,000 geological disaster risk surveys, geological mapping primarily includes topographic-geological mapping and engineering-geological mapping. For instance, when preparing a topographic-geological map, instruments like total stations are used for detailed topographic surveying while observing and recording geological information such as lithology and structure. This information is then plotted on the map according to a specific scale. Geological mapping provides foundational data for subsequent geological disaster analysis and evaluation.

4.1.2. Geological Drilling

Geological drilling is an essential method for obtaining deep subsurface geological information. Drilling retrieves core samples, revealing vertical variations in stratigraphy and lithology, and the physical and mechanical properties of rock and soil masses. In geological disaster surveys, for hazards like landslides and ground collapses, drilling can determine key parameters such as slip surface depth and the extent and depth of collapse zones. For example, during the investigation of a potential landslide site, core sample analysis obtained through drilling revealed the slip surface was located 6-8 meters below ground, primarily composed of soft plastic silty clay. This provided crucial basis for subsequent landslide stability analysis and mitigation engineering design.

4.2. Modern Technological Means

4.2.1. Remote Sensing (RS) Technology

Remote sensing technology offers advantages in macroscopic, rapid, and dynamic monitoring for geological disaster risk surveys. Beyond its use in hazard identification mentioned earlier, it also enables monitoring the development and change processes of geological disasters through multi-temporal image comparison. For example, comparing satellite images from different periods can reveal displacement changes in landslide bodies or the evolution of debris flow gullies. Furthermore, hyperspectral remote sensing technology can acquire spectral characteristic information of surface features, further identifying the types and properties of rock and soil masses, providing richer data for geological disaster analysis.

4.2.2. Global Positioning System (GPS)

GPS is primarily used for the precise positioning and displacement monitoring of geological disaster hazard points. By setting up GPS monitoring stations at hazard points, real-time three-dimensional coordinate information of monitoring points is acquired, enabling the precise calculation of parameters such as displacement magnitude, direction, and rate of the hazard body. For example, during the monitoring of a large landslide, GPS data revealed a significant increase in displacement rate during the rainy season, prompting timely early warning and averting potential disaster losses.

4.2.3. Geographic Information System (GIS)

GIS is a powerful tool for spatial data analysis and management. In 1:10,000 geological disaster risk survey and assessment, GIS integrates multi-source data including geology, topography, meteorology, and elements at risk for spatial analysis and visualization. For instance, overlaying and analyzing data on hazard points, topography, and population distribution can visually display the distribution of different risk zones and the number of threatened people. Simultaneously, utilizing GIS spatial analysis functions like buffer analysis, slope analysis, and hydrological analysis allows further assessment of the impact range and severity of geological disasters. Moreover, GIS platforms can be used to develop geological disaster risk assessment models and early warning systems, enabling dynamic monitoring and warning of geological disasters.

5. Application of Results

5.1. Territorial Space Planning

In territorial space planning, the results of 1:10,000 geological disaster risk surveys serve as crucial reference materials. By analyzing the survey and assessment results, planning departments can rationally delineate prohibited construction zones, restricted construction zones, and suitable construction zones. For example, areas at high risk of geological disasters are designated as prohibited construction zones where large-scale engineering projects are strictly forbidden; in restricted construction zones, strict geological disaster assessment and mitigation requirements are imposed on engineering projects. This effectively prevents blind development in high-risk areas, ensuring rational land use and sustainable development. In the territorial space planning of a certain city, based on geological disaster risk survey results, land use in mountainous areas was optimized, reducing construction projects in landslide and debris flow-prone zones and mitigating future disaster risks.

5.2. Disaster Prevention and Mitigation Engineering

5.2.1. Determination of Engineering Design Parameters

The results of geological disaster risk surveys provide key parameters for the design of disaster prevention and mitigation engineering. For instance, in landslide mitigation engineering, stability analysis of the landslide body and testing of the physical and mechanical properties of the rock/soil determine parameters like landslide thrust and slip surface position, thereby enabling the design of appropriate mitigation structures like anti-slide piles and retaining walls. In debris flow mitigation engineering, parameters such as flow velocity, discharge, and solid material content guide the design of structures like check dams and drainage channels. Accurately obtaining these parameters enhances the targeting and effectiveness of disaster mitigation engineering.

5.2.2. Evaluation of Engineering Effectiveness

Following the implementation of disaster mitigation engineering, the results of 1:10,000 geological disaster risk surveys can be used to evaluate the engineering's effectiveness. By comparing indicators such as changes in the stability of hazard points and reductions in risk levels before and after project implementation, the achievement of the intended engineering effects can be assessed. For example, after the completion of a landslide stabilization project, regular monitoring and risk assessment showed a significant decrease in displacement and marked improvement in stability, with the risk level reduced from high to medium, indicating the successful outcome of the mitigation project.

6. Prospects

6.1. Trend Towards Intelligence

With the rapid development of technologies like big data, artificial intelligence (AI), and the Internet of Things (IoT), 1:10,000 geological disaster risk survey and assessment will evolve towards greater intelligence. Big data technology can rapidly process and analyze massive geological disaster datasets, uncovering underlying relationships and patterns. AI technologies, such as machine learning and deep learning, can establish more precise geological disaster risk prediction models, enabling automatic hazard identification and early warning. IoT technology facilitates real-time monitoring of hazard points and automatic data transmission, improving monitoring efficiency and the timeliness of warnings. For example, by installing various sensors (e.g., displacement, rainfall, ground stress sensors) at hazard points, monitoring data can be transmitted in real-time to a data center. AI algorithms can then analyze this data to promptly detect disaster precursors and issue warnings.

6.2. Multidisciplinary Integration

Future 1:10,000 geological disaster risk survey and assessment will increasingly emphasize multidisciplinary integration. Beyond traditional disciplines like geology, surveying, and geoinformatics, it will integrate with meteorology, hydrology, ecology, and others. For instance, integrating meteorological data allows analysis of the influence of rainfall, temperature, and other weather factors on disaster occurrence, enabling the establishment of meteorological condition-based early warning models. Integration with hydrology facilitates research into the mechanisms of surface water and groundwater movement in disaster formation. Integration with ecology supports the assessment of ecological damage caused by disasters and the impact of ecological restoration measures on disaster prevention. Multidisciplinary integration enables a more comprehensive and in-depth understanding of the formation mechanisms and evolution patterns of geological disasters, enhancing the scientific rigor and accuracy of risk survey and assessment.

6.3. Refinement in Survey and Assessment

With continuous technological advancements, 1:10,000 geological disaster risk survey and assessment will develop towards greater refinement. Regarding survey content, increased attention will be paid to the micro-characteristics and change processes of geological disasters, such as the microstructure of rock/soil masses and the dynamic changes in their mechanical properties. Regarding evaluation methods, risk assessment models will be continuously refined to improve precision and reliability. For example, using micro-mechanical testing techniques to study microstructural changes in rock/soil under different stress conditions provides more accurate mechanical parameters for stability analysis. Simultaneously, integrating numerical simulation technology allows for refined simulation of the initiation and development processes of geological disasters, predicting impact ranges and severity, thereby providing more precise decision support for disaster prevention and mitigation.

7. Conclusion

1:10,000 geological disaster risk survey and assessment plays an irreplaceable and vital role in geological disaster prevention and mitigation work. Through detailed investigation and analysis of main contents such as geological disaster hazard identification, analysis of disaster-pregnant geological conditions, survey of elements at risk, and risk assessment, combined with traditional and modern technological means, comprehensive and accurate geological disaster risk information can be obtained. These results have been widely applied in areas like territorial space planning and disaster mitigation engineering, making significant contributions to safeguarding people's lives and property and promoting sustainable socio-economic development. With continuous technological progress, 1:10,000 geological disaster risk survey and assessment will evolve towards greater intelligence, multidisciplinary integration, and refinement, providing more robust technical support for geological disaster prevention and mitigation efforts.

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