Statistical Analysis In The Monitoring Of Geohazards

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Abstract
Geostatistics is widely used in research and engineering as a branch of statistics. In particular, in the field of geology, it serves as the basis for collecting up-to-date information on the risk of hazardous geological processes and their analysis. Also, on the basis of statistical data, it is possible to predict dangerous geological processes in advance, make appropriate decisions by analyzing large amounts of statistical data. This article discusses the role of geostatistics in the analysis of dangerous geological processes, as well as the expected results, opportunities and prospects for the introduction of information and communication technologies in the analysis processes.
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In the 1960s, a new theory of geostatistics — the assessment of spatial variables — emerged in the world and began to develop rapidly. This theory was based on the empirical research of scientists such as D. Krige, H. De Wijs, J. Serra, and others. The mathematical development of the theory was significantly advanced by the French scientist J. Matheron, who later became the president of the International Association for Geostatistics.

Geostatistics is a branch of statistics concerned with the analysis and prediction of values associated with spatial and spatiotemporal phenomena. Initially, many geostatistical tools were developed as practical means for interpolating values in unmeasured locations and for spatial characterization.

Geostatistics is widely applied in many fields of science and technology. It is used at various stages of mining industry projects. For example, at the initial stage, geostatistics regularly supports decision-making regarding which ore should be processed and which should be considered as waste. Later, when new data becomes available, it allows us to accurately estimate the amount of mineral resources and assess the economic efficiency of the project.

Geostatistics is also used in meteorology to predict phenomena such as temperature, precipitation, and acid rain. In addition, it is applied in environmental sciences to forecast pollution levels and study their correlation with cancer incidence, making it useful in fields related to public health and environmental research.

This field has also proven its superiority as a method for assessing various types of reserves during the initial stages of mineral exploration. The use of geostatistics can demonstrate significant effectiveness when applied by geologists involved in forecasting and designing exploration networks. Finally, geostatistics offers us various methods for evaluating mineral reserves.

Geostatistics is effectively used in many other fields, including oceanography, hydrogeology, forestry and agriculture, fisheries, soil science, ecology, and materials science.

The widespread adoption of geostatistics is due, firstly, to the fact that it provides a strong theoretical foundation for geologists' rich intuitive experience, thus being closely connected with practical applications.

Secondly, unlike classical statistical methods used in natural resource assessment, geostatistics allows for unbiased evaluations and results with minimal error.

Geostatistics provides reliable tools for optimizing exploration and evaluation programs of mineral deposits, as well as for monitoring and managing ore flow quality in mining enterprises. Based on primary geological data, geostatistics enables solving numerous geological evaluation, design, and planning tasks that arise at all stages of exploration and development of mineral deposits. Moreover, it allows for the assessment of many other geological processes.

This requires the development of software, methodologies, and the application of extensive practical experience from geologists and mining professionals around the world. Due to the vast range of geostatistical capabilities, this field offers each qualified specialist the opportunity to access additional data necessary for making informed decisions.

The development of information technologies has given a powerful impetus to the advancement of this field, as without computer technologies, it is impossible to efficiently process massive volumes of primary geological data in geostatistics. The analysis of such vast geological datasets enables geologists and business users to optimize and accelerate decision-making based on information that was previously unavailable or impractical to use.

Data analysis is usually a process aimed at optimizing existing workflows; therefore, it plays a critical role in answering complex questions and making decisions about the implementation of intelligent software solutions.

The rapid development of geological data collection systems also demands the accelerated development of artificial intelligence (AI) systems in the field of creating intelligent algorithms for storing and managing geological data. This, in turn, serves as a driving force for improving geological database management systems.

Regional geological, geophysical, and exploration activities represent the initial stage of geological study of the country's subsurface. Alongside the resource component (forecasted resources and mineral reserves), these activities are aimed at obtaining relevant geological data — including geological-geophysical, geochemical, hydrogeological, engineering-geological, environmental-geological, and other types — which constitute the main target product of geological exploration.

In the transition to the digital management of planning, designing, constructing, and operating geological processes, one of the key tasks is the identification and monitoring of hazardous geological processes (HGPs) and the areas where they may potentially manifest.

In today's conditions, the growth rate and scale of the mining industry in the field of geology are closely linked to the increasing occurrence of hazardous geological processes, both natural and technogenic in nature.

Failure to adequately assess these risks can lead to significant material losses, the scale of which is often disproportionate to the costs of preventive protective measures. More importantly, it can pose serious threats to human life. At the same time, unjustified overestimation of risk levels can lead to excessive and unnecessary expenditures, which in some cases may exceed the actual level of threat. Therefore, the accuracy of geodynamic situation assessment is critically important for minimizing damage, as it is not always possible to prevent catastrophic events. Moreover, it is not always feasible to determine the genetic origin of developing processes and phenomena. A clear example of this is the frequent collapses, landslides, rockfalls, and earthquakes occurring in seismic zones, which may be caused by either natural or technogenic processes.

In both natural conditions and subsurface resource exploitation, identifying the patterns of development of hazardous geological processes is one of the key elements in assessing the risk of emergencies.

One of the important methods in this regard is conditional modeling of hazardous geological zones. These models are often used for assessing hazardous geological zones, analyzing variability during different stages of technological processes, selecting parameters, and solving other related issues.

The main goal of implementing digital technologies for monitoring hazardous geological processes is to ensure the automation of data collection, input, and transmission from all observation stations and directly from areas where hazardous geological processes may develop — in real-time (online mode). This is achieved through the use of modern devices (including mobile technologies) designed for collecting, entering, transmitting, and displaying information.

The ultimate aim is to increase the speed and accuracy of identifying the development trends of hazardous geological processes and to enable the timely forecasting of their activation.

The successful resolution of the problem of developing a geoinformation-based technology for studying landslide processes is based on identifying a set of interrelated challenges, including:

- Engineering-geological: studying soil properties, the structure of soil masses, and the characteristics of various natural and technogenic factors affecting them;
- Technical: selecting appropriate geoinformation system tools for monitoring the study object, establishing communication channels and computational infrastructure;
- Informational: storing, visualizing, and using the collected data for analyzing, forecasting, and managing landslide conditions;
- Mathematical: building and utilizing models of the studied processes and decision-making procedures and others.

By implementing geoinformation technologies for the study of landslide processes in the field of geology, tasks aimed at protecting the population and territories from hazardous natural processes can be successfully addressed.

As a result, a unified monitoring system will be created that meets the modern needs and requirements of various organizations involved in the study, monitoring, and forecasting of hazardous natural processes in specific regions.

This will lead to the development of remote sensing methods, the establishment of a geographic information system (GIS), improvement in data exchange between databases, and the creation of an aerospace imagery archive that can be used across various sectors.

One of the most valuable outcomes of statistical analysis is predictive modeling. By learning from historical data, statistical models can forecast future hazard events with increasing accuracy. These models support early warning systems and guide decision-making for emergency response and land-use planning.

Despite its strengths, statistical analysis in geohazard monitoring faces challenges, such as data incompleteness, variability in natural processes, and the need for real-time analysis. However, with the integration of machine learning and advanced computing, statistical tools are becoming more robust and adaptive.

Based on the above, it can be concluded that geostatistics plays a crucial role in monitoring hazardous geological processes. In addition to geologists' intuitive evaluation experience, geostatistics enables unbiased assessments and calculations with minimal errors. This makes it possible to analyze and interpret large volumes of data collected during the monitoring of hazardous geological processes and, based on the results obtained, to provide accurate and reliable forecasts.

At present, one of the most urgent tasks is the continuous retraining of models used in the analysis process. If a model is capable of independently selecting relevant data, interpreting it, and using it for self-learning, this would significantly assist scientists in the field of data analysis and may even become the first step toward a powerful era of artificial intelligence.

In the long-term perspective, such systems could potentially develop creative thinking, draw experience from entirely different fields, and generate new knowledge.

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